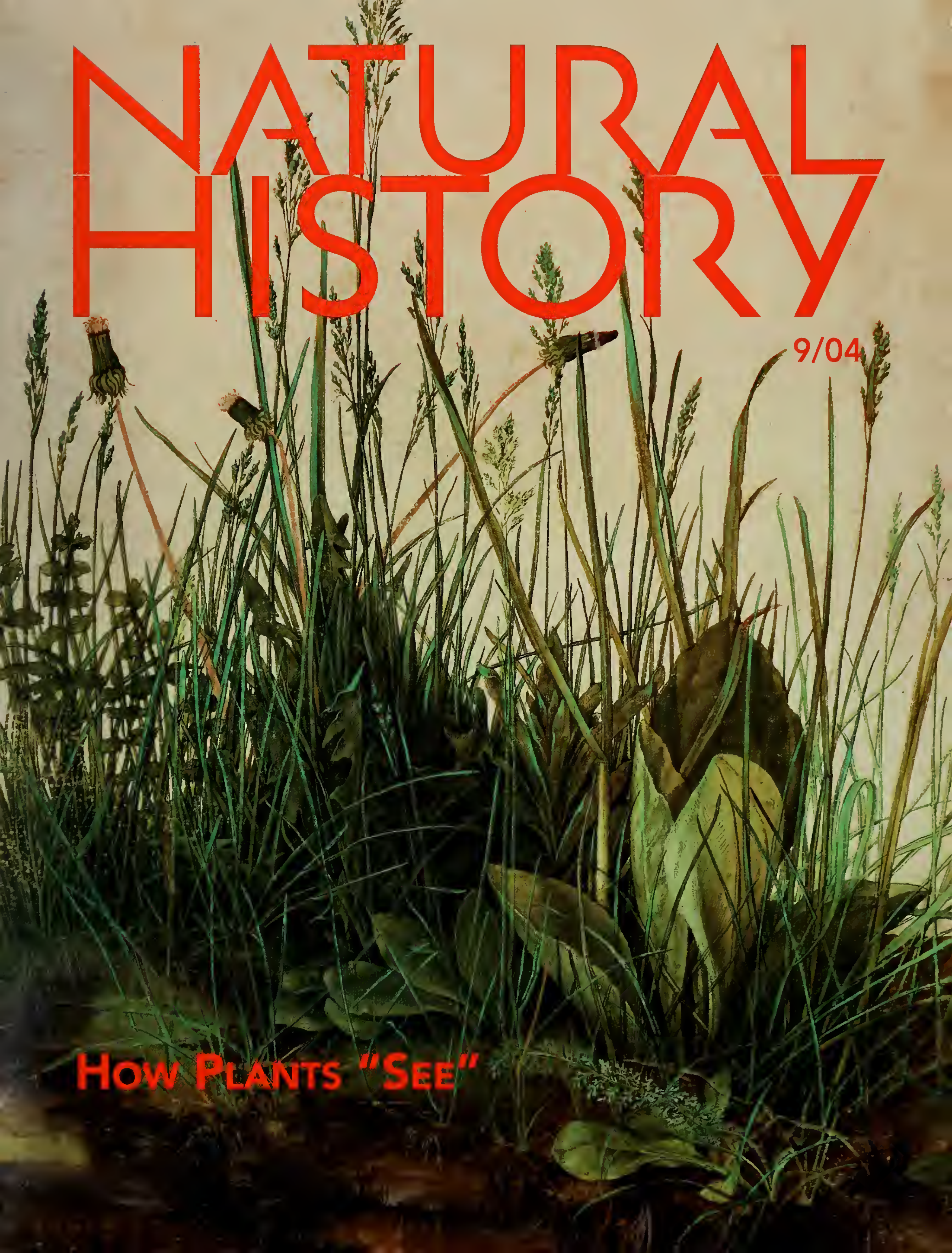
NATURAL HISTORY

9/04



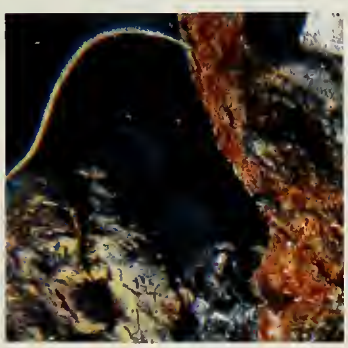
How Plants "See"


TOYOTA
Alabama

NATURAL HISTORY

SEPTEMBER 2004 VOLUME 113 NUMBER 7

FEATURES



ON THE COVER: Albrecht Dürer, *A Large Piece of Turf*, 1503

NATURAL HISTORY

DEPARTMENTS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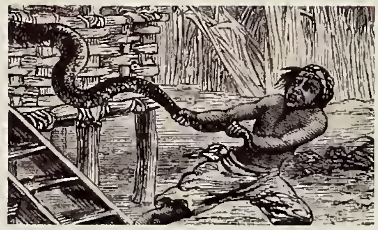
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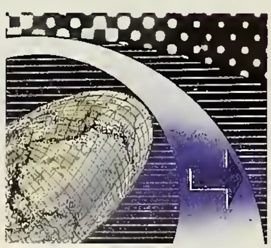
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THE NATURAL MOMENT

Rest Stop

Photograph by Roger Eriksson

THE NATURAL MOMENT

◄ *See preceding two pages*

Flying long distances can take the wind out of almost any traveler. Even members of the hummingbird family, champions of the continuous wing beat, can tire on their long seasonal migrations. The female ruby-throated hummingbird *(Archilochus colubris)* pictured here was probably leapfrogging its way south for the winter when it landed on a feeder in Michigan one sunny August morning and dropped into an energy-conserving state even deeper than sleep: torpor. In torpor, brain waves slow down, the body cools, and the metabolic rate plummets.

Sara Hiebert, a biologist at Swarthmore College in Pennsylvania, studies torpor and stress in a similar migratory "hummer," *Selasphorus rufus*. She recently found that the birds go into torpor most often just before they head south, when their energy reserves are greatest. In winter, torpor is less frequent, but more closely tied to the birds' day-to-day stress-hormone levels than it is in summer. Torpor is also known to happen almost exclusively at night in *S. rufus*, ending like clockwork about two hours before sunrise.

The hummer in our picture was literally at the lip of a liter of sugar water when photographer Roger Eriksson spotted it at the feeder. As Hiebert put it, the bird was probably "in energetically deep trouble." Eriksson took a few pictures, and then moved both feeder and lolling bird to a safe area. A few hours later the rubythroat revived and quickly flew off—renewed, one hopes, for its flight south.

—*Erin Espelie*

UP FRONT

It Came from Outer Space

Strange things are happening here, on this old, familiar planet. The age of terrestrial exploration, sometimes thought to have burned itself out for lack of the fuel of new frontiers, is still raging for those willing to probe. And the more you probe, the less familiar, the more, well, extraterrestrial the Earth and its life-forms seem to be. The organisms and behavioral patterns we're covering in this issue are not what most people mean when they think of life on Earth.

Some of the creatures occur in plain sight, in fields and forests, not to mention on the windowsills of urban apartments. Others are so well hidden that the habitats themselves were unimaginable just a few decades ago, and the creatures still go unobserved. Consider the familiar scale insects, as inconspicuous as they are ubiquitous on plants. Once you begin to look closely, though, at the ways they transfer their genes, these creatures might as well have blown in from another solar system on stellar winds (see "The Sex Lives of Scales," by Benjamin B. Normark, page 38).

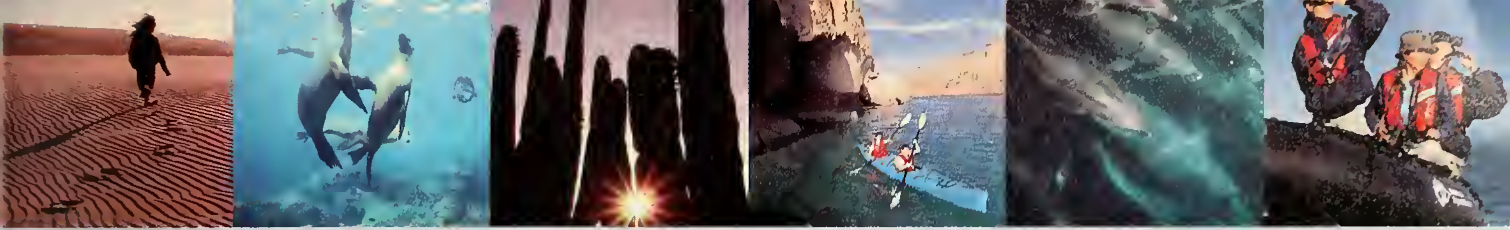
Here's another example. Ordinary weeds and grasses are proving to have elaborate systems for discrimination and action that go far beyond conventional "vegetable intelligence." The plants look around; they measure the length of the day; they check out the density of nearby plants and adjust their growth accordingly. In their intelligence report from the front, Marcelo J. Yanovsky and Jorge J. Casal describe their surprising findings about the molecular details of "How Plants 'See'" (page 32).

But "extraterrestrial" bugs and plants are just warm-ups for an even weirder life-form. Peter A. Rona, the author of "Secret Survivor" (page 50), was the first scientist to discover an undersea community thriving on the deep-sea floor of the Atlantic, living on chemicals cooked up by Earth's own internal heat. Among the traces of life he found were bizarre hexagonal patterns of holes in the seafloor. Years later, Rona became a scientific adviser to the makers of the recent IMAX film, *Volcanoes of the Deep Sea,* and the filmmakers adopted his quest to identify the hexagonal patterns as a story line for their movie. In his article for this issue, Rona makes a positive connection, only guessed at in the movie, between those holes and the fossil remains of a creature thought to have been extinct for the past 50 million years.

How the creature survived environmental change and catastrophe in its refuge on the seafloor poses a pertinent rejoinder to those who imagine that other planets offer a refuge for humanity, in case the Earth becomes uninhabitable. Wouldn't it be just as "easy" to follow the example of that mysterious creature, and seek bleak refuge in the warmth from the fires that burn inside the planet, on the bottom of the sea?

• • •

Late this month on *NOVA*, PBS will broadcast a four-hour television miniseries hosted and narrated by our "Universe" columnist, Neil deGrasse Tyson. The show, titled "Origins," will air in two 2-hour segments, 8–10 P.M. eastern time, on September 28 and 29 (www.pbs.org/wgbh/nova/origins/). —PETER BROWN



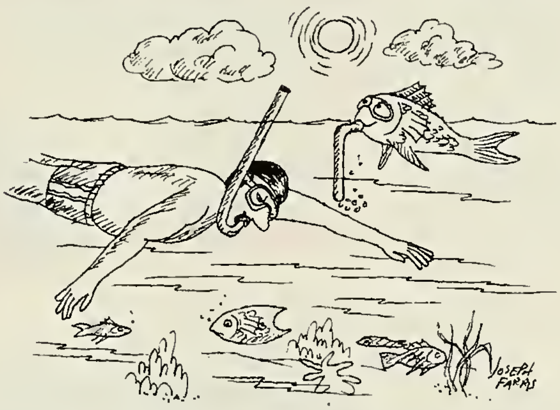
Little Souls

In his review of *Soul Made Flesh*, by Carl Zimmer, and *The Birth of the Mind*, by Gary Marcus ("The Fate of the Soul," 6/04), William H. Calvin seems to have little appreciation of the complex history of religious institutions or of theological dialogues. For example, he mentions that "The tortures imposed on dissenters by the inquisitions of the Roman Catholic Church attested to the dangers of thinking differently." That may be true, but in the context of his discussion of seventeenth-century English thinkers it would have made more sense to have mentioned the equivalent dangers imposed by the Church of England, which since 1563 had been the official church in that land.

Similarly, quoting Zimmer, Mr. Calvin refers to the bishops who in 1666 blamed London's fire and plague on Thomas Hobbes's atheism. I would assume these were the bishops of the Anglican Communion, not the Roman Catholic Church.

These may seem small points, but the attitude of the Roman Catholic Church toward science from the fifteenth through the seventeenth centuries is often seen to be wholly negative and obstructionist, whereas the attitude actually varied wildly from avidly pro scientific research to rabidly against it.

Mary Fain
Gaylord, Michigan



William Calvin's review is a welcome voice of reason over what amounts to a superstition—a belief in the "little soul," a vestige of pre-seventeenth-century thinking. If the concept of soul could be released from its archaic limitations, it would no longer be pertinent for us to labor over such silly questions as whether other animals "have" what we call "souls." All creatures vary in their awareness, as individuals and as species. A sign of higher consciousness is the ability to appreciate the variations on all levels.

Jeffrey Aaron
Highland Park, New Jersey

I found the view of humanity expressed by William Calvin in the last sentence of his review frightening. Mr. Calvin states that in the continuum of life from fertilized egg to maturity, there is some point where "one cell slowly becomes a real person, gradually able to comprehend life's great journey." The inference is that unless you are able to comprehend, then somehow you are not a real person. Thus, a retarded adult and a small child do not qualify as real persons, the dream of every despot who would stifle humanity.

Unable to precisely define when one cell becomes a person, I simply observe facts. The fertilized egg cannot exhibit a personality, but it is life, and its genetic makeup shows it to be human life. These facts stand, even if "nature seems rather careless with early embryos" or some women choose to abort.

Philip J. Lehpamer
Brooklyn, New York

WILLIAM H. CALVIN REPLIES: I mostly agree with Mary Fain's points, and indeed gave, as briefly as I could, a Catholic and an Anglican example. That I did not elaborate my discussion of them hardly means that I "have little appreciation of the complex history of religious institutions or of theological dialogues."

Jeffrey Aaron has it about right, but note that we humans have added a new kind of level via the emergence (quite late in the hominid lineage) of structured thought—syntax, contingent planning, polyphonic music, chains of logic, games with rules. Ethics are possible only because of a human level of ability to speculate, judge quality, and modify our possible actions accordingly. The result is a big step up from whatever altruism and empathy might have existed earlier. It certainly is one of the modern connotations of "soul."

Philip J. Lehpamer is trying to put words in my mouth. To say that "The inference is that unless you are able to comprehend, then somehow you are not a real person" is hardly a fair inference from the rhetorical flourish at the end of my essay.

Artistic License

As a former high school track coach and biology teacher, I have been dismayed and somewhat amused by the trophies that often depict runners in motion with the right arm and right leg extended in the same direction. I see that the makers of modern trophies may have gotten their model from the Greek Olympics. The urn shown on the opening pages of David C. Young's article ("With Hands or Swift Feet," 7-8/04) makes the same mistake!

Warren Whitaker
Chillicothe, Ohio

DAVID C. YOUNG REPLIES: Warren Whitaker is quite right: anyone running as that ancient vase painter has it will immediately fall down. Many ancient vase paintings have it right, but a handful have it wrong—unfortunately, several of the most attractive of the lot.

Fitness Test

Donald Goldsmith's article on the anthropic principle ("The Best of All Possible Worlds," 7-8/04) suggests that we must believe either that the one and only universe just happens to be finely tuned to produce life—an improbable coincidence—or that there are so many alternate universes that the existence of one like ours isn't so improbable after all. But that is a false dichotomy, resting on the arrogant notion that we can predict the necessary preconditions for sentient life in alternate universes, when we can't even predict the necessary preconditions in our own. For example, Mr. Goldsmith points out that if deviations in the distribution of matter in the early universe had been "a bit larger," galaxies might never have formed. But we have no idea what complexity such a universe might spontaneously produce, and we can't deny the possibility that it might produce beings even more glorious (gasp!) than humans. If so, the "cosmic coincidence" that the universe is finely tuned to support humans is no more astounding than the "coincidence" that the Arctic is finely tuned to support polar bears.

Tucker McCrady
New York, New York

DONALD GOLDSMITH REPLIES: In my article I attempted to present both sides of the argument over the anthropic approach: Either the existence of life, as well as other "fine tuning" of the cosmos, cries out for an explanation, or else things just happened to turn out that way. Although my own feelings closely correspond to Tucker McCrady's, I apparently presented the opposite conclusion with greater vigor. The beauty and interest of the anthropic argument reside in the fact that it provokes strong opinions that cannot be quickly tested.

Getting Warmer

In his review of my book *The Discovery of Global Warming* ("Heat Exchange," 4/04), Robert Ehrlich asks why I did not mention satellite data on global temperatures, which "show a much smaller increase in global warming than do measurements at ground stations or projections based on computer climate models." My answer is that I was reluctant to devote space to the arcane technical interpretations of such data because most scientists find the subject suspiciously complex and uncertain. My hesitancy appears justified by the results of more recent studies, which indicate that the satellite measurements have underestimated tropospheric warming. It now appears that these data offer no support to the position of those who would deny the probability of global warming.

(Continued on page 71)

CONTRIBUTORS

A city boy from Detroit, **Roger Eriksson** traces his longstanding interest in birds ("The Natural Moment," page 6) to childhood weekends in Ontario's Point Pelee National Park. His passion grew in his teens, when he banded birds as a volunteer with the U.S. Fish and Wildlife Service. When he became a professional wildlife photographer, he decided to specialize in birds. But training and passion notwithstanding, Eriksson says he was just plain lucky to discover a female ruby-throated hummingbird in torpor.

Inspired by the research interests of his father, a microbiologist who studied Chagas' disease, **Marcelo J. Yanovsky** (left) ("How Plants 'See,'" page 32) became a biologist. His interest was soon drawn to plants and, in particular, to how seasonal changes affect plants' growth and development. For his doctoral research he studied plants' rudimentary "visual" systems and their photoreceptors with

Jorge J. Casal, his co-author. Casal is a plant physiologist and associate researcher and professor at the Institute for Agricultural Plant Physiology and Ecology in Buenos Aires. He earned his Ph.D. at the University of Leicester in England. Casal and his former student now work closely together at the Institute.

As a kid growing up in Seattle, **Benjamin B. Normark** ("The Sex Lives of Scales," page 38) was fascinated by the creatures of the intertidal zone. But he studied linguistics, specializing in the history of the Germanic languages, and became a lexicographer. Stephen Jay Gould's essays in this magazine persuaded him that the most interesting ancient "text" was DNA, so he talked his way into the doctoral program in ecology and evolutionary biology at Cornell University in Ithaca, New York. He is now an assistant professor at the University of Massachusetts Amherst.

Photographer and writer **Rosamond Purcell** ("A Room Revisited," page 46) grew up in Cambridge, Massachusetts, not far from the Museum of Comparative Zoology at Harvard University, where she formed early impressions—initially unpleasant—of the appearance of animal remains. Between 1986 and 2000 Purcell and Stephen Jay Gould collaborated on three books, including *Finders, Keepers: Eight Collectors.* Her latest book, *Owls Head,* is a nonfiction meditation on the nature of ruined objects, as well as a biography of one man who collected them.

A leader in the exploration of the deep-sea floor, **Peter A. Rona** ("Secret Survivor," page 50) was thrilled to work with director Stephen Low and others on the IMAX film *Volcanoes of the Deep Sea.* The film highlights Rona's discovery of the enigmatic living fossil *Paleodictyon,* the subject of his article in this issue. He is also the author of an earlier article for *Natural History,* "Metal Factories of the Deep Sea" (January 1988). Rona is a professor of marine geology and geophysics at Rutgers University in New Brunswick, New Jersey, and a consultant to the United Nations on seafloor resources. He continues to make dives in deep-sea submersibles, an activity that he considers safer than driving to work.

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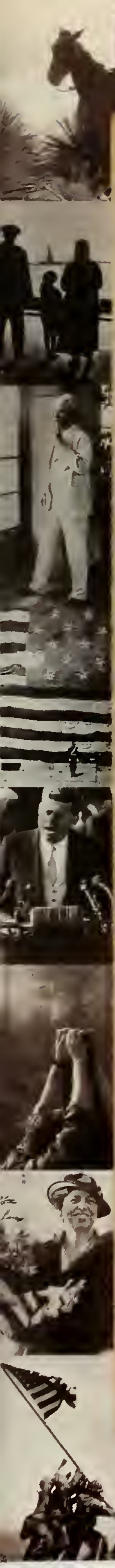


BRITISH ROC AGAINST

Breaking Up Is Hard to Time

Ever since plate tectonics began to gain acceptance in the 1960s, investigators have been trying to deduce the distribution of landmasses and life-forms in earlier eras. One persistent puzzle is the breakup of the southern supercontinent known as Gondwana, source of the modern continents of Africa, Antarctica, Australia, and South America, as well as the Indian subcontinent and the large island of Madagascar. When, and in what sequence, did the whole become parts?

Southern supercontinent Gondwana, about 190 million years ago

One hypothesis has been that Africa split off first, between 140 million and 120 million years ago, and that the two key remaining land bridges—one linking Antarctica with South America, the other linking Antarctica with Australia—broke off between 90 million and 80 million years ago. Based on recent fossil discoveries, however, Paul C. Sereno, a paleontologist at the University of Chicago, and his colleagues reject that hypothesis.

Working in Niger, the investigators uncovered the 95-million-year-old fossilized remains of an abelisaurid dinosaur—remains that bear a strong resemblance to fossils found recently in South America. Nearby, Sereno and his colleagues also found fragments of the abelisaurid's forerunners, dating to about 110 million years ago. The finds indicate the persistence of a trans-Atlantic land bridge between Africa and the rest of Gondwana, via South America, as late as 95 million years ago. The story of evolution in the ancient Southern Hemisphere may now need some major editing. ("New dinosaurs link southern landmasses in the Mid-Cretaceous," *Proceedings of the Royal Society of London* B 271:1325–30, July 7, 2004)

—*T.J. Kelleher*

Hunters and Freeloaders

Puzzling over the whys and wherefores of wolf packs, evolutionary biologists have noted that they are often larger than they "should" be. Most carnivore species hunt alone, and so each individual gets to eat what it kills. Group hunting, by contrast, makes it possible to take more prey, but the bounty must then be shared. And if a pack exceeds a certain number of animals (a number based on such variables as available food, the risks of nutritional shortfall, and the energy requirements of territorial defense), competition for food becomes so intense that its members should, theoretically, fare better if they hunt alone. Yet wolf packs frequently exceed the expected optimum number.

To resolve the paradox, say John A. Vucetich, an ecologist at Michigan Technological University in Houghton, and his colleagues, the focus needs to shift from the wolves to their hangers-on: ravens. More mobile than wolves, ravens often manage to steal a large proportion of a wolf pack's kill. One raven can consume or hoard four pounds a day from a large carcass. The key, say the investigators, two of whom have studied the wolves of Isle Royale National Park in northern Michigan for decades, is that wolves in large packs lose less food to ravens, simply because the carcass gets consumed faster. That single benefit of belonging to a large group outweighs the costs of having to hunt more often and share the kill among more packmates. ("Raven scavenging favours group foraging in wolves," *Animal Behaviour* 67:1117–26, June 2004)

—*Nick W. Atkinson*

FRIED RICE

To a vacationer in Southeast Asia, increasingly balmy March nights might mean more strolling and less clothing. But to a rice plant they mean hard times, say Shaobing Peng of the International Rice Research Institute (IRRI) in Manila, Philippines, and his colleagues.

In that part of the world there are two rice-growing seasons: dry (January to April) and wet (late June to September). Average nighttime lows at IRRI during the dry season have risen by a total of 2.39 degrees Fahrenheit (1.33 degree Celsius) in the past twenty-five years. Throughout the year the days, too, have become warmer, as have nights during the wet season—but both have warmed substantially less than the dry-season nights.

Peng and his associates found a strong correlation between dry-season nighttime lows and the yield of one popular high-yielding cultivar: for each increase in the average temperature of two degrees Fahrenheit, the yield of the cultivar declined by nearly 10 percent. That's bad news. The Earth's rice production must expand by about 1 percent annually to meet increasing demand, and almost no available uncultivated land is suited to intensive agriculture. Dealing with that challenge alone has been daunting for farmers and plant scientists. Now, it seems, global warming will add to their woes. ("Rice yields decline with higher night temperature from global warming," *Proceedings of the National Academy of Sciences* 101: 9971–75, July 6, 2004)

—*Stéphan Reebs*

Rice yields threatened by global warming?

Hard-Hat Zone

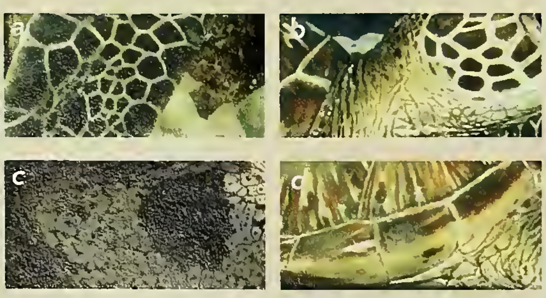
You may never hear the sound of one hand clapping, but if you visit the western reaches of Amazonia, you will certainly hear one leaf falling.

One of the most common Amazonian trees is the stilt-rooted palm *Iriartea deltoidea*, whose cousins you may have seen if you've ever sunned yourself on the beaches of the Caribbean or the Indian Ocean. Those majestic fronds swaying in the tropical breezes are single leaves, subject, like any other leaf, to desiccation and death. And when a twenty-foot-long, thirty-pound dead leaf falls to the ground from a height of, say, ninety or a hundred feet, it not only makes quite a noise but also has a long-term impact.

Stilt-rooted palm, soon to drop a lethal frond on the forest below

Halton A. Peters, an ecologist at Stanford University, and his colleagues recently determined that even though an *I. deltoidea* drops just two or three fronds a year, the fronds do so much damage that they "weed out" many of the saplings beneath the tree. The saplings that survive are, disproportionately, members of species whose root systems hold large reserves of nutrients, making them better able to compensate for aboveground breakage. Because *I. deltoidea* is so abundant, the ecologists note, it ends up determining the composition of much of the rainforest understory. ("Falling palm fronds structure Amazonian rainforest sapling communities," *Proceedings of the Royal Society of London* B (Suppl.) 271:S367–69, August 7, 2004) —*S.R.*

Cryptic Creatures



Only three of these pictures are close-ups of the same animal. Which one doesn't belong?

(Answer on page 71)

POSTCARDS FROM SPACE

Fifty years from now, the year 2004 may well be remembered as a high point in space and planetary science. Here are some late dispatches.

Roving

Intended primarily to find out if and where water once existed on the now-dry Martian surface, the two Mars Exploration Rovers (Spirit and Opportunity) that landed on the planet this past January continue to photograph their surroundings and check out the rocks and soil. Both rovers have found hematite, often a mineralogical sign of water. Investigators say it's clear that parts of Mars's surface were once sopping wet and, at least for some time, habitable. The rovers were expected to poop out in April or so, but as of press time, they're still on a roll. (marsrovers.jpl.nasa.gov/home/)

Lord of the Rings

Meanwhile, the *Cassini* spacecraft has been orbiting Saturn since June 30. It has captured the closest-ever look at the planet's icy rings, and provided new insights on Saturn's vast magnetosphere—the invisible bubble of magnetic fields, electric currents, and trapped radiation that surrounds the planet. On Christmas Eve 2004 the Huygens probe, which has been hitching a ride with *Cassini*, will separate from the mother ship and, three weeks later, plunge into the nitrogen- and methane-rich atmosphere of Saturn's largest moon, Titan—where signs of former or (who knows?) present-day life might be lurking. (saturn.jpl.nasa.gov/home/index.cfm)

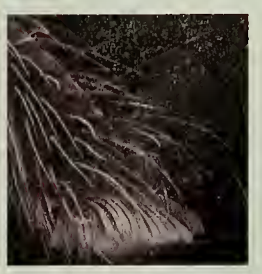
Comet Catcher

On January 2, 2004, NASA's *Stardust* spacecraft, launched in February 1999, came within 150 miles of a several-mile-wide comet named Wild 2. Attached to the craft was a 155-square-inch racket-shaped dust collector made of aerogel, a prodigiously tangled material that is 99.8 percent air, with a dash of silicon dioxide added. The collector slowed and trapped some of Wild 2's minuscule particles as it swept past the comet at 13,000 miles per hour. *Stardust* has since collapsed itself into a capsule and is set to land in Utah on January 15, 2006. Soon afterward, analysts at the Johnson Space Center in Houston will get the first-ever chance to take a close-up look at the ingredients of a comet. (stardust.jpl.nasa.gov/)

Lest We Forget . . .

Launched in March 1972, *Pioneer 10* passed within 81,000 miles of Jupiter in December 1973 and then moved out beyond the solar system. Until February 2003 its transmitter stayed in contact with Earth. On board *Pioneer 10* and its sister probe, *Pioneer 11* (launched in April 1973), are plaques showing the figures of a man and a woman along with several symbols meant to indicate the origin of the spacecraft: a kind of interstellar message in a bottle. Now about 8 billion miles from home, *Pioneer 10* is coasting in the direction of the star Aldebaran. The spacecraft will take more than 2 million years to reach it. (spaceprojects.arc.nasa.gov/Space_Projects/pioneer/PNhome.html) —*Joe Rao*

Defying Gravity



Hairs on the leg tip of a spider, magnified seventy diameters

The next time you see an ant or a spider walking upside down, consider this: rope systems designed to hold rock climbers can support at least ten times the weight of an average adult, but the critter clinging to your ceiling has vastly more protection than that. Now Antonia B. Kesel, a zoologist at the University of Applied Sciences in Bremen, Germany, and her colleagues have applied a technique called atomic force microscopy to precisely measure the adhesive forces involved.

To hold on, insects, including ants, rely on small claws or on sticky foot secretions. Spiders, however, have a different adhesive structure at the tip of each leg, formed from a dense aggregation of miniature hairs called setae. Each seta is covered with even smaller hairs whose tips are shaped like sails. The "sails" can conform to every bump and cranny of a surface, acting as intimate contact elements between the wall and the foot. At each contact point, interactions between molecules set up a so-called van der Waals force, a weak electrostatic attraction; collectively, the innumerable points of attraction create a powerful adhesion.

How powerful? Kesel and her colleagues found that when all eight legs of the quarter-inch-long spider *Evarcha arcuata* are applied to a surface, 624,000 hairs can make contact, giving rise to a force 173 times stronger than what's needed to keep the creature from dropping off the ceiling. That makes the spiders the champion surface clingers by a wide margin; the closest insect competitor is an ant, with a safety factor of about 100. So how does the spider ever get its leg unstuck? It just pulls along a single edge of hairs, much as you do when you peel off a piece of tape. ("Getting a grip on spider attachment: An AFM approach to microstructure adhesion in arthropods," *Smart Materials and Structures* 13:512–18, June 2004) —*S.R.*

What Is a Picture Worth?

Maxime van de Woestyne, *Self-Portrait*, 1951

The average human brain has 100 billion neurons, and, contrary to myth, a person uses every one of them. But how many are needed at a given time for a simple task?

Ifat Levy, a neuroscientist at the Hebrew University of Jerusalem, and her colleagues have calculated that when you see the image of a face or a house, at least a million neurons fire in the area of your brain responsible for object recognition, and between 30 million and 400 million fire in the visual cortex as a whole. So, as the investigators titled their article, "One picture is worth at least a million neurons." (*Current Biology* 14:996–1001, June 8, 2004) —*S.R.*

GRAINS OF EVIDENCE

Exactly when did barley and wheat become staples of the human diet in the Mediterranean basin? The question has been hard to answer, in part because ancient plant remains are so scarce. But recent excavations at Ohalo II, a 23,000-year-old archaeological site on the shores of Lake Tiberias (aka the Sea of Galilee) in Israel, have yielded more than 90,000 extremely well preserved botanical remains. Nearly a quarter of this enormous cache consists of the grains of various wild cereals and grasses, some of which were found next to a grinding stone in the remnants of a hut. Other edibles in the cache include wild almonds, figs, grapes, legumes, olives, pistachios, and raspberries.

Among the grains, more than 16,000 have been identified as seeds gathered from a dozen species of very small-grained grasses, particularly brome. About 2,500 of the grains are from wild barley and 100 from wild emmer wheat. The barley and wheat, though, would collectively have yielded roughly double the amount of food yielded by the 16,000 small grains. Indeed, by 8,000 years ago, wild brome and its ilk had disappeared from the Levantine diet, having been decisively supplanted by domesticated barley and wheat.

Brome, a small-grained but edible grass

According to Ehud Weiss, an archaeobotanist at Harvard University who first examined the evidence, and his colleagues, this finding pushes back the evidence for grass collecting 10,000 years earlier than previously known, and strongly supports the hypothesis that agriculture (more precisely, the cultivation of large-grained cereals) had its roots in the practice of foraging for a wide variety of relatively unproductive grasses. ("The broad spectrum revisited: Evidence from plant remains," *Proceedings of the National Academy of Sciences* 101:9551–55, June 29, 2004) —*S.R.*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Flexible Feeders

The lower bill of the hummingbird makes a nectar-drinking beak into one for catching insects.

By Adam Summers
Illustrations by Roberto Osti

Hummingbirds, those common visitors to bird feeders and honeysuckle vines, seem adapted for one primary task: gathering nectar from flowers. Consider the apparent singularity of purpose with which these animals are shaped. Their wing bones are fused into a stiff paddle that enables them to hover at a bloom while drinking. Their tongues are long and specially shaped to hold an abundance of the sugary liquid on which they feed.

Their beaks, though, represent a truly brilliant fit between form and function. Hummingbirds with long bills feed on deep flowers, while those with shorter bills head for smaller blooms. Even the degree of bill curvature of any particular hummingbird species matches the arc of the birds' preferred floral food source [*see "All the Right Curves," by Ethan J. Temeles, November 2002*]. But all is not sweet water and bliss, for the hummingbird's beak must perform another task that seems opposed to nectar gathering—catching insects on the fly.

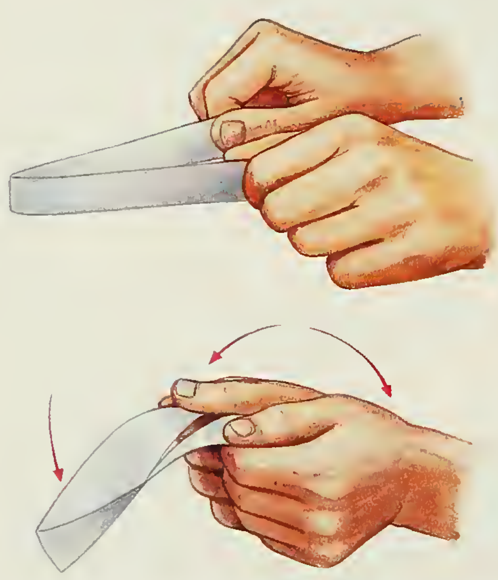
Nectar is the avian equivalent of Coca-Cola—it's not much more than sugar and water. In the course of a day a hummer drinks more than its body weight in nectar, and the bird burns through the solution—which is 20 to 50 percent sugar by weight—at a furious pace. But as parents point out to their kids, you can't live on sugar alone, and that fact is as true for hummingbirds as it is for people. The birds must supplement their carbohydrate-rich diet with daily helpings of insects to get necessary fats and amino acids that are scarce or even nonexistent in nectar.

Birds have two strategies for snagging insects on the wing. Some species with large mouths and small bills, such as nighthawks, whip-poor-wills, and the aptly named frogmouth owls, open their bills wide as they fly into insects, and the prey is captured in the birds' gaping maws. In contrast, narrow-billed birds such as flycatchers rely on their bills to catch flying prey; some flycatchers are so specialized that they maneuver the tips of their bills like forceps, pinching insects out of the air.

The hummingbird might seem best suited to the forceps approach, though a bird with such a long bill might have a hard time snapping both quickly and precisely on an evasive gnat. Gregor M. Yanega and Margaret A. Rubega, both biologists at the University of Connecticut in Storrs, have discovered that not only do hummers act more like nighthawks than like flycatchers, they also manage to widen their needlelike bill to better snag their prey.

To see how hummingbirds catch insects, Yanega and Rubega ran a video camera at 500 frames a second to film individuals of several species in slow motion as they fed on fruit flies. Projected at far slower rates, the movies reveal that a hummingbird catches flies at the base of its bill rather than at the tip. Most surprising, as the bird opens its beak to catch a fly, the lower bill suddenly bends downward at a point near the middle and widens, enlarging the bird's mouth to the detriment of the fly.

The upper and lower parts of a bird's beak correspond to the upper and lower jaws in people. The bones of both parts of the beak are covered with a structure known as a rhamphotheca, a sheath made of keratin, the same stuff your fingernails are made of. Unlike most vertebrates, many birds have a joint in the upper jaw, behind the beak, that enables the upper beak to bend toward the head as it opens. Some bird species also have a joint in the lower jaw, but in most species the lower bill is inflexible: it opens by rotating at the jaw joint, just like your mandible, and, also like your mandible, it does not bend in the middle. Careful examination of hummingbird skeletons shows that they belong to the latter, mainstream crowd.



Ruby-throated hummingbird (opposite page) depends, as do other hummingbird species, on a beak specially shaped for gathering nectar from flowers. But the bird must also eat insects to survive. How, then, to catch insects with a thin, nectar-drinking beak? The solution is a flexible lower bill, which widens and bends downward as the bird opens its mouth, presenting a larger "mitt" for catching flies. The action can be modeled by twisting a narrow strip of folded paper (above), as described in the text.

How, then, does a hummingbird manage to expand its lower bill when hunting insects? Despite decades of study, specialists were still surprised when they took a close look at this part of the hummingbird's anatomy. It turns out that the bone of the lower beak both twists and bends like a strip of thin plastic when the lower bill opens far enough. Bones that bend? No wonder the anatomists missed that one. But bendy bones, though rare, are not unheard of. For example, the bones in a bat's wing bend [*see "Flap Your Hands," by Adam Summers, February 2003*], and so do the tongue bones of woodpeckers.

You can get a feel for the remarkable bending action of the hummingbird's lower bill by cutting a narrow strip from the long dimension of a piece of typing paper, making a rectangle one inch by eleven inches long. Fold the strip in half along the short axis, leaving a V whose two legs are each one inch by five-and-a-half inches long. Hold an end between the thumb and forefinger of each hand, with the vertex of the V pointing away from you [*see illustration at left*]. Touch your thumb knuckles together while keeping your palms parallel to the ground. The paper "bill" should now be pointed straight out in front of you, ready to open wide. Rotate your palms together and you will see that the sides of the bill spread apart while the far end rotates downward, about an axis roughly midway between your thumbs and the tip of the V. Like the narrow paper bill, the real hummingbird's lower bill splays apart into a shape that is far better—though certainly not ideal—for catching insects.

The beak of any bird, even of a dietary specialist such as a hummingbird, serves multiple functions. Potential conflicts, such as the simultaneous need for a long, narrow bill to fit flowers and a broad bill to catch insects, often give rise to the most interesting cases of natural selection in action. The hummer resolves the conflict by devoting the shape of its bill to one purpose and its material properties to the other.

ADAM SUMMERS (asummers@uci.edu) *is an assistant professor of ecology and evolutionary biology at the University of California, Irvine.*

The Information Trap

Tempted by the devil in the details

By Neil deGrasse Tyson

Gyorgy Kepes, *Cosmological Eye*, 1941

Most people assume that the more information you have about something, the better you understand it.

Up to a point, that's usually true. When you look at this page from across the room, you can see it's in a magazine, but you can't make out the words. Get closer, and you'll be able to read the article. If you put your nose right up against the page, though, your understanding of the article's contents will not improve. You may get more

"How long is the coast o

visual detail, but by being so close you'll sacrifice crucial information—whole words, entire sentences, complete paragraphs. The old story about the blind men and the elephant makes the same point: if you stand a few inches away and fixate on the hard, pointed projections, the long rubbery hose, the thick, wrinkled posts, and the dangling rope with a tassel on the end that you quickly learn not to pull, you won't be able to tell much about the animal as a whole.

One of the challenges of scientific inquiry is knowing when to step back—and how far back to step—and when to move in close. In some contexts, approximation brings clarity; in others it leads to oversimplification. A raft of complications sometimes point to true complexity and sometimes just clutter up the picture. If you want to know the overall properties of an ensemble of molecules under various states of pressure and temperature, for instance, it's irrelevant and sometimes downright misleading to pay attention to what individual molecules are doing. A single particle cannot have a temperature, because the very concept of temperature addresses the average motion of all the molecules in the group. In biochemistry, by contrast, you understand next to nothing unless you pay attention to how one molecule interacts with another.

Let me put the issue this way: When does a measurement, an observation, or simply a map have the right amount of detail?

Britain?" asked Mandelbrot. The answer is not so simple.

In 1967 Benoit B. Mandelbrot, a mathematician now at IBM's Thomas J. Watson Research Center in Yorktown Heights, New York, and also at Yale University, posed a question in the journal *Science:* "How long is the coast of Britain?" A simple question with a simple answer, you might expect. But the answer is deeper than anyone had imagined.

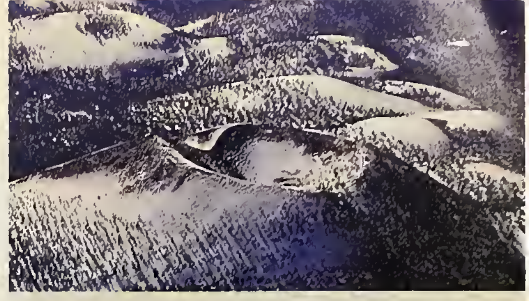
Explorers and cartographers have been mapping coastlines for centuries. The earliest drawings depict the continents as having crude, funny-looking boundaries; today's high-resolution maps, enabled by satellites, are worlds away in precision. To begin to answer Mandelbrot's question, however, all you need is a handy world atlas and a spool of string. Unwind the string along the perimeter of Britain, from Dunnet Head down to Lizard Point, making sure you go into all the bays and headlands. Then unfurl the string, compare its length to the scale on the map, and voilà! you've measured the island's coastline.

Wanting to spot-check your work, you get hold of a more detailed Ordnance Survey map, scaled at, say, two and a half inches to the mile, as opposed to the kind of map that shows all of Britain on a single panel. Now there are inlets and spits and promontories that you'll have to trace with your string; the variations are small, but there are lots of them. You find that the O.S. map shows the coastline to be longer than the atlas did.

So which measurement is correct? Surely it's the one based on the more detailed map. Yet you could have chosen a map that has even more detail—one that shows every boulder that sits at the base of every cliff. Cartographers usually ignore rocks on a map, unless they're the size of Gibraltar. Well, I guess you'll just have to walk the coastline of Britain yourself if you really want to measure it accurately—and you'd better carry a very long string so that you can run it around every nook and cranny. But you'll still be leaving out some pebbles, not to mention the rivulets of water trickling among the grains of sand.

Where does all this end? Each time you measure it, the coastline gets longer and longer. If you take into account the boundaries of molecules, atoms, subatomic particles, will the coastline prove to be infinitely long? Not exactly. Mandelbrot would say "undefinable." Maybe we need the help of another dimension to rethink the problem. Perhaps the concept of one-dimensional length is simply ill suited for convoluted coastlines.

Playing out Mandelbrot's mental exercise involved a newly synthesized



field of mathematics, based on fractional—or fractal (from the Latin *fractus,* "broken")—dimensions rather than the one, two, and three dimensions of classic Euclidean geometry. The ordinary concepts of dimension, Mandelbrot argued, are just too simplistic to characterize the complexity of coastlines. Turns out, fractals are ideally suited for describing "self-similar" patterns, which look much the same at different scales. Broccoli, ferns, and snowflakes are good examples from the natural world, but only certain computer-generated, indefinitely repeating structures can produce the ideal fractal, in which the shape of the macro object is made up of smaller versions of the same shape or pattern, which are in turn formed from even more miniature versions of the very same thing, and so on indefinitely.

As you descend into a pure fractal, however, even though its components multiply, no new information comes your way—because the pattern continues to look the same. By contrast, if you look deeper and deeper into the human body, you eventually encounter a cell, an enormously complex structure endowed with different attributes and operating under different rules than the ones that hold sway at the macro levels of the body. Crossing the boundary into the cell reveals a new universe of information.

How about Earth itself? One of the earliest representations of the world, preserved on a 2,600-year-old Babylonian clay tablet, depicts it as a disk encircled by oceans. Fact is, when you stand in the middle of a broad plain (the valley of the Tigris and Euphrates Rivers, for instance) and check out the view in every direction, Earth does seem to be a disk.

Noticing a few problems with the concept of a flat Earth, the ancient Greeks—including such thinkers as Pythagoras and Herodotus—pondered the possibility that Earth might be a sphere. In the fourth century B.C., Aristotle, the great systematizer of knowledge, summarized several arguments in support of that view. One of them was based on lunar eclipses. Every now and then, the Moon, as it orbits, intercepts the cone-shaped shadow that Earth casts in space. Across decades of these spectacles, Aristotle noted, Earth's shadow on the Moon was always circular. For that to be true, Earth had to be a sphere, because only spheres cast circular shadows via all light sources, from all angles, and at all times. If Earth were a flat disk, the shadow would sometimes be oval. Sometimes, when Earth's edge faced the Sun, it would be a line. Only when Earth was face-on to the Sun would its shadow cast a circle.

Because spinning makes the Earth bulge, one degree of latitude is slightly longer at the Arctic Circle than it is at the equator.

Given the strength of that one argument, you might think cartographers would have made a spherical model of Earth within the next few centuries. But no. The earliest known terrestrial globe was built in 1490–92, on the eve of the European ocean voyages of discovery and colonization.

So, yes, Earth is approximately a sphere. But the devil, as always, lurks in the details. In his *Principia,* published in 1687, Sir Isaac Newton proposed that, because spinning spherical objects thrust their substance outward as they rotate, our planet (and the others as well) is a bit flattened at the poles and a bit bulgy at the equator—a shape known as an oblate spheroid. To test Newton's hypothesis, half a century later the French Academy of Sciences in Paris sent mathematicians on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two expeditions—one to the Arctic Circle and one to the equator, both assigned to measure the length of one degree of latitude on Earth's surface along the same line of longitude. The degree was slightly longer at the Arctic Circle. Newton was right.

The faster a planet spins, the greater its "equatorial bulge." A single day on fast-spinning Jupiter, the most massive planet in the solar system, lasts ten Earth-hours; Jupiter is 7 percent wider at its equator than at its poles. Our much smaller Earth, with its twenty-four-hour day, is just 0.3 percent wider at the equator—twenty-seven miles on a diameter of just under 8,000 miles. That's hardly anything.

One fascinating consequence of this mild oblateness is that if you stand at sea level anywhere on the equator, you'll be farther from Earth's center than you'd be nearly anywhere else on Earth. And if you really want to do things right, climb Mount Chimborazo in central Ecuador, close to the equator. Chimborazo's summit is four miles above sea level, but more important, it sits a mile and a third farther from Earth's center than does the summit of Mount Everest.

Satellites have managed to complicate matters further. In 1958 the small Earth orbiter *Vanguard 1* sent back the news that "the equatorial bulge south of the equator was slightly bulgier than the bulge north of the equator," as the prolific science writer Isaac Asimov put it. In addition, sea level at the South Pole turned out to be a tad closer to the center of the Earth than sea level at the North Pole. In other words, the planet's a pear.

Next up is the disconcerting fact that it's not rigid: Earth's surface rises and falls daily as the oceans slosh in and out of the continental shelves, pulled by the Moon and, to a lesser extent, by the Sun. Tidal forces distort the waters of the world, making their surface oval. Turns out, tidal forces stretch the solid Earth as well, and so the equatorial radius fluctuates daily as well as monthly, in tandem with the oceanic tides and the phases of the Moon.

So Earth's a pearlike, oblate-spheroidal hula hoop.

Will the refinements never end? Seemingly not. Fast forward to 2002: a U.S.-German space mission named GRACE (Gravity Recovery and Climate Experiment) sends up a pair of satellites to map Earth's geoid, which is the shape Earth would have if sea level were unaffected by ocean currents, tides, or weather—in other words, a hypothetical surface where the force of gravity is perpendicular to every mapped point. [*See "Serious Gravity" in "Samplings," by Stéphan Reebs, October 2003*]. Thus, at any given point on Earth's surface, the geoid—even though it turns out to be riddled with bumps and cavities because of the uneven density of matter *below* Earth's surface, inducing uneven gravity *at* Earth's surface—also embodies the truly horizontal. Carpenters, land surveyors, and aqueduct engineers have no choice but to obey.

Here's another category of problematic shapes: orbits. Not one-dimensional, not merely three-dimensional, orbits are multidimensional: they happen in both space and time. Aristotle took the position that the Earth, the Sun, and the stars were locked in place, attached to crystalline spheres. It was the spheres that rotated, and their orbits traced—what else?—perfect circles. To Aristotle and nearly all the ancients, Earth lay at the center of all this activity.

Nicolaus Copernicus disagreed. His 1543 magnum opus, *De Revolutionibus,* placed the Sun in the center of the cosmos (the same suggestion had been made in the fourth century B.C. by Aristarchus of Samos, and mostly dismissed). Copernicus, however, did hold to the notion of circular orbits, unaware of their mismatch with reality. Half a century later, Johannes Kepler put matters right with his three laws of planetary motion, one of which showed that the orbits

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are not perfect circles, but ellipses of varying elongation.

We have only just begun.

Consider the Earth-Moon system. The two bodies orbit their common center of mass, their barycenter—which lies roughly a thousand miles below the spot on Earth's surface closest to the Moon at any given moment. So instead of the planets themselves, it's actually their planet-moon barycenters that trace the Keplerian elliptical orbits around the Sun. So now what's Earth's trajectory? A series of loop-the-loops—thirteen of them in a year, one for each cycle of lunar phases—rolled together with an ellipse.

The ballet of the solar system is a performance only a computer can know and love.

Meanwhile, not only do the Moon and Earth tug on each other, but all the other planets (and their moons) are tugging on them too. Everybody's tugging on everybody else. As you might suspect, it's a complicated mess [*see "Going Ballistic," by Neil deGrasse Tyson, November 2002*]. Plus, each time the Earth-Moon system takes a trip around the Sun, its orbit shifts slightly, not to mention the fact that the Moon is spiraling away from Earth at a rate of one or two inches a year, and that some orbits are chaotic.

All told, this ballet of the solar system, choreographed by the forces of gravity, is a performance only a computer can know and love. We've come a long way from single, isolated bodies tracing pure, simple circles in space.

The course of a scientific discipline gets shaped in different ways depending on whether theories lead data or data lead theories. A theory tells you what to look for, and you either find it or you don't. If you find it, you move on to the next open question. If you have no theory but you wield tools of measurement, you'll start collecting as much data as you can and hope that patterns emerge. But until you arrive at an overview, you're mostly poking around in the dark.

Nevertheless, one would be misguided to declare that Copernicus was wrong simply because his orbits were the wrong shape. His deeper concept—that planets orbit the Sun—is what mattered most. From then on, astrophysicists have continually refined the model by looking closer and closer. Copernicus may not have been in the right ballpark, but he was surely on the right side of town. Geometers—those who measure the Earth—didn't suddenly find our planet to be a cube; dynamicists didn't suddenly find Earth's orbit to be a triangle. But looking closer only rarely simplifies things. If Kepler had had the ability to measure the actual trajectory of each planet in the solar system, he might still be scratching his head.

[*This is part one of a two-part article.*]

Astrophysicist NEIL DEGRASSE TYSON *is the Frederick P. Rose Director of the Hayden Planetarium in New York City. He is also host and narrator of the PBS* NOVA *miniseries "Origins," which will air in two 2-hour segments, 8–10 P.M. eastern time, on September 28 and 29* (www.pbs.org/wgbh/nova/origins/).

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How Plants "See"

Plants catch light for the information it carries as well as for its energy. The light helps plants determine when to germinate, when to flower, or how to respond to neighboring plants.

By Marcelo J. Yanovsky and Jorge J. Casal

Douglas Prince, *Seed Chamber*, 1970

Two dozen grass plants, each one surrounded by a fine circle of red lights, stood in the stillness of the morning air. From a distance they looked just as they had when a team of investigators had left them a few weeks before. But in fact, they had changed. What the members of the team were about to observe, after a five-hour journey across the hot Argentine Pampas, would come as a generous reward for their labors.

One of us (Casal) was a member of that team, which had come to the plants' natural environment hoping to answer an unusual question: What are the limits of plant "vision"? When a verdant locale becomes overpopulated, and the plants start shading one another, some species display a remarkable strategy: they restrict the development of their own new shoots and accelerate stem growth instead, thus becoming more aggressive competitors for light. Somehow, these plants seemed to be sensing the shadow cast by other plants; but, how were they doing it?

At that time, most plant physiologists thought that mutual plant shading simply reduces the amount of light available for photosynthesis, the process whereby plants build organic molecules with energy from sunlight; shaded plants, after all, grow fewer new shoots than plants growing in the sunlight. A second hypothesis was that plants in the shade detect more specific changes in the light environment caused by the presence of other plants, presumably via an array of molecules called photoreceptors, which work much like a visual system. No one knew which hypothesis was correct.

In recent decades, plant physiologists have become increasingly aware that plants use light for much more than photosynthesis. Plants have sophisticated skills for obtaining and processing the information that light carries about their local environment. Not only can they sense the presence of other plants and react in ways that maximize their chances of survival. But more, light enables plants to determine that spring is beginning or that winter is ending. Via light, seeds know when to germinate, and adult plants know when to flower.

The flowering process is particularly intriguing because, in most plants, it is precisely synchronized with seasonal changes. Certain plant species do not flower if the days are too long; others flower only when daylight lasts longer than a certain number of hours. This observation suggests that plants can assess the changing length of the day as the seasons come and go, a complex and difficult task. To do so, they must discriminate day from night, measure the passage of time, and integrate the information. Do plants possess the means of carrying out such a complex process? They certainly do. Just as plants measure light with photoreceptors, they measure time, appropriately, with a biological clock. And as for the integration of light and time, we have been able to show, after countless hours of experimentation, that plants are constantly, monotonously making and then destroying molecules that help control flowering. The concentration of those molecules is the key to a seemingly complex decision.

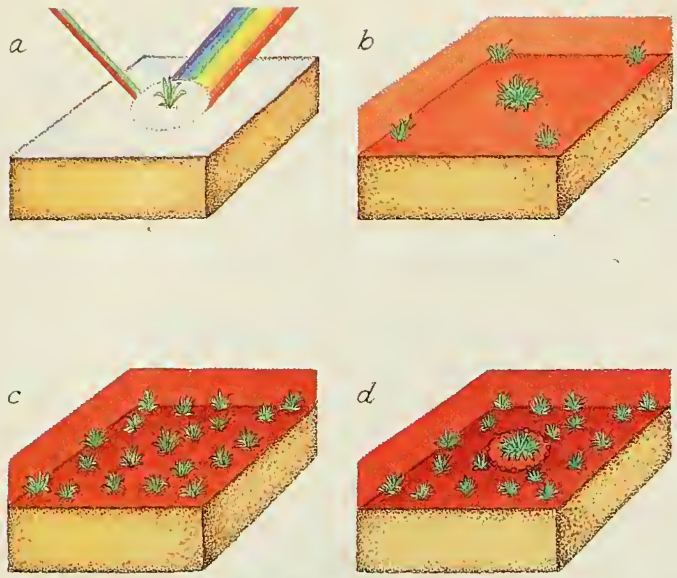
The whole idea that plants can perceive such subtle variations in light as the ones caused by nearby plants, and respond to them with dramatic changes in their own growth patterns, has always fascinated us. Light, of course, carries a wealth of information for those able to decode it. Plants begin decoding light by "dissecting" the ambient white light, which is made up of all the colors of the rainbow. Molecules such as chlorophyll, present throughout the leaves and stems, selectively extract specific colors, or wavelengths, from the white light. Green foliage absorbs most of the red and the blue, and reflects, as well as transmits through its

With red light we fooled the plants into "thinking" there were few other plants around.

leaves, a color known as "far-red," whose wavelength lies just outside the range of visible light [*see illustration on next page*]. And the reason plants look green is that they reflect green light.

Plants can measure not only the amount, or intensity, of each of several colors, but also the ratios of certain pairs of colors. At the time of the experiments in the Pampas, the team had hypothesized that plants can "see" the overshadowing leaves of other plants by measuring the ratio of red to far-red. The idea was that a densely populated, shaded environment is rich in the far-red wavelengths that other plants reflect, but is poor in red, the color that the other plants absorb. Thus, a plant detecting the ratio of red to far-red would immediately "know" if it is being shaded; with other shading plants around, the red-to-far-red ratio would be low.

In the field, the uppermost leaves of grass plants are exposed to full sunlight; only their bases are mutually shaded. Hence, only the plant's base is exposed to a low red-to-far-red ratio. Is that light signal enough to modify their growth pattern? That was the big question for Rodolfo A. Sánchez, a plant physiologist, and Victor A. Deregibus, a forage scientist, both at the University of Buenos Aires, in 1980, when Casal joined them as a undergradu-



Plants absorb mainly red and blue light and reflect green and far-red light (a color invisible to the eye, but rendered here as dark red) (a). They also transmit far-red. Thus when the density of plants is low, the ambient light is rich in red and poor in far-red. Grass plants can sense the ratio of red to far-red light; when the ratio is high (b), the plant at the center of the illustration "knows" the competition from other, surrounding plants is minimal, and so it grows many new tillers. When the density of surrounding plants is high, the ambient light is rich in far-red, and so the central plant greatly reduces its production of tillers (c). To demonstrate the effect experimentally, investigators illuminated the central plant with red lights (d), to make it "think" it had little competition, even though it was densely surrounded by other plants. The high ratio of red to far-red light in the central plant's micro-environment "tricked" it into growing abundant new tillers.

ate. The three investigators studied the reaction of the grasses *Paspalum dilatatum* and *Sporobolus indicus* to the red-to-far-red ratio. Those two grasses, an important source of food for cattle in the Pampas, also turned out to be good experimental models for the studies.

The team devised a beautifully simple experiment to test the color-ratio hypothesis. If plants were using color ratios to estimate the population around them, they could be tricked simply by illuminating them with artificial red lights, thereby changing the red-to-far-red ratio. In the experiment on the Pampas, the team chose a small patch of soil where dozens of grass plants lived in cramped, high-density conditions. But if they were grown with supplementary red lights (actually red LEDs, or light-emitting diodes), they might act as if they had unlimited territory. That was just what happened. "Treated" plants, the ones that got a little more red light at the right place—but not enough to affect photosynthesis—grew far more shoots that their "untreated" counterparts. The artificial red light had delivered a message, and the plants had deciphered it.

After those encouraging first results the team returned to the experimental plot a few times throughout the season to follow the tillers—the shoots that had been tricked into growing at the base of the plants. Most of those plants died later on; they had indeed overextended themselves. They had, it seemed, been fooled by the red lights into "thinking" there were very few other plants nearby—and hence that their competition for resources in later life would be minimal. In fact, though, the competition was fierce; the environment was already overcrowded, and could not sustain the population explosion the team had caused.

To better understand the effect of the red-to-far-red ratio, Casal conducted laboratory experiments in which he manipulated not only the color of the light reaching the plants, but the plants' density as well. As in the field experiments, he exposed half the plants to red LEDs, and left the other half alone. And just as in the field, the plants bathed in red light grew the most new tillers. The big surprise for him, though, was that even when plants were grown at very low density—so low that the shade of a neighbor could not even reach them—the plants were sensing their neighbors. The result was baffling.

At that time, Carlos L. Ballaré, another student of Sánchez's, was facing a similar problem with another species, the weed *Datura ferox*. His plants, too, were responding to the presence of neighbors before mutual shading took place. Ballaré and Casal joined forces.

In all the experiments they performed, the results were so consistent that once they, like Sherlock Holmes, had eliminated the impossible, they had to accept the most improbable explanation of all. Plants can "see" their competitors long before their competitors cast a shadow on them. Even minor changes in spectral composition—the increase in far-red-light reflected and transmitted by leaves—give plants an early warning signal, before the competition actually starts, that competitors have arrived. We can hardly overstate the importance of this discovery.

Light strongly affects developmental processes throughout the life cycle of a plant, starting with germination. Many seeds germinate only when exposed to light. Ana L. Scopel, a plant physiologist also at the University of Buenos Aires, and her colleagues knew that the seeds of the weed *Datura* are enormously sensitive to light. They determined in 1991 that several milliseconds' exposure to sunlight—even, for example, when a field is being plowed—is enough to enable light to reach *Datura* seeds buried in the field and trigger germination. After that brief interruption of the darkness, most of the seeds fall back to a position relatively distant from the dry soil surface. Once germinated, the *Datura* stem grows rapidly beneath the soil. When the plant emerges from the ground, its environment is practically free of vegetation and competition is minimal.

Datura's strategy has turned out to be highly successful, and the seeds of many weed species have adopted it. In fact, it may have evolved as a result of plowing, which favors plants that are extremely sensitive to light. Knowledge about those plants could improve weed management in agriculture, minimizing the need for herbicides. In fact, Scopel and others have shown that such weeds as *Datura* are strongly suppressed when plowing is done at night, or in some other way that minimizes the chances of exposing buried seeds to light.

Of course, light not only triggers the emergence of a plant from its seed. Plant physiologists recognized more than eight decades ago that light also plays an essential role in determining how fast a plant grows and when it flowers. But those early investigators assumed that photosynthesis was the link between light and developmental milestones, just as later plant physiologists had assumed that photosynthesis was the link between the shading of light by neighboring plants and the diminished production of new shoots. But by now, both links have come to seem simplistic. Plants schedule their development not by gathering the energy of light, but by gathering and processing the information it carries. Although they do not have organs for perceiving, much less focusing, light, they do have photoreceptors in virtually every cell of the plant body. Photoreceptors enable the plant to sense the presence of light, its intensity, its duration, its direction, and the relative proportion of its colors.

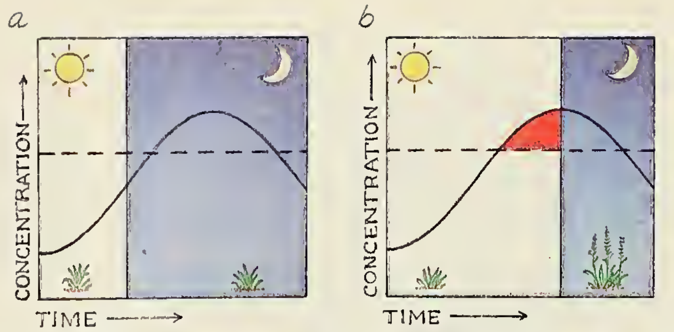
Olivia Parker, *Specimens*, 1993

As the complexity of plant "vision" has been recognized, plant physiologists have sought to describe how it works in molecular terms. Photoreceptors, for instance, are now known to be two-part molecules, a protein and a "pigment" that reacts to light. Most of the recent experiments that have led to an understanding of how plants use light at those molecular levels were performed on *Arabidopsis thaliana*, the thale cress.

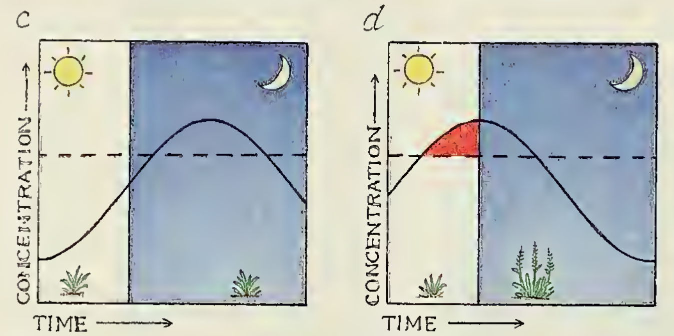
Arabidopsis bears three classes of photoreceptors: phytochromes, phototropins, and cryptochromes. Phytochromes exist in two forms, an "inactive" one that absorbs red light, and an "active" one that absorbs far-red. When the inactive form absorbs red light, it rapidly metamorphoses into the active form, which then regulates numerous developmental processes. Conversely, when the active form absorbs far-red light, it soon changes back into the inactive form. Under natural, unchanging light, the two forms reach dynamic equilibrium, and the ratio of the active form to the inactive form reflects the ratio of red to far-red light reaching the plant.

In environments that sustain only a few plants, the proportion of red light reaching a given plant is high. That pushes the equilibrium toward the active form of the phytochrome in *Arabidopsis,* suppressing the elongation of the stem. The plant starts to grow compact and robust. In a dense patch of grass, however, red light is scarce at ground level because most of it is absorbed, and the ratio of red to far-red light is sharply reduced. That pushes the equilibrium between the two forms of the phytochrome molecules toward the inactive form. Hence the plant grows taller and develops a body shape better suited to the competition for light in the patch of grass. The interplay between the two forms of the phytochrome gives a solid physiological underpinning to the color-ratio hypothesis about how plants sense their neighbors.

But red and far-red are not the only colors plants can "see." The effect of blue light on plant growth has been known since the late nineteenth century, when naturalists such as Charles Darwin and his



According to the "external coincidence model," the concentration of some regulatory molecule builds up, peaks, and falls off every twenty-four hours. Flowering is triggered only when daylight overlaps with any part of the cycle at which the concentration of the molecule reaches or exceeds some threshold value (dashed red line). On short days (a), the concentrations reach threshold levels only after sunset, and so no flowering takes place. On long days, however (b), the concentrations reach threshold levels during the day (area in red), and flowering is triggered.



Daily cycle in the concentration of the precursor of the Constans protein in plants is similar to that of the generic molecule in the external coincidence model. On short days (c) the threshold levels of the precursor are not reached during daylight, and so flowering does not occur. In certain mutant plants the twenty-four-hour cycle of the precursor's concentration is shifted in phase (d). Threshold concentrations are thereby reached during daylight on short days (area in red), and so the plant is forced to flower.

son Francis became interested in phototropism, the bending of plants toward blue light. By isolating mutants of *Arabidopsis* that failed to bend, investigators later identified the second class of photoreceptors: the phototropins. Phototropins, it turns out, control many other plant responses to blue light besides phototropism, such as the rhythmic opening and closing of minute pores called stomata on the surfaces of leaves.

Blue light, like red, also regulates stem growth in seedlings. Cryptochromes, the third class of photoreceptors, mediate that process and play an important role, as well, in the regulation of flowering. But to schedule developmental processes such as flowering throughout the year, plants cannot depend on photoreceptors alone; they also need to measure the length of the day.

Most organisms are adapted to the Earth's twenty-four-hour day-night cycle, and plants are no exception. As a consequence, most biological processes, from sleep-wake cycles in people to leaf movements in plants, follow a daily, circadian rhythm. As long ago as the early 1930s the German physiologist Erwin Bünning hypothesized that plants measure day length with an internal circadian clock—and biological clocks are now thought to be virtually ubiquitous. Circadian rhythms, however, are not mechanically precise; their cyclical period lasts approximately, not exactly, twenty-four hours. Accordingly, biological clocks are constantly adjusted, or synchronized, with the light-dark transitions of the physical solar cycle. Synchronization is done, not surprisingly, by the light-sensitive photoreceptors.

In 1998 Steve A. Kay, a plant biologist at the Scripps Research Institute in La Jolla, California, and his group became the first to identify the photoreceptors that synchronize circadian clocks in plants. Those molecules turned out to be the already familiar phytochromes and cryptochromes. More recently, the two of us (Yanovsky and Casal), together with M. Agustina Mazzela, a graduate student working in our laboratory, discovered that even plants lacking the main phytochromes and cryptochromes could measure time. Other photoreceptors had to be involved.

Soon afterward, Yanovsky joined Kay's laboratory, where he continued to study the elusive mechanism of photoperiodic flowering. The work was guided by a version of Bünning's hypothesis that was proposed in 1964 by Colin S. Pittendrigh, another pioneer in the study of biological clocks. Pittendrigh suggested that a clock directs the production of a molecule that is somehow essential to the plant's seasonal responses to light, and whose concentration builds and declines according to circadian rhythms. The way the molecule functions, he said, would depend on whether light triggers nearby photoreceptors. According to the hypothesis, a photoresponse such as flowering is set in motion when daylight overlaps with a part of the cycle at which the concentration of the molecule exceeds a certain threshold value. Pittendrigh's version of Bünning's hypothesis is known as the "external coincidence model" [*see illustration at the top of this page*]. One of its predictions is that neither the molecule nor the photoreceptors alone can explain photoperiodic flowering; plants need both.

Evidently, a key step in confirming Pittendrigh's hypothesis was to identify the generic molecule he had described in his model. One protein, called Constans, seemed a likely candidate. Although the concentrations of Constans could not be directly measured at that time, Yanovsky knew that the abundance of its precursor was controlled by a cirabundance of its precursor was controlled by a circadian clock. The precursor acted like Pittendrigh's generic molecule. On short days there was virtually no overlap between high levels of the Constans precursor and daylight; on long days the overlap was maximized.

The relevance of that pattern for the precise regulation of flowering in response to day length became apparent when Yanovsky studied the Constans precursor in a mutant plant whose clock runs faster. The faster clock led to a "phase shift" in the production of the Constans precursor, making it peak during the daylight hours of a short day instead of after dark. Remarkably, those plants, which usually blossom only when the days are long, were blossoming on short days [*see lower illustration on opposite page*]. Here was powerful confirmation that Constans protein was integrating information about light and time.

Yanovsky's discovery left many questions unanswered. Why is the overlap of light with a high concentration of Constans necessary for flowering? And what is the connection between Constans and flowering?

In February 2004, Federico Valverde, a plant physiologist at the Max Planck Institute for Plant Breeding Research in Cologne, Germany, and his team were finally able to make direct measurements of the concentration of the Constans protein. They discovered that the integrity of Constans depends on its exposure to light. Without light, the protein is destroyed and its concentration remains low, even when its precursor is abundant. To reach high levels of Constans, there must be an overlap between the clock-controlled Constans precursor and the photoresponse of the photoreceptors, the two key elements of Pittendrigh's model. As for the connection between Constans and flowering, it turns out that Constans switches on a gene called *Flowering Locus T*, which induces a small group of undifferentiated cells to produce flowers at the tip of a plant stem.

Although we photobiologists are delighted with our recent successes, we are also well aware that we understand in detail only a handful of the many mechanisms whereby plants, through a complex network of interacting signals, coordinate their development with their changing environment. The continuing study of *Arabidopsis* and other species will surely enable us to expand our knowledge of plants and their exquisite ability to respond to the subtlest light signals. □

Michael Pole, *Tree and root system*, 2002

Bird-of-paradise flies—which are not really flies at all, but members of the scale-insect family Margarodidae—are a rarely seen kind of scale insect: mature males. Here are two of them on one enormous female. On reaching adulthood, the typical male scale insect lives just a few days. The genetic system of many margarodids, unlike that of most scale insects, is "conventional": both mother and father contribute half of their genome to each of their offspring.

Female scale insects of the family Ortheziidae have sunk their mouth parts into a leaf, where they will stay, feeding on the plant sap, for much of their sedentary, parasitic lives. The sap gives the insects access to a practically unlimited supply of sugars.

The Sex Lives of Scales

Scale insects have evolved one bizarre genetic system after another. The author argues that they are caught in a game of cat and mouse with internal, symbiotic bacteria, which has unleashed genetic bedlam.

By Benjamin B. Normark

If you were in the backyard this summer, watering your lilacs or checking your apple trees for pests, you may have noticed that the plants were afflicted with little bumps on the leaves or bark, coming down with what looks like nothing so much as a case of botanical acne. Many people are surprised the first time they find out that each bump is actually an animal: a scale insect. Many scale insects look more like mollusks or turtles than like beetles or cicadas—the bodies aren't obviously segmented into head, thorax, and abdomen, and the six legs and four wings typical of most insects are nowhere to be seen. Yet those little bumps are indeed insects, related to aphids, whiteflies, and jumping plant lice.

All scale insects are parasites of plants, and the insects' habit of sucking the sap out of plants makes them generally disliked by farmers and gardeners. In a sense, scale insects have taken the parasitic lifestyle to the farthest extreme: the females of some lineages have evolved into legless, eyeless blobs that are permanently attached to their hosts.

Even among the most casual keepers of houseplants, most people's reactions to scale insects run from mere distaste to full-blown disgust. But if you take the trouble to look beneath the surface, scale insects turn out to be quite fascinating creatures. In particular, the laws of genetics—the rules that describe how the DNA of one generation is passed on to the next—seem to have gone totally haywire as the scale insects have evolved. The group encompasses more weird variations on the laws of genetics than does any other group of animals.

But surely, weirdness is in the eye of the beholder. Just because mammals don't have such varied genetic systems, is that grounds for calling scale insects strange? Well, consider this: From a genetic

Female scale insect of the genus Steatococcus is a margarodid, like the bird-of-paradise fly pictured at top left of opposite page. Although the genetic system of Steatococcus is as yet unknown, it is possible that the system (deduced from that of its close relatives) is decidedly unconventional. The male might develop from an unfertilized egg and thus have only half the DNA that the female has—a genetic state that would make him little more than flying sperm that can spread half of his mother's genes.

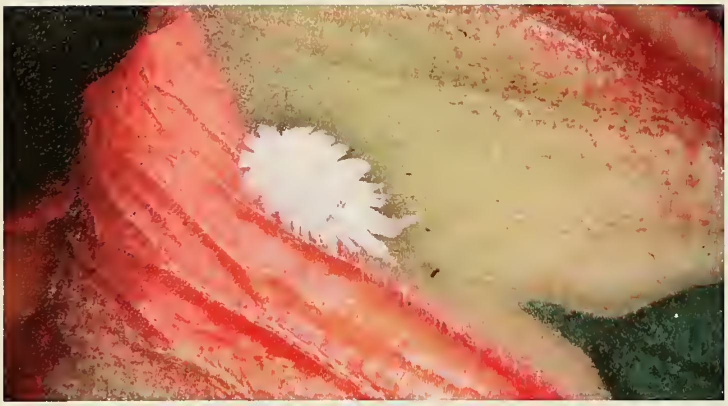
point of view, a typical multicellular animal is an assemblage of cells that are nearly all clones, or genetically identical to one another. Yet in most species of scale insects, not all the cells of an individual get the same genes from the insect's mother. Furthermore, scale-insect fathers vary widely in the genes they contribute (or, often, do not contribute) to their sons: In some species the males are the product of asexual reproduction and have no father at all. In other species the males have fathers, but all the chromosomes they get from the fathers are deactivated. In still other species the chromosomes from the fathers are present in some cells but not in others.

Much of this is not news. Thanks to the pioneering work of the American geneticist Sally Hughes-Schrader and others, many of these facts have been known since the 1920s. Only recently, however, has evolutionary theory begun to catch up with those facts, and to describe them with concepts powerful enough to explain the data in a satisfactory way. Only now do biologists have an inkling about what might be causing the apparently staid world of blobby little plant parasites to be convulsed by so many sexual revolutions.

It is not readily apparent why scale insects, of all life-forms, should exhibit such a diversity of genetic systems. After all, other, related groups of insects show nothing approaching the same degree of variation in their genetic machinery. Particularly puzzling is the scale insects' patrilineal inheritance. Why is it so frequently sabotaged? Those are unsolved mysteries, but quite recently, suspicion has fallen on some unusual suspects: bacteria.

The bacteria in question are not disease organ-

Mealybug females (rough white line of insects), like many other scale insects, defecate the excess sugar they ingest while feeding on the sap of plants. That waste, commonly called honeydew, provides a good source of food for other insects (and sometimes even humans). Asian weaver ants are tending the mealybugs above, protecting the defenseless scale insects and, in return, getting access to the honeydew.



Female putoid scale insect depends, as do other scale insects, on symbiotic bacteria for nutritional aid. In putoids, the bacteriome cells, where the bacteria reside, appear to be passed down intact from mothers to offspring. That may make it more difficult for the bacteria to develop a male-killing habit, because they are always insulated from genetically male tissues and so may be unable to distinguish between male and female hosts.

Mealybugs, such as the male citrus mealybug above, have independently evolved a bizarre system for creating a bacteriome, which is quite similar to the method of the armored scales (see diagram on opposite page).

isms; rather, they live symbiotically with their scale-insect hosts, a relationship that is vital to both organisms. The bacteria derive their very livelihoods from the insects, and the insects in turn depend on their resident bacteria for help surviving on a diet that is conspicuously lacking in protein. Yet despite the aid the bacteria render the insects, the bacteria may still interfere with the insects' genetics. To understand why, it is helpful to understand something about the lives of scale insects and the bacteria that live inside them.

Immature scale insects do not look much like the little bumps on plants that many of them are destined to become. During the first, or "crawler," stage in the life cycles of scale insects, the animal looks a bit like a small potato bug. The typical crawler, after hatching from its egg, walks a short distance on its natal plant, then inserts its mouthparts into the plant and becomes immobile. There the insect generally remains through subsequent immature stages, regardless of its sex.

The life and form of an adult scale insect, however, depends heavily on its sex. The males are not exceptionally strange-looking insects. Most people would probably mistake them for small flies, such as gnats or midges. Their strangeness becomes apparent only when you look more closely: they have only two wings (like true flies but unlike almost all other insects) and simple, rather than compound, eyes, and they always lack functional mouthparts; grown males never feed. Much more unusual looking are the adult females; they are the bumps you may have seen on your houseplants. Adult females never have wings, and they often lack legs and eyes as well; for antennae, many possess only the tiniest nubs.

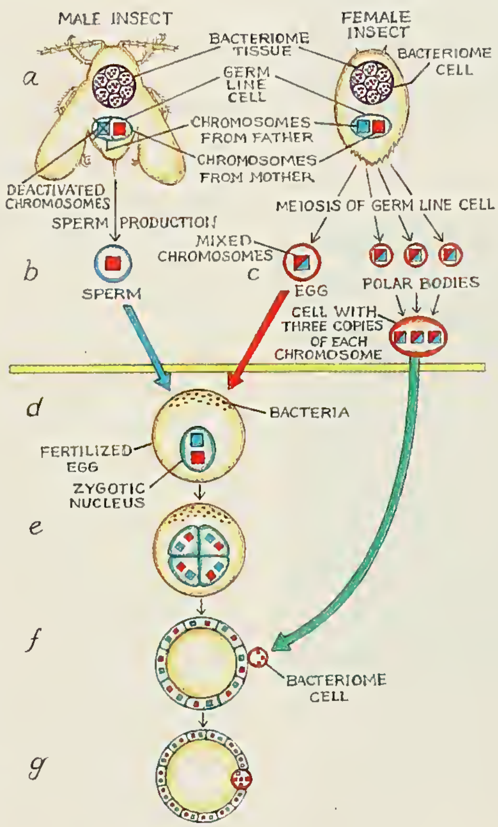
All scale insects feed by sucking up plant juices, and most feed directly on the phloem sap of long-lived trees and bushes. Phloem sap is typically rich in sugar, and most scale insects ingest far more sugar than they can use; they simply defecate the excess. The sugary excrement, called honeydew, is often consumed by ants. Sometimes it is even consumed by people, particularly in arid regions where evaporation of dripping honeydew can leave a solid sugary residue called manna. The manna referred to in the Bible, in Exodus 16:14, seems to have been the dried excrement of *Trabutina mannipara,* a scale insect that feeds on tamarisk trees.

But even though plant sap is rich in sugar, it is poor in other nutrients, particularly amino acids. Partly on the basis of studies of scale insects' better-known relatives, the aphids, one can infer that the symbiotic bacteria living inside scale insects manufacture essential amino acids lacking in the insect's diet.

The essential bacteria in scale insects (and aphids) live inside the cells of an organ called the bacteriome. (The location and size of the organ varies, depending on the species of insect.) Each scale insect inherits the bacteria in its bacteriome from its mother. When the adult female scale insect is provisioning its eggs, cells from the mother's bacteriome discharge bacteria into the yolk. No scale insect gets bacteria from its father. Thus, the bacteria in the cells of male insects are effectively sterile; in an evolutionary sense, they are as good as dead.

John H. Werren, a biologist at the University of Rochester in New York, has described how certain insects' maternally inherited bacteria rebel against the inglorious destiny of winding up in a male [*see "Invasion of the Gender Benders," February 2003*]: they kill the male in which they live. Although that act is suicidal (the bacteria in the male they kill die along with the insect) and so might seem gratuitous, it is not pointless. Each bacterium in an embryo is practically identical to the bacteria that populate other individuals in the same insect brood. Moreover, if the goal of each bacterium is to pass its DNA on to future generations of bacteria, what is good for one bacterium is good for the rest. Thus a bacterium's suicide by killing its male host makes evolutionary sense, as long as such a killing helps the bacterium's kin to prosper.

It's easy to imagine how that circumstance could arise. For example, if female scale insects harboring bacteria were forced to compete with their brothers, the competition could very well be detrimental to the bacteria in the females. But from the perspective of the bacterial genome, the bacteria in the male insects are expendable, since they are guaranteed never to reproduce. Their suicidal killing of the males, though, gives the female insects (and their bacteria) freer run of available resources. That cold calculation holds particularly true among scale insects, partly because their host plants live so long, and partly because the insects move around so little. There is plenty of time in the life span of a long-lived plant for the insects that live on it to produce enormous extended families. Moreover, the females' sedentary nature keeps close kin, and their closely related bacteria, on a single host plant. Insects in such close proximity are particularly likely to compete with one another for hiding places or other resources, and the genes of their resident bacteria are so similar that the common bacterial genome is particularly likely to benefit if male insects are killed.



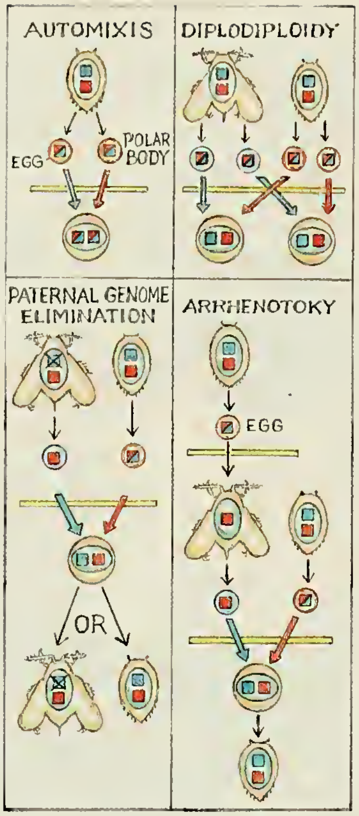
Both male and female armored scale insects and mealybugs (a) host bacteria within the cells of an organ called the bacteriome. A male produces sperm (b) that carries only his mother's genome; a female produces an egg and three polar bodies (c) with a mixture of chromosomes from both her parents. The union of DNA from both egg and sperm form a zygotic nucleus within the egg cell, constituting a new genetic individual; the egg in these two groups of scale insects also hosts symbiotic bacteria in the yolk. The chromosomes from both sperm and egg in each new individual are "imprinted" as paternal (blue) or maternal (pink) in source (d). As the nucleus begins to divide and the embryo grows (e), the three polar bodies fuse with each other and then fuse with one of the cells of the embryo (f). The resulting cell has four copies of the maternal chromosome and one copy of the chromosome of the paternal grandmother. That cell becomes the parent cell of the new scale insect's bacteriome (g), to which the bacteria from the egg yolk then migrate.

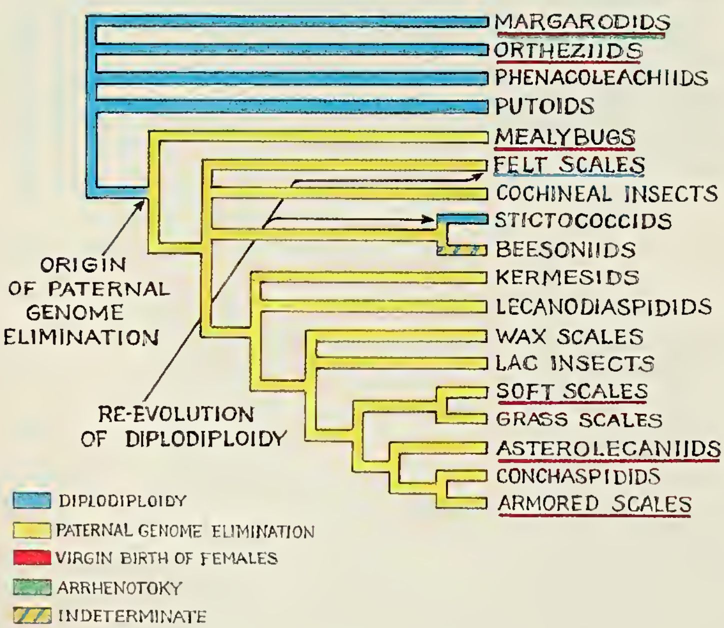
Thus one might expect a kind of struggle between scale insects and their bacteria. On the one hand, the scale insects are under pressure to keep their sons alive. On the other hand, the bacteria can benefit by killing males and only males. (Killing a female host insect is decidedly against the interests of the bacteria, since they cannot spread beyond their host except through her egg cells.) For the bacteria to kill males and not females, they must be able to distinguish male from female hosts, and it is possible they detect the sex of their host by interacting with their host's chromosomes. (Males often have a deactivated set of chromosomes or otherwise differ genetically from the females.) How could this struggle escalate? One way is that the scale insects might "fool" the bacteria into not killing males by keeping the bacteria inside cells that lack any clear sign about the sex of the host insect. Remarkably, that is exactly what many scale insects have evolved to do.

To understand how a scale insect might pull off that bit of legerdemain, it is helpful to start with some of the most ancient groups of scale insects. Their genetic characteristics are the most similar, among the scale insects living today, to those of the superfamily's long-dead ancestors. Each cell in each insect has a full set of functional chromosomes, one set from its father and one set from its mother. Such groups include the scale-insect families Ortheziidae and Phenacoleachiidae, and many branches of the family Margarodidae (but not all branches; even within families, the scale insects have more genetic systems than I have space to discuss).

Many ortheziids, as they

Sex (or the lack of it) among scale insects gives rise to a bewildering variety of systems of genetic inheritance. Four of them are detailed at right, based on the same scheme as in the diagram on the preceding page. Parthenogenesis, or the virgin birth of females, takes several forms, but in automixis, the form pictured here, the female egg fuses with a polar body instead of with a sperm. In diplodiploidy, which is also the human genetic system, both the mother and the father contribute one copy of each of their chromosomes to each offspring, which can be either male or female. In paternal genome elimination, the most common method of genetic inheritance in scale insects, the male can pass along only those genes he received from his mother. In arrhenotoky, the male develops from unfertilized eggs. Those males mate with females, and every egg that gets fertilized develops into a female.





Cladogram, or biological "family tree," of the scale insects shows how the genetic systems of scale insects—four of which are outlined in the diagram at the top of this page—are distributed through the various families; the significance of the colors on the branches of the cladogram and of the underlining of family names is given in the color key. Branch color indicates the predominant genetic system in each family; underlining indicates genetic systems that have evolved independently in one or more groups within the family.

are known, live in soil or leaf litter and feed on fungi, lichens, mosses, and plant roots. Margarodids comprise a diverse group, found on all parts of plants; the family includes the largest and most striking scale insects, such as Australia's bird-of-paradise flies [*see photograph at top left on page 38*]. The phenacoleachiids comprise a "living fossil" group; today only two species exist, and they occur on the South Island of New Zealand and on adjacent islands. All three families include scale insects that are relatively "normal" insects—not very normal; they are scale insects, after all. But they have more in common with other insects than most scale insects do. Adult females have functional legs and eyes. The sex chromosomes are distributed in a reasonably ordinary way: as in aphids, males have one sex chromosome and females have two. And the entire insect has the same genome in every cell, including the cells of the insect's bacteriome.

But genetic simplicity is rare for the scale insects. Consider the family Putoidae. Putoids typically occur on the foliage or roots of woody plants in the southwestern United States. They, like their ancient relatives, look fairly "primitive": adult females retain their eyes and legs, and they can walk. Putoids also have the ancestral number of sex chromosomes: one for males, two for females. Yet according to the German biologist Paul Buchner, a microscopist and pioneer in the study of symbiosis, putoid bacteriomes are deeply strange.

The putoids, unlike other scale insects, are apparently not content to simply insert bacteria from the mother's bacteriome cells into the yolk of the fertilized egg. Instead, when the essential but potentially troublesome bacteria move from the mother putoid to her offspring, entire cells from the mother's bacteriome move with them, taking up residence to form the bacteriome of the embryo.

It is hard to overstate how weird that process seems to a geneticist. (It is so weird, in fact, that some biologists think Buchner must have gotten it wrong.) For the most part, we animals grow our own organs. Each of my organs is genetically "me." Putoids are the only animals I know of that appear to import one of their organs and then pass it down from mother to offspring much the way people pass along the family china or silverware. Normally an animal's germ line—the cells that give rise to gametes—is the only cell line that is, potentially, immortal: the only cell line inherited by offspring. But in putoids the cells of the bacteriome are equally immortal, yet they are independent of the germ line and not even closely related to it.

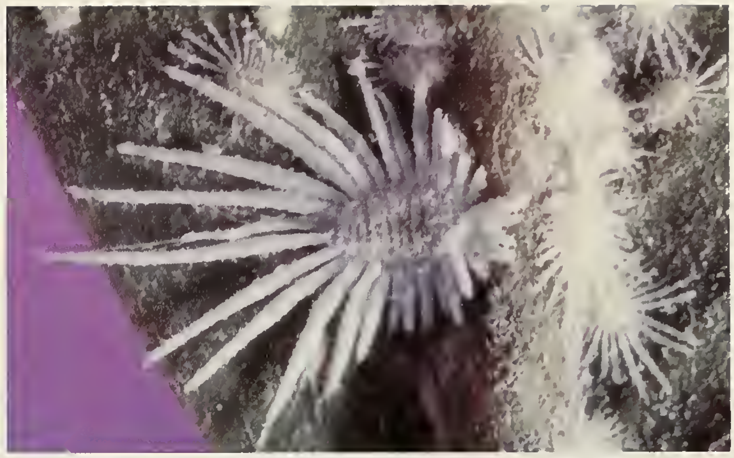
Biologists still do not really know what originally led to the evolution of such a wholesale migration of maternal cells (though those cells might play a role in provisioning the embryo). But one effect of the migration is that bacteriome cells in males are genetically identical to the bacteriome cells in their sisters. That may make it hard for the bacteria to identify the sex of their host insect—and thus too risky to their own genetic well-being to kill their hosts at all.

Two other families of scale insects form their bacteriomes in bizarre ways. One is the family Pseudococcidae, another ancient, primitive-looking group whose females retain their legs. Pseudococcids are commonly known as mealybugs, a name referring to a coating of fine wax on their bodies that makes them look as though they had been rolled in flour. The other family with extraordinary bacteriomes is Diaspididae, the armored scale insects. Whereas mealybugs retain many of their ancestral characteristics—like legs—the armored scales lie at the opposite extreme in the morphological evolution of scale insects. Adult female armored scales lack legs and eyes, and they barely have antennae. Taken together, the mealybug and armored-scale families encompass more than 4,300 species, some 60 percent of all scale-insect species. Yet despite their clearly visible differences, the two families have each evolved, apparently quite independently, similar yet highly exotic systems of bacteriome development.

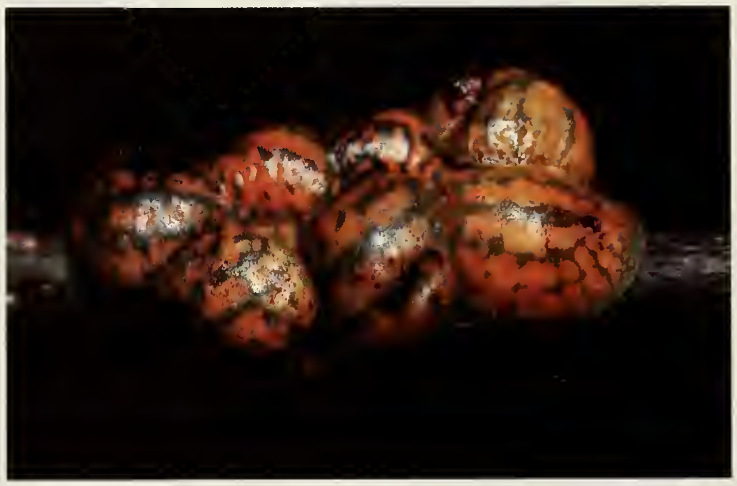
Most animal cells, including the cells of the germ line, have two copies of each chromosome: one from the animal's mother, the other from the father. Egg and sperm cells, though, which are derived from germ-line cells, each have only one copy of each chromosome. In particular, to make an egg cell, a female animal must throw away one copy of each chromosome. That is accomplished, among other things, during a process called meiosis.

Meiosis actually starts with the duplication of every chromosome in the germ-line cell, followed by two divisions of the nucleus. Thus, one nucleus with two copies of each chromosome first gives rise to a nucleus with four copies of the chromosome. Then that nucleus splits into two nuclei, each with two copies of each chromosome; those nuclei in turn split into four nuclei, each with one copy of each chromosome. One of those four becomes the egg nucleus; the other three are called polar bodies.

In most organisms, the polar bodies are simply destroyed; only in a few cases do they avoid destruction. One such case is prominent and important: the nutritive tissue packaged into the seeds of



Females of mealybug species that is closely related to the mealybug species in the photograph at the bottom of page 39



Tuliptree scale insects are members of the soft-scale family, but they do a remarkable imitation of a cluster of arboreal turtles. Many soft-scale species engage in paternal genome elimination: the genome of the father is disabled or eliminated in male progeny. Some species have done away with males altogether.

Black thread scales, here shown infesting a leaf, are members of the armored scale family. Although many armored scales reproduce sexually by paternal genome elimination, black thread scales have eliminated fathers—in fact, all males—completely.

flowering plants contains polar-body genomes. But even in that case, the polar bodies don't wind up in the embryo of the plant. The only case for which polar bodies from the mother are actually incorporated into the body of her offspring occurs in scale insects. And where the polar-body genomes wind up is, as you might have guessed, the bacteriome.

After a mealybug or an armored scale female forms her three polar bodies, the three fuse into a single nucleus; that nucleus thereby contains three full copies of the mother's genome, the three "extras" left over from meiosis. The nucleus is engulfed by the developing embryo, and then fuses with a cell from the embryo to form a cell with five copies of each chromosome. That cell proliferates to form the bacteriome [*see illustration on page 41*].

No one really knows why polar bodies survive destruction in those scale insects, why they fuse with a cell from the embryo, or why they then form the bacteriome. But one consequence is that the genomes of bacteriome cells of males are identical to those of their sisters. The participation of polar bodies in forming the bacteriome, like the inheritance of the maternal bacteriome in putoids, would seem to make it hard for the bacteria to selectively kill males.


Female margarodid scale insect

Bacteriome formation is probably the strangest aspect of scale-insect genetics, and the one in which bacteria are most obviously involved. But a close runner-up for strangeness is the genetics of male scale insects. The male scale is originally endowed with two sets of chromosomes, but the ones from his father typically form an inactive clump in every cell. They never direct the synthesis of proteins, and they are discarded from the germ line when sperm are made. Hence each sperm a male produces has exactly the same genome—the genes he got from his mother. That, of course, is in marked contrast with most male organisms, including men, who each produce a diversity of genetically unique sperm. It also differs sharply from the genetics of the female scale, which has an active paternal genome and apparently produces genetically diverse eggs.

In some species of armored scale insects, the father's genes are not merely deactivated; rather, they are completely eliminated from cells early in embryonic development. In a few scale insect groups the father's genes have become reactivated, and there is one tissue in most scale insect species—those unusual bacteriomes of mealybugs and armored scale insects—that retains active paternal genes, though even there they are greatly outnumbered by maternal ones.

Geneticists have long wondered how genetic systems involving the deactivation or destruction of the paternal genome could ever have arisen, since the first males to completely lack a paternal genome probably did not survive. But the recent focus on the bacterial genome gives a possible answer to the puzzle. Symbiotic bacteria had both the motive and the opportunity to destroy the paternal genome in males, particularly if they could thereby kill the male. But the destruction of paternal genomes in sons could also be a phenomenon that the females have turned to their own advantage. In most genetic systems, such as the mammalian one, a typical male endows his offspring, on average, with half the genes he received from his mother and half the genes he received from his father. In contrast, a male armored scale or mealybug that manages to survive the depredations of the bacteria is twice as efficient as the typical mammalian male at transmitting his mother's genes. After all, the male scale insect's cells have basically jettisoned the genes the male received from his father. Thus the destruction of the paternal genome may have begun as a means of male-killing by bacteria. But over evolutionary time it may have been co-opted by females as a way to spread their own genes at the expense of the genes of their mates.

The ongoing partnership between scale insects and their bacteria is evidently a stormy one. Their conflict and its shifting tactics could well be what drive the dynamic evolution of the scale insects' genetic systems. But no one knows for sure. To find out, new generations of naturalists will need to explore the field, people who are subtle enough to resist the allure of prettier creatures and delve into the deep enigmas that are scale insects. □

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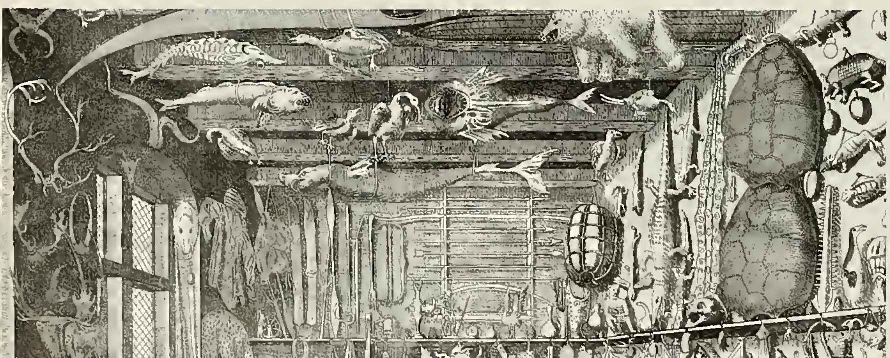
A Room Revisited

A contemporary artist is inspired by a "cabinet of curiosities" collected by a naturalist of another era.

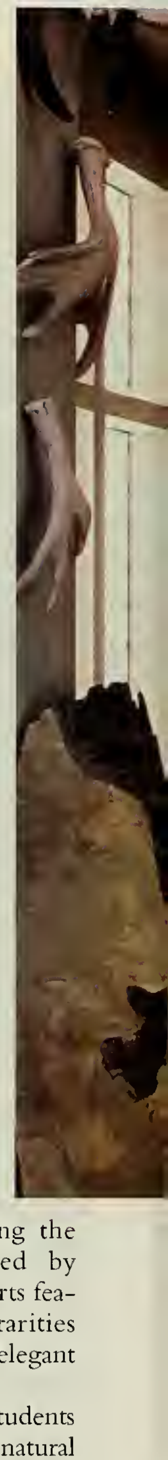
By Rosamond Purcell

In 1985, in a back room of the Museums of Natural History in Copenhagen, I came face to face with a wall-size reproduction of a familiar engraving. It depicted the interior of a museum—the Museum Wormianum—established by Ole Worm, a seventeenth-century Danish archaeologist, embryologist, natural philosopher, physician, and teacher. The engraving was the frontispiece to his 400-page catalog *Worm's Museum; or, History of Very Rare Things, Natural and Artificial, Domestic and Exotic, Which Are Stored in the Author's House in Copenhagen,* published (in Latin) in 1655, a year after his death.



One-room natural history museum created in the seventeenth century by the Danish physician Ole Worm, as depicted in the frontispiece to his catalog of the museum's collection

Near the reproduction of the picture I saw one of the few known survivors from Worm's collection: the jaw of a horse, clasped by the branch of a tree that had grown around it. In the engraving, this curious object appears, pale and shadowy, alongside hundreds of other objects. But here, in the modern museum, that single element had been uprooted, transported to the present, and transmuted, as if by alchemy, into three-dimensional bone and wood. I photographed the captive jaw from every angle.



As the years passed, I stared at the frontispiece to Worm's catalog wherever it appeared (and it appears often in writings on the history of science). Small private museums, often referred to as "cabinets of curiosities," were commonplace during the seventeenth century. Those created by Worm's English and Italian counterparts featured both natural and artificial rarities housed inside or displayed on top of elegant pieces of furniture.

Worm's collection, created for his students and his peers, was a compendium of natural objects and ethnographic and archaeological artifacts. Like his fellow European collectors, Worm took pleasure in amassing treasures from exotic places: coconuts, coins, and corals; fossils and twisted roots; magnifiers, mirrors, and other instruments for measuring. He owned artifacts from the daily lives of peoples from the circumpolar region, including baskets, spears, and tools; he displayed stuffed gulls, a polar bear, and a grinning croc-

Recent re-creation of Ole Worm's museum, by Rosamond Purcell

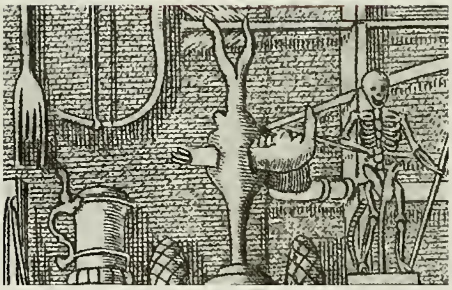
odile; he possessed partial skeletons of whales, seals, and the long-toothed narwhal. Worm collected monstrous specimens, too, including a horse with horns growing from inside its ears, a unicorn goat, and what sounds, by his description, like an enormous hydrocephalic skull, thin as an eggshell, found in a local field. Some of these objects are visible in the frontispiece to his catalog; others are simply described. Behind the public showcase, then, was perhaps a storeroom.

Worm's room, in contrast to the rooms of other collectors, is depicted as a modest space, unadorned. Everything—whether arranged on the shelves, suspended from the ceiling, or placed on the walls—is in plain sight. After his death, the contents of his museum were absorbed into the larger collection of his royal patient King Christian V of Denmark, and much of that was later dispersed.

It takes a certain suspension of disbelief to dream one's way back into a picture. Yet whenever I stared at the engraving, it was as if I were actually there, inside a day-lit room among so many mysterious and familiar things I might touch or even hold. When, in 2002, the curatorial staff at the Santa Monica Museum of Art, in California, began negotiations for an exhibition of my studio, they observed my obsession with Ole Worm and decided to commission me to create a full-scale replica of both his room and mine.

I worked my way into understanding something about Worm's methods of classification by studying how his collection was arranged. Placed on his open shelves, such boxes as *Lapides* (stones), *Salia* (salts), *Sulphura* (sulfur), and *Terrae* (earths) follow conventional seventeenth-century taxonomic thinking. For Worm and his contemporaries, the category "stones," for instance, could include fruit pits as well as fossils, and the category "fossils" referred to anything dug from the ground, including pottery shards and ancient coins. Reptiles—a crocodile, lizards, snakes, and turtles—share a wall in Worm's museum. Yet, suspended between his lizards and near his giant turtle shells, is a large armadillo, which is no reptile, though it certainly looks like one. Thus all the scaly and armored creatures hang together—a reminder to the modern viewer that certain animals had not yet been precisely classified, and that certain rules of taxonomy did not yet exist.

Even after the Swedish botanist Carolus Linnaeus established the binomial system of scientific classification in his *Systema Naturae,* published in 1735, the boundaries between creatures of the sky, the earth, and the ocean were blurred. People spoke of river horses (hippopotamuses) and vegetable lambs (sheep supposedly engendered by plants). The names of fishes, too, were commingled with those of birds and mammals. The goosefish and wolffish that are depicted hanging from the rafters in the engraving more closely resemble the deep-sea monsters depicted on early maps than the dried planks that such specimens in fact become. These fish swim above the visitor's head; alongside them fly the birds.



Jaw of a horse (top), encircled by a branch as it grew, is one of the few extant objects known to have been in Ole Worm's museum. The jaw is shown above in a detail of the frontispiece to the museum's seventeenth-century catalog.

Worm sought to represent "the world as known." He taught his students to make direct observations of natural phenomena rather than to memorize the observations made by earlier scholars, including Aristotle. In this approach to natural history he was a pioneer. As a physician, he conducted his own experiments: hanging spiders above a sick person's bed to banish disease, or giving a dog some poison and then feeding it a putative remedy so as to test the remedy's curative properties. But Worm struggled to subject himself to the unfamiliar discipline of scientific thinking. He reports that in Iceland, in 1648, many people ate narwhal meat without suffering repercussions, yet he still repeats the anxious warnings of his day that partaking of the narwhal is to risk "danger of death." In general, though, his experiments demonstrate his commitment to distinguishing myth from fact, to drawing firmer lines between superstition and scientific proof.

As I stare at the wide-angle depiction of Worm's narrow room, its walls and even its corners seem to unfold like a body splayed open for autopsy. What, I wonder, was actually on the shelves in 1655, and what was in storage or had already passed into King Christian V's collection? How much of the engraving (done not by Worm himself but by a contemporary artist) derived from well-documented observations of the scene, and how much from the artist's imagination? The engraving accurately depicts familiar animals and objects, as well as cartoonlike renderings of other things, yet I treat it as a cross-section of an authentic archaeological site.

My mission was to make a physical re-creation of Worm's room. With the help of artists who simulated certain artifacts, and with the benefit of indispensable loans from natural history collections, I have produced a version of the past. But, paradoxically, each gesture we made toward replicating the room led away from it. The closer we came to matching each three-dimensional object against its shadowy twin, the more the original form receded. There can be no perfect replication, of course. Worm's collection exists best in the engraving. Our replica is one attempt to bridge an unbridgeable gap. □

"Bringing Nature Inside," an exhibition that includes Rosamond Purcell's re-creation of Ole Worm's museum, opens September 27 and runs through January 2005 at the Collection of Historical Scientific Instruments, Harvard University Science Center, Cambridge, Massachusetts.

Alvin, a deep-sea submersible vehicle, is pictured here in a nighttime photograph, much as it would appear in the ocean depths. Arrayed with lights and carrying a pilot, a cinematographer, and an IMAX camera, the vehicle captured the most detailed images of undersea hydro thermal vents ever made, including the image on the opposite page.

Secret Survivor

"Extinct" for 50 million years, an enigmatic fossil species may still live at the bottom of the sea—but it defies capture.

By Peter A. Rona

So little is known about the deep ocean, that those of us who explore it should expect surprises. Yet even I and my research team from the National Oceanic and Atmospheric Administration were dumbfounded in 1976, when we studied photographs of the seafloor in the middle of the Atlantic Ocean. From our research ship *Discoverer,* we had slowly towed a deep-sea camera on a cable two and a half miles long. Pings of sound had guided the camera roughly ten feet above the seafloor, while strobe lights fired every twenty seconds to illuminate patches about the size of a bed sheet. In those days we had to wait until we were back on land—Florida, in this case—to process the film and view the images.

At first all we saw was the silt that coats the ocean floor. Then something a little bigger than a poker chip caught our attention. Under a magnifying glass, a distinctive pattern of black dots appeared in our photograph. The dots were evenly spaced and arranged in crisscrossing rows, forming a perfect six-sided figure that resembled the center of a board of Chinese checkers [*see lower photograph on page 53*].

Once we knew what to look for, we recognized thousands of these hexagonal forms in our sequence of hundreds of photographs. Could such a uniform pattern be the sign of some unimagined life-form? Certain corals, for example, build structures with hexagonal symmetry, but not in seafloor sediment. Our imaginations ran wild. Was this a hoax perpetrated by the people who had processed our film? Was this some strange cargo spilled from a shipwreck? A message left by extraterrestrials? Surely my local marine biology colleagues at the University of Miami would quickly enlighten us. But they were just as puzzled as we were. They referred me to their counterparts at the National Museum of Natural History, Smithsonian Institution, in Washington.

The area we had surveyed was in the rift valley that lies along the center of the Mid-Atlantic Ridge, a mile-high undersea volcanic mountain range that traverses the Atlantic from north to south. The ridge links with similar ridges in the Arctic, Indian, and Pacific oceans [*see map on page 52*]. Along this global ridge system, continent-size tectonic plates, which form the outer shell of the planet, are moving apart, and new crust is constantly being created by the upwelling of magma from the Earth's hot interior. As it emerges, the molten rock cools, solidifies, and spreads apart at a rate of a few inches per year. Earthquakes accompany the slow widening of the seafloor.

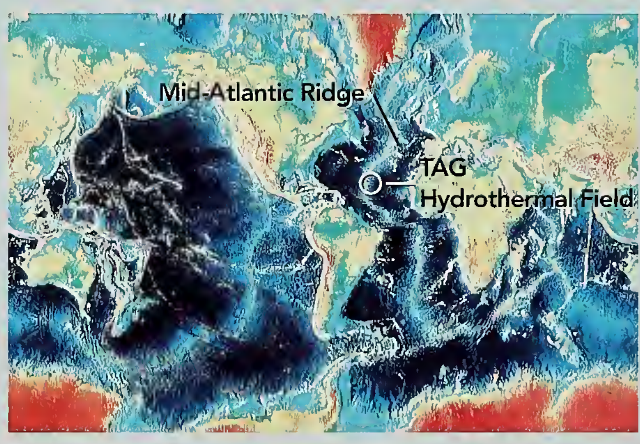
Armed with a dozen black-and-white photographs, I made the rounds behind the scenes at the Smithsonian. My first consultation was with Frederick M. Bayer, an expert on corals. But Bayer concluded that the form was not a coral at all, and introduced me to an expert on another phylum of marine invertebrates. By the end of the day, specialists in every major group of marine invertebrates had examined the photographs and had drawn a blank. Their only advice was to prepare an article for publication in a scientific journal, with photographs showing the pattern as related to "an invertebrate of uncertain identity."

No sooner had the suggested article appeared,

"Eyeless" shrimp, belonging to a species discovered by the author, cluster around a hydrothermal vent along the Mid-Atlantic Ridge, two and a half miles beneath the ocean surface. They live off bacteria, which derive their energy from the rich, sulfurous brew (smokelike discharge) created when water leaks into the rock below the seafloor, gets heated by nearby magma, and circulates up to the vent.

than I received a letter and a reprint of a paper from Adolf "Dolf" Seilacher, a paleontologist then at the University of Tübingen in Germany. Seilacher is an expert on classifying and interpreting traces of life—such as the trails left by worms—that are preserved in ancient marine sediments. "Your pictures were a real thrill to me," his letter began. "Hoping that you have in the meantime received my reprint, the perfect identity with the trace fossil *Paleodictyon nodosum* of my paper is beyond any doubt."

Seilacher's paper described a fossil form preserved at least 50 million years ago in sediments of the deep-sea floor, which were now exposed on land at various sites in continental Europe. He was particularly excited that our discovery would enable us to find out what had left this enigmatic form in the fossil record. In other words, he proposed, we had stumbled onto evidence that a creature presumed to have been long extinct was still alive today. If we could confirm Seilacher's confident belief in the identity of the fossil and the pattern on the seafloor, it also seemed possible that we could discover what creature had produced it.



Hydrothermal vent system dubbed the TAG Hydrothermal Field was discovered by the author. It lies in the rift valley of the Mid-Atlantic Ridge, an undersea volcanic mountain range that connects with ridges in the Arctic, Indian, and Pacific oceans.

From the sketches in Seilacher's paper, we learned that the black dots visible in our photographs might be holes that led straight down a fraction of an inch to a horizontal network of tubes or tunnels just beneath the sediment surface. The tubes in the fossil forms interconnected in an orderly hexagonal network [*see upper photograph on opposite page*]. Seilacher's interpretation was that the network was a tunnel system excavated by some kind of worm. This creature, he believed, augmented its sparse supply of food in the deep ocean by "farming" and harvesting bacteria in the tunnels. Furthermore, he proposed, the hexagonally arranged network was an evolutionary descendant of simpler traces preserved in 500-million-year-old sediments. As he envisioned it, the first organisms that excavated such tunnels inhabited shallow waters, but soon they retreated to the deep sea, perhaps a place where they could pursue their feeding strategy undisturbed. Over time the tunnels became more regular, and multiple exits were added to improve circulation, culminating in the strikingly regular *Paleodictyon* form.

In 1977, a discovery was made near the Galápagos Islands, in the eastern equatorial Pacific, that fundamentally changed the biological understanding of life on Earth. At a depth of about a mile and a half—far deeper than sunlight can penetrate to provide the energy needed for photosynthesis—an oasis of life was unexpectedly found in the desert of sediment and lava flows that covers most of the deep-sea floor. In an area about the size of a football field lived foot-long clams and red-plumed tubeworms that stood taller than a person.

These and what turned out to be hundreds of other animal species new to science were prospering in warm springs issuing from cracks in pillow-shaped lava flows. Biologists immediately wondered how these animals could make a living, apparently without depending on nutrients generated through photosynthesis. It turned out that at the base of the food chain were bacteria that nourished themselves through a process of chemosynthesis. Drawing their energy from gases dissolved in the warm springs, mainly hydrogen sulfide, they were able to manufacture sugars and starches from carbon dioxide and water.

The Galápagos discovery was soon followed by the revelation of similar ecosystems at hot springs discharging from spectacular "black smoker" vents along the ridge system in the Pacific. The temperatures in these hydrothermal vents ranged as high as a scalding 750 degrees Fahrenheit (400 degrees Celsius). With these discoveries geologists realized that the ocean basins are really leaky places. The cold, heavy seawater can sink downward for miles, through cracks in the underlying volcanic rock. There it is heated as it flows near reservoirs of magma at sites beneath the ridge system, expanding and rising until it discharges from the seafloor. Along the way it dissolves metals and picks up gases from the rocks and the magma. The metals precipitate out of solution as iron-rich sulfides, coalescing into chimney-like structures and pouring into the surrounding cold seawater as a black cloud of particles (hence the name "black smoker").

For marine biologists, discovering these new ecosystems was like being a member of a *Star Trek* crew and finding a previously unknown basis for life on another planet. More astonishing still, certain heat-loving, chemosynthetic microorganisms living in those ecosystems turned out to have genetic characteristics that place them near the base of the tree of life. That raises the tantalizing possibility that life on Earth began at such hydrothermal vents in the early ocean, rather than in shallow waters at Earth's surface.

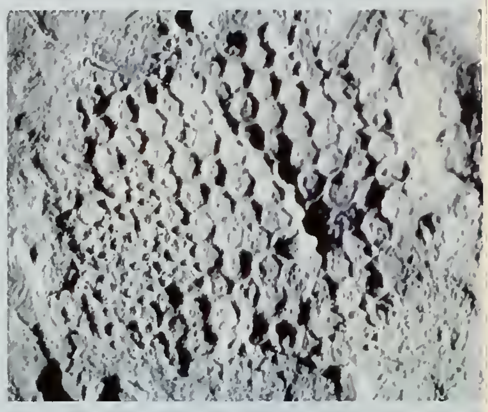
The initial consensus of the scientific community was that the hot springs and their ecosystems were confined to the Pacific Ocean, where the seafloor is spreading as much as ten times faster than it is in other ocean basins. Challenging such a consensus can give one pause, but I became convinced that similar hot springs and ecosystems existed along the slow-spreading Mid-Atlantic Ridge. I spent several years with my team developing techniques to explore the mountainous terrain of the Atlantic seafloor, both by remote sensing and by sampling in situ with instruments lowered from the surface. In 1985 our efforts paid off. We discovered the first hydrothermal field, or vent area, and associated vent ecosystem in the Atlantic Ocean—still one of the largest such fields known. We named it the TAG Hydrothermal Field, after the Trans-Atlantic Geotraverse Project that brought us there.

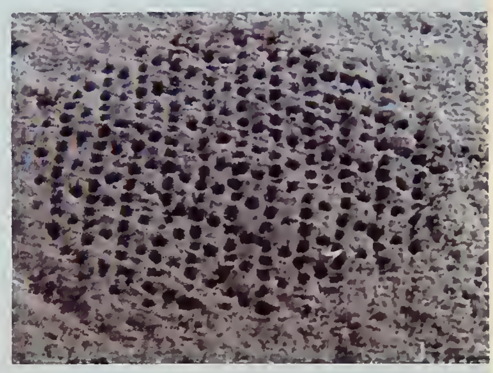
For biologists, the most surprising aspect of our discovery was that the animals at the Atlantic vents differed from those in the Pacific. The red-plumed tubeworms and giant clams were nowhere to be seen. In their place, the dominant vent animal is a new variety of shrimp. But for me the greatest surprise was that the vent field lay in the same region of the Mid-Atlantic Ridge—near the latitude of Miami, Florida—where we had photographed the hexagonal forms nearly a decade earlier.

Our Atlantic site now became the cutting edge of seafloor hydrothermal research. Almost overnight, we gained ready access to collaborators and support for undersea expeditions in human-occupied deep-sea-diving submersibles. Although we were focusing our efforts on an actively venting mound the size and shape of the Houston Astrodome, in 1990 I managed to piggyback some dive time with the submersible *Alvin* to visit the east wall of the rift valley, about a mile east of our mound. That was where our photographs of *Paleodictyon*—or whatever the creature was—had been taken years earlier.

Accompanied by Dudley Foster, *Alvin*'s pilot, I was able to view our mysterious hexagonal patterns up close. Then, with one of the sub's manipulator arms, Foster and I pushed clear plastic tubes, about two-and-a-half inches in diameter, a foot down into the seafloor sediments. The coring tubes were just wide enough to recover a cylindrical sample of the sediment with the intact pattern on the top. Back on the surface support vessel, I could see that what had appeared as black dots on our original photographs were indeed tiny holes, just like the ones in Seilacher's sketches of the fossil *Paleodictyon*.

But to my dismay, when we sieved some samples to look for the worm or other organism that might have made the pattern, the sediment passed through the sieve and left nothing behind. Other samples that we preserved in formalin to take back for study by biologists were also a disappointment: the pattern of holes collapsed and disappeared, and the expected underlying hexagonal network of tunnels or tubes was nowhere to be seen.





Cast of a fossil Paleodictyon, *shown actual size (top), has been interpreted as an orderly network of tunnels excavated just beneath the surface of sediment on the deep-sea floor, possibly by a marine worm. Whatever organism was responsible, it was thought to have become extinct about 50 million years ago, until the recent discovery of mysterious arrays of holes (above) that might overlie a similar tunnel network. The arrays were found near the field of active hydrothermal vents that the author discovered in the Atlantic Ocean.*

My next opportunity to pursue this elusive phenomenon came in 1991, when the Canadian director Stephen Low began work on his IMAX film about the *Titanic*. Because the wreck lies in 12,500 feet of water several hundred miles off Newfoundland, Low had contracted with the P. P. Shirshov Institute of Oceanology in Moscow to use its two state-of-the-art submersibles *Mir 1 and Mir 2*. The underwater photographer Emory Kristof of the National Geographic Society in Washington, D.C., and I arranged for a series of dives en route to the filming off Newfoundland, in which we would test the IMAX cameras while exploring the TAG Hydrothermal Field. Our tests of the cameras contributed little to the film, revealing only the inadequacy of the lighting system then available. In research terms, however, the dives paid rich rewards.

The *Mir*'s passenger compartment—a steel sphere no wider than one person's outstretched arms—can accommodate only three people at a time. I made the first of the research dives with Yury Bogdanov, a senior research scientist with the Shirshov Institute, and *Mir* chief pilot Evgeny Chernjaev. Our aim was to explore the region from our Astrodome mound eastward to the hexagonal forms.

The dive was breathtaking. After a two-and-a-half-mile descent, at a rate of about one mile an hour, we landed on top of the Astrodome mound next to chimneys that poured forth turbulent clouds of black "smoke" and swarmed with shrimp. From there we set our course eastward, slowly gliding away from the rusted bright red and yellow mineral deposits of the mound and over the monotonous light tan sediments and pillow-shaped lava flows of the surrounding seafloor. Then we began to see the hexagonal patterns on the surface of the sediments.

As we continued eastward, the sediments gradually changed from light tan to reddish brown. Inactive chimneys, several feet high, began to appear, while the hexagonal patterns disappeared. Farther on, the chimneys became much taller, and we found ourselves traveling about a hundred feet above the seafloor near the level of the dead chimney tops, weaving our way as if we were flying through a forest of redwoods. Finally we were able to descend near to the seafloor, which was littered with fallen chimneys, each several feet in diameter and fluted like a column of a Greek temple.

We sieved samples to find the organism that made the patterns, but the sediment passed through, leaving nothing behind.

After fifteen hours on the seafloor, my companions apologetically asked me whether I was ready to ascend. By comparison, the *Alvin* typically spends only about four hours on the deep-sea floor. When Bogdanov, Chernjaev, and I returned to the surface, we were chilled to the bone. The temperature of the deep water is near freezing, and deep-diving submersibles lose heat quickly through their metal hulls. But back up on the support vessel, we warmed up quickly in a mercifully hot sauna.

We collected no hexagonal forms during the *Mir* dive, but I did secure several a couple of years later, using the *Alvin*. One core was dried and impregnated with liquid epoxy resin, finally preserving the curious surface pattern of holes. But nothing more definitive was learned, and the sample was stored away.

My next close encounter of the hexagonal kind came in 2001, when I joined a team making a new IMAX film, again directed by Stephen Low. The star of the enterprise was the *Alvin*, now equipped with IMAX and high-definition TV cameras and a powerful underwater lighting array capable of illuminating an area half the size of a football field. The team had already made spectacular images of a vent site in the Pacific. I was there to help with filming the contrasting Mid-Atlantic Ridge.

The new equipment performed beautifully. Only one thing seemed to be missing—a story that could tie together all the spectacular images. When I recounted how Seilacher and I had converged on the fossil *Paleodictyon* and its apparently living counterpart, and how we were trying to solve its mysteries, Low became intrigued. He invited me to make a dive with Emory Kristof to point out the form and its setting. We used the high-definition TV camera and replayed the video to a packed house in the ship's laboratory that evening. The next day, Low sent his director of photography, William Reeve, down with the IMAX camera to make some more images. Our detective story ultimately became the narrative thread for the film, *Volcanoes of the Deep Sea*.

With *Paleodictyon* in the limelight, some nagging questions resurfaced: Did the form on the seafloor really correspond to the fossil? If it did, where was its hexagonal network of tubes or tunnels? I remembered the sample I'd preserved in epoxy and gave it to Seilacher, who set out to dissect it. I received a photo from Seilacher with a handwritten note: "Epoxy did not evenly penetrate. Still hexagonal network of tunnels can clearly be seen." Drawing on his mental picture of what it should look like, Seilacher could see a network, but I was skeptical. By now the film was a wrap, but to unequivocally prove the existence of the network, and to try to discover what was making the patterns on the seafloor, Low supported an *Alvin* dive for Seilacher and me.

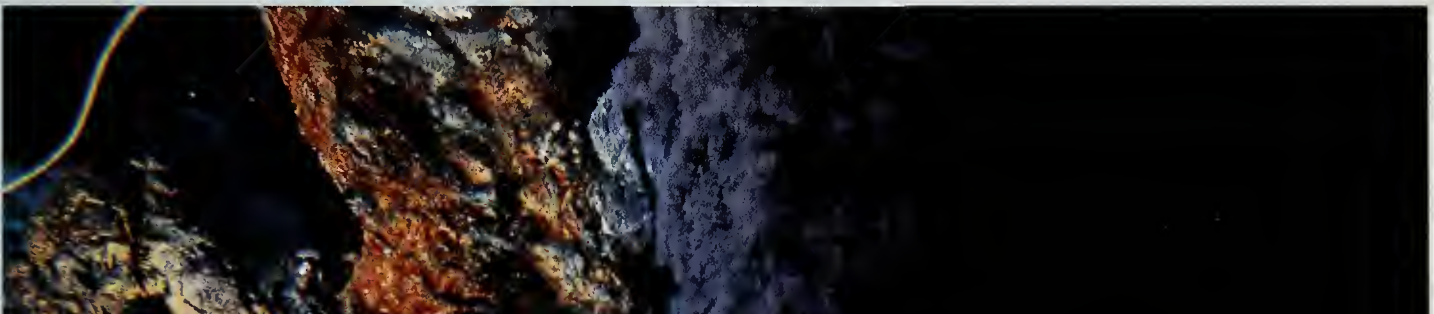
The dive took place in July 2003. Twenty-five years had passed since I had received Seilacher's excited letter proposing a link between his ancient fossils and my seafloor photographs. We climbed into the *Alvin* together and, after our long descent, landed "knee deep" in hexagon country. Crouched by the window on his side of the sub, Seilacher exclaimed at the abundance of the patterns. We immediately began collecting cores, targeting the freshest-looking hexagons with the sharpest margins.

With time growing short, our pilot, Pat Hickey, dexterously aimed a hose he had rigged at a fresh pattern and began blowing away the surface sediment with a gentle stream of water. Within seconds, as we watched on the video monitor, the hexagonal pattern of tiny holes on the sediment surface disappeared and a hexagonal network of tubes or tunnels emerged, exactly like those in the fossil form.

For me, it was a "eureka" moment! Unable to jump up and down in the confined space, I reached across and shook hands with my companions. The living form on the seafloor and the fossil form that lived on the seafloor more than 50 million years ago were indeed one and the same. The deep ocean had served as a sanctuary, a place where *Paleodictyon* had lived on for an unimaginably long time, protected even from the global environmental changes that caused the extinction of many of the animals living in shallow water and on land.

We carefully preserved the sediment cores we had collected, and I felt confident that we finally had the answer in hand. Experts are now examining the structure of the forms and the microorganisms they contain, and chemically analyzing the sediment and sampling it for organic matter that will be genetically sequenced.

But *Paleodictyon* remains elusive. Two hypotheses for its origin are being tested. One is Seilacher's original explanation, that the form is constructed as a burrow by an as-yet-unknown worm. The alternative hypothesis is that the form itself reflects the shape of the organism, perhaps a large single-celled organism whose living tissue fills the horizontal network. In that event, the organism might take up the sediment to make a kind of hexagonal exoskeleton, leaving holes in the sediment open to catch food from above. These studies are in progress. After nearly thirty years, to my surprise, the mystery of *Paleodictyon* still seems as deep as the waters where it lives. □



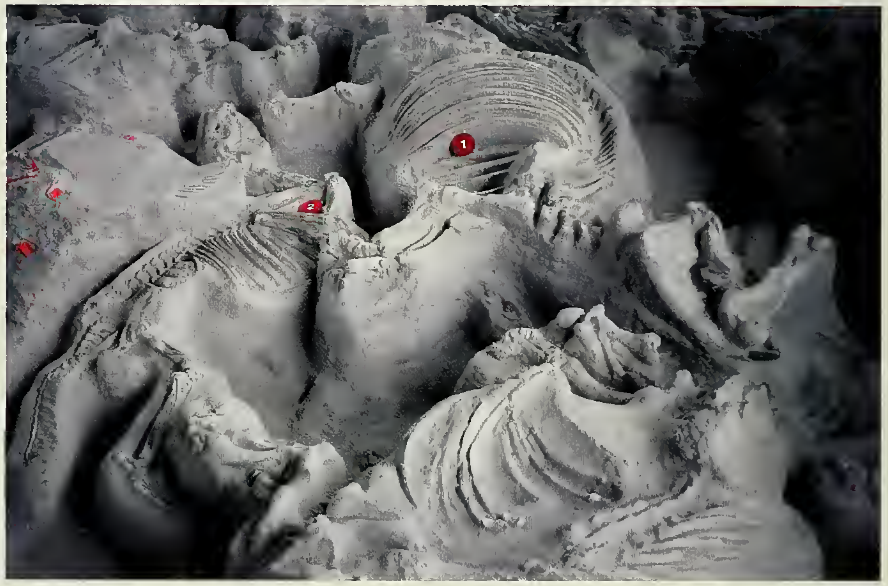
"Black smoker," an undersea vent in the Pacific, discharges hot water carrying a cloud of iron-rich mineral particles. The accretion of iron-rich minerals that forms a chimney around the vent is partly oxidized, creating a range of rusty colors.

From Water Hole to Rhino Barn

Twelve million years ago, a volcanic ashfall entombed prehistoric animals that roamed what is now Nebraska.

By Sandy S. Mosel

If you drive across northeastern Nebraska on U.S. Highway 20, you see about what you'd expect: fields of corn and soybeans, rolling pastures with grazing cattle. But if you could travel in time, back to, say, 12 million years ago, you'd come face to face with a very different scene: an African-style savanna, teeming with herds of camels, elephants, rhinoceroses, and small horses, all grazing in seas of grass or browsing on shrubby trees. As rich as it once was, though, this ancient savanna and its ecosystem have left few traces in soil that has been tilled or pastured for more than a century.



Fossil skeleton of the three-toed horse *Cormohipparion occidentale* (left) lies near the fossil rib cage of the barrel-bodied rhinoceros *Teleoceras major* (top center).

But in some places the evidence of that distant time is still well preserved. The most spectacular remains occur at Ashfall Fossil Beds State Historical Park, about 140 miles northwest of Omaha. There the articulated skeletons of many extinct mammals have been preserved in a bed of volcanic ash. More than 200 complete or nearly complete skeletons have been exposed through patient paleontological excavations, and more, undoubtedly, are still to come.

The Ashfall site occupies a hill overlooking a tributary of Verdigre Creek, which flows into the Niobrara River—itself a tributary of the Missouri River. Cutting a rugged course through northern Nebraska, the Niobrara has exposed abundant remains of fossilized mammals, which paleontologists have been collecting since the 1850s.

Until 1971, however, the Ashfall site remained hidden. In that year, while exploring the upper slope of a ravine, Michael R. Voorhies, a paleontologist at the University of Nebraska State Museum in Lincoln, noted that a recent rainfall had revealed a thick layer of volcanic ash. Looking at it closely, he found the intact skull and jaws of a baby rhinoceros eroding out of the ash. Subsequent digging yielded the entire skeleton, then several more—a highly unusual phenomenon. (Almost all fossilized mammals occur in ancient stream deposits: logjams of scattered bones and teeth. Fully articulated skeletons are extremely rare.)

Voorhies directed a major excavation of the Ashfall site during the summers of 1978 and 1979, bringing to light dozens of skeletons of birds, camels, horses, and rhinoceroses. That work continues. Geologists think this mass graveyard was one consequence of a great volcanic eruption that took place 12 million years ago in what is now southwestern Idaho, nearly 900 miles due west. Prevailing winds carried the ash eastward, blanketing a huge area of the Great Plains. Exposures of the same ash layer—usually about a foot thick—occur in various places along a 250-mile stretch of northern Nebraska. At Ashfall, though, the layer becomes ten feet thick. The site was a water hole: essentially, a large depression in the landscape that retained water during the wet seasons but could dry out in times of drought.

Made up of minute shards of volcanic glass, the ash clouds that drifted across Nebraska from the west were abrasive and dangerous. Small animals, especially birds, must have succumbed almost immediately. Larger animals could have survived the initial ashfall, but they would then have encountered a landscape covered with powdery, abrasive dust that buried their food supplies and became airborne again at the slightest step or breeze. The camels, horses, and large rhinoceroses suffocated within days or weeks, as their lungs filled with ash. Ill and feverish, they probably converged on the water hole. As they perished, some of their remains were scavenged by animals such as *Aelurodon,* a bone-crushing predator in the dog family. But little by little, windblown ash filled the water hole, until it covered the carcasses.


Buried in fine ash, the skeletons of the animals were preserved in the round.

The most abundant skeletons—more than a hundred have been excavated to date—are those of *Teleoceras major,* a short, stocky rhinoceros with stout legs and a large, barrel-like midsection. With so many skeletons available from one population, investigators can infer a good deal about the species' behavior and ecology. Young adult males are notably absent, and only one mature adult male turns up for every five adult females, suggesting that the rhinoceroses formed harems. Numerous skeletons of young calves have also been unearthed, many of them nestled next to adult females, no doubt their mothers. Because the calves are all generally about the same age, calving must have taken place at a particular season.

Fossilized grass seeds lodged between the teeth of the rhinoceros fossils belong to subtropical species that resemble grasses that now grow in Central America, indicating that the climate was warmer than it is today. Supporting that conclusion are the fossilized giant tortoises that have been discovered at the site: such large land reptiles could not have survived where temperatures dipped below freezing.

Fossil plants, animals, and ancient soils throughout Nebraska show that by 12 million years ago, woodland environments were giving way to grasslands. The horse skeletons from the Ashfall site corroborate that inference: Some of the horse species have three toes on each foot—a large toe in the middle and a smaller one on each side. Other species have just one large toe. Side toes may have provided extra traction on soft forest floors, but they were less useful on the harder ground of the open grassland.

Structures that are not helpful to an organism are weeded out by natural selection, because, at minimum, they cost calories to maintain. One of the horse species in particular shows evolution in action. *Pliohippus pernix* was essentially a one-toed horse, but it retained vestigial side toes that did not provide support. This lineage of horses had likely moved into open grassland to take advantage of new niches, and the side toes were on their way to vanishing.

In 1991 the Ashfall site was opened as a state historical park, operated by the University of Nebraska State Museum and the Nebraska Game and Parks Commission. The park is open seasonally to the public. A structure, aptly named the Rhino Barn, covers part of the fossil bed, where paleontologists have excavated two dozen skeletons and left them for viewing in situ, as a snapshot in time. Displays and exhibits in the Rhino Barn, the visitor center, and along various trails inform visitors about the history and scientific relevance of the site.

Meanwhile the research continues. Are there even more species of plants or animals whose fossils lie buried in the ash? What happened to the elephants and the carnivores—the saber-toothed cats and those bone-crushing dogs—that also inhabited the area? Did they find a way to survive the ancient catastrophe? Or are their skeletons, too, just waiting to be discovered in some unexcavated part of the fossil bed?

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Alfred Russel Wallace (right), aged about thirty-eight, with F.F. Geach, a mining engineer and a long-time resident of Timor, in 1861

"A Paradox to Everyone but Himself"

The naturalist who almost scooped Darwin about natural selection was also an ardent mystic.

By Menno Schilthuizen

The Heretic in Darwin's Court: The Life of Alfred Russel Wallace
by Ross A. Slotten
Columbia University Press, 2004; $39.50

An Elusive Victorian: The Evolution of Alfred Russel Wallace
by Martin Fichman
University of Chicago Press, 2004; $40.00

Last month my students and I took a field trip to a small forest reserve a couple of miles from our university campus in Malaysian Borneo. Slip-sliding down a steep jungle path, clutching the soggy stems of wild yams in a futile attempt to stay upright, we collapsed into a pebbly streambed. As we regained our composure and began to look around the steep-sided valley cluttered with the mossy logs of fallen rainforest giants, one of the students, Sharifah Ibrahim, suddenly pointed upward: "A Rajah Brooke!" We all looked, and down came the graceful butterfly, gliding on its long emerald and black wings and settling at a puddle to drink.

A hundred and fifty years ago, Alfred Russel Wallace must have stood in similar awe when he first saw this spectacular birdwing butterfly in Sarawak, a few hundred miles down the coast from where we were hiking. Having arrived in Borneo in November 1854, the naturalist struck up a friendship with the legendary Sir James Brooke, the first "white rajah" of Sarawak. It was Brooke who gave him a specimen of the as-yet-unnamed species. Wallace immediately dispatched a note to the Entomological Society of London, naming the species *Ornithoptera brookiana* after his new friend, "whose benevolent government of the country in which it was discovered every true Englishman must admire."

It is tempting to see the note as an early sign of Wallace's ability to marry science with social issues and with loyalty to a person or a cause, traits that were to both drive and plague him in his later career. But when the thirty-one-year-old Wallace, as the guest of Brooke, was amusing those at the rajah's dinner table with "his clever and inexhaustible flow of talk—really good talk," as one dinner guest recalls—his career was just beginning.

Born to a middle-class family of scant means, the young Wallace worked in England and Wales as a land surveyor and schoolteacher, all the while educating himself as a naturalist. At the age of twenty-five, he embarked on the life of a traveling collector, living off the sale of his specimens to museums and private collectors in the British Isles. His travels took him first to South America, where he spent four years traversing the Amazon basin. But he lost most of the collection he amassed there when the vessel carrying him back to England sank in the middle of the Atlantic. Undaunted, he spent the next eighteen months mustering the courage and funds for another trip, this time to the Malay Archipelago, where he would spend eight years before finally settling down in his native country.

Traveling naturalists were not uncommon in the nineteenth century, and Wallace probably would have remained relatively obscure had he not had two world-shattering insights during his stay in Southeast Asia. The first came to him around the same time he penned his description of the Rajah Brooke birdwing. It was the height of the monsoon season, and the incessant rains gave Wallace, who was sojourning in Brooke's riverfront villa, little else to do but "ponder over the problem which was rarely absent from my thoughts." Evolution—though not yet called by that name—was a hot topic in the mid-nineteenth century. Nobody, however, had a clear idea of what it was or how it might work—nobody, that is, except Charles Darwin, who for ten years had shared his thoughts with only a few friends.

In Brooke's villa, Wallace wrote the treatise now known as the "Sarawak Law." In it he deduces, from the geographic distributions of animals and plants, that ancestor species whose ranges were physically separated split over time into multiple descendant species, a process that biologists today call allopatric speciation. The paper, published in 1855, drew the attention of the leading English geologist of the day, Charles Lyell. Lyell warned his friend Darwin that Wallace seemed on the verge of scooping him. And that, in fact, is what almost happened. Laid up on the island of Ternate in 1858 with a bout of malarial fever, Wallace, in a flash of inspiration, discovered natural selection. When he recuperated, he spent three evenings writing "On the Tendency of Varieties to Depart Indefinitely from the Original Type," and quickly sent the manuscript off to Darwin for comments.

Then unfolded one of the best-known episodes in the history of science. Realizing that Wallace, in his hut in the Orient, had independently stumbled upon natural selection, Darwin was thrown into a fit of panic and depression. To Lyell he wrote, "Your words have come true with a vengeance. . . . All my originality will be smashed." Lyell and the botanist Joseph Dalton Hooker helped save the day by arranging for Wallace's "Ternate essay" and abstracts of Darwin's still-unpublished treatises to be read jointly

T. W. Wood, Natives of Aru Shooting the Great Bird of Paradise

Thomas Baines, Ejecting an intruder. *All pictures on this page appear in* The Malay Archipelago, *by Alfred Russel Wallace, published in London in 1869.*

at the July 1, 1858, meeting of the Linnaean Society. The rest is history.

Or is it? Wallace is well known today, not only for independently describing natural selection, but also for writing *The Malay Archipelago* and discovering what has come to be known as Wallace's Line, the faunal divide that runs between eastern and western Southeast Asia [*see "The Lizard Kings," by Samuel S. Sweet and Eric R. Pianka, November 2003*]. Few, however, will know that, though he never returned to the Tropics after going home to England in 1862, Wallace's mind continued to

Thomas Baines, My House at Bessir, in Waigiou, *from a sketch by Wallace*

cross boundaries in the second half of his life. His intellectual wanderlust took him, for the most part, away from the field of his early successes and into theism, spiritualism, phrenology, mesmerism, socialism, land nationalization, environmentalism, antivaccinationism, and geocentrism. In truth, he became something of a Victorian cult figure. Most Wallace biographers have ignored, avoided, or derided this latter Wallace, to focus instead on the youthful genius. Now the authors of two new biographies, Ross A. Slotten and Martin Fichman, have sought to correct the bias in an attempt to see the man as a whole.

Slotten's *The Heretic in Darwin's Court* is the more conventional of the two. A physician from Chicago and a Wallace enthusiast, Slotten has produced an admirable biography that conveys sympathy for its misunderstood hero. That sympathy, Slotten's predilection for quirky details, and his talent for imaginative investigation often make Wallace and his world spring to life.

In 1866, for instance, Wallace had just published *The Scientific Aspect of the Supernatural,* his first work on spiritualism, and a bundle of copies sat wrapped and bound on his sister

Fanny's table. One morning the bundle was inexplicably scattered about, and Fanny (an ardent spiritualist herself) consulted a Ouija board about the cause of the disruption. The "spirit" guiding Fanny's hand on the Ouija board urged her to distribute the booklets as quickly as possible, then wrote Fanny's name in one of them while she held it closed under her hand. Slotten is not content to take the episode on indirect authority. He describes how his research takes him to the archives of the Oxford University Museum of Natural History, where he finds that very copy of Wallace's book, with the "spirit writing" in red crayon still plainly visible inside it.

Wallace's fascination with spiritualism also plays an important role elsewhere in Slotten's book. Not only incidental manifestations of spirits, but especially formal séances made a deep impression on Wallace. An interest in such matters was not as strange as it may seem today. Spirits were all the rage in mid-Victorian London, and organizing or attending séances was a favorite pastime among the higher echelons of society, right up to Queen Victoria herself. The proceedings were normally held in darkened rooms, where tables might float through space, and musical instruments might be played by invisible hands (sometimes, as Wallace wrote in *The Scientific Aspect of the Supernatural,* "in so wretched a style that the company begged that it might be discontinued").

But in what Slotten calls a "fatal attraction," Wallace began his own investigations into the supernatural in 1865. He became a dedicated supporter of several mediums, and urged his fellow scientists to take spiritualist claims seriously, most famously when he chaired a biology section of the annual meeting of the British Association for the Advancement of Science, and used (many said abused) his position to secure the presentation of a paper on spiritualism. Meanwhile, other members of the scientific community in London were doing their best to expose the same mediums as frauds. Darwin's son George organized a séance at the home of Charles's brother Erasmus, and urged Charles Darwin's intellectual "bulldog," the anatomist and biologist T.H. Huxley, to attend and help detect the "jugglery" of the medium. And at another séance, the zoologist E. Ray Lankester caught the medium Henry Slade in the act of scribbling his own "spirit writings," which led to the infamous Slade trial. (Wallace testified as a witness for the defense at the trial, while Darwin discreetly offered to foot part of the bill for the prosecution.)

Z. B. Zwecker, A Malayan forest, with its characteristic birds. From The Geographical Distribution of Animals, *by Alfred Russel Wallace, published in London in 1876.*

Wallace's precarious circumstances within the scientific establishment is a recurrent theme in Slotten's book. The author cites the so-called spiritualist wars of 1870s London, which featured vitriolic exchanges in *Nature* (a journal Wallace had helped found) between Wallace and such figures as William B. Carpenter, a physiologist, anatomist, and dedicated ghost buster. The occasion was only one of many, Slotten tells us, in which Wallace found himself at loggerheads with colleagues who had revered him as an evolutionist.

By the late 1860s, evolutionary theory itself was no longer safe from Wallace's unorthodox ponderings, and he began publishing several provisos, much to Darwin's horror. In a collection of essays that appeared in 1870, Wallace claimed that natural selection was not a strong enough process to have caused the appearance of humans, and he invoked a Supreme Intelligence. In a shockingly vehement reproach, Darwin told his friend: "You write like a metamorphosed (in retrograde direction) naturalist. . . . Eheu! Eheu! Eheu! . . . I defy you to upset your own doctrine."

The publication of the 1870 essays was the beginning of Wallace's descent into theism. His flirtations with such unpopular causes as spontaneous generation, antivaccinationism, and land nationalization, combined with his newfound belief in God, made him a highly controversial figure. And yet, several times when his popularity appeared to hit rock bottom, he rekindled it with such masterpieces of natural history as *The Geographical Distribution of Animals* (1876) and *Island Life* (1880). The latter, in fact, spurred Darwin and Huxley to arrange a civil pension for the often penurious Wallace.

Slotten seems as bewildered as Wallace's Victorian contemporaries were by his eclecticism, and makes little attempt to explain Wallace's many-sided

Blurring Wallace's Line

By Robert R. Dunn

"As a few lost letters may make a sentence unintelligible," Alfred Russel Wallace once wrote in a paper on the geography of the Malay Archipelago, "so the extinction of the numerous forms of life which the progress of cultivation invariably entails will necessarily obscure this invaluable record of the past."

When Wallace recorded those thoughts in 1863, the evolutionary record of the fauna and flora of Southeast Asia was clearer than it would ever be again. That "invaluable record of the past," and Wallace's own detailed observations of it, led to Wallace's momentous insights about natural selection and biogeography.

What Wallace found was that many of the organisms he studied were restricted to single islands or groups of islands, and that such idiosyncratic distributions of species often told important stories about the past. In Bali, he found "birds of the genera *Copsychus, Megalaima, Tiga, Ploceus,* and *Sturnopastor,* all characteristic of the Indian region." On a subsequent trip, to an island little more than fifteen and a half miles away, he noticed that "on crossing over to Lombock, during three months collecting there, not one [of the bird genera he had observed on Bali] was ever seen." More than a century before the acceptance of the theory of plate tectonics, Wallace began to imagine the movements of continents that might lead to such distinct variety and patterning.

I crossed Wallace's line when I traveled recently from Australia to the Malay Archipelago. It should have been easy to observe the transition in organisms that Wallace recorded: kangaroos in Australia that give way to tapirs in Asia; Australian cockatoos that cede to hornbills in Southeast Asia. But when I landed in Singapore, the first thing I saw was a cockatoo. Such introduced species, dragged across Wallace's Line, have partly obscured it, and helped blot out the traces of evolutionary history that the boundary had preserved for so long.

The evolutionary record has been most obscured on the island-nation of Singapore, where Wallace did most of his collecting. More than 99 percent of the mature forest that once covered the island is gone [*see "Singapore's Vest-Pocket Park," by Jamie James, April 2004*], and Singapore has lost about half its animal species in the past two centuries. The last tiger—from a population so numerous in Wallace's time that they terrified him at night—was killed in 1930 [*see photograph above*].

Deforestation and the loss of indigenous species have all been far more dramatic in Singapore than anywhere else in Southeast Asia. Still, Singapore is hardly unique. Recent studies by Barry W. Brook of Northern Territory University in Darwin, Australia, Navjot Sodhi of National University of Singapore, and their colleagues noted that forests are disappearing in this region faster than anywhere else on the globe—at a rate of about 0.9 percent annually, compared with 0.4 percent a year in Africa and South America. Another study found that more timber has been harvested in Borneo alone in the past two decades than from Africa and South America combined.

During his stay in the Malay Archipelago, from 1854 until 1862, Wallace collected 900 new species of beetles, 200 new species of ants, fifty new species of butterflies, and 212 new species of birds. If current estimates of extinction rates are correct, between 13 and 42 percent of all species that inhabited the region at the beginning of the nineteenth century could be gone by 2100. Yet, sadly, not only has the evolutionary record been blurred, but a valuable baseline for estimating the changes of the past century and a half—Wallace's own observations and collections—has also been undermined by a lack of reliable biohistorical research. Finding clear examples of individual species that Wallace observed in abundance but that today are rare or extinct is no easy task. No comprehensive list of the species Wallace collected exists, or, to my knowledge, is even in the works.

The key to Wallace's particular contributions was his ability to recognize biogeographic boundaries. That ability rested on the possibility of moving among neighboring islands that clearly demonstrated differences in plant and animal species. Yet in Bali today, for instance, Wallace would be hard-pressed to find birds of the *Copsychus* and other bird genera he wrote about. They survive, all right, but they are hiding in ever-diminishing patches of forest. Wallace would now have to travel farther down every trail, deeper into every forest refuge, to observe what he could so plainly distinguish from boats and coastlines in the mid-nineteenth century.

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personality. He calls Wallace "a paradox to everyone but himself," and documents his intellectual twists and turns with a hint of pity.

Historian Martin Fichman has a different take on Wallace. In *An Elusive Victorian*, he condemns the caricature painted by those who glorify the naturalist-evolutionist Wallace but view the older Wallace as a bit of a crackpot. Instead, Fichman says, "the whole of Wallace's oeuvre [must be] taken seriously."

In spite of that admonition, Fichman's book is not a conventional, chronological biography. He says little about Wallace's personal life, and the obvious comparison with Darwin, a main theme of other biographies (including Slotten's), is largely absent. Instead, Fichman takes a thematic approach, analyzing each of Wallace's main preoccupations in turn. A disadvantage of the method is that the text becomes a bit repetitive here and there, with, for instance, identical (and sometimes quite long) excerpts from Wallace's writings quoted in multiple chapters. For the rest, the writing is elegant and accomplished (though, to my taste, too cluttered with jargon from the humanities).

Fichman's main point is that Wallace himself sought to integrate all his various interests and convictions into a single view of life. Wallace the spiritualist believed that what he saw at séances was real proof of a higher level of human existence; he thought spirits could form societies infused with a benevolence that most flesh-and-blood humans had not yet achieved. But Wallace the socialist was confident that such benevolent societies would eventually come into existence. Thus, humans had already evolved to rise above the mere material stage at which other organisms were still stagnating.

And Wallace the evolutionist, according to Fichman, felt that the human spirit—even the mind, the faculty of speech, and the "marvelous beauty and symmetry of his whole external form"—had attained a level far beyond that needed for mere survival and reproduction, and that, therefore, human evolution was no longer within the realm of natural selection. In *The World of Life: A Manifestation of Creative Power, Directive Mind, and Ultimate Purpose,* published three years before his death in 1913, Wallace the teleological theist invokes God as the great instigator and director of life, and places the world at the center of the universe to act as the stage for the evolution of man, the crowning glory of creation.

It is a surprising conclusion for the man who is often mentioned in the same breath as Darwin, and Fichman does a good job of trying to explain how Wallace the evolutionist arrived at such a mystical, utopian optimism. From Fichman's fascinating re-creation and analysis of the intellectual world Wallace moved in, it is clear that many beliefs that are held in disrepute today were hardly unique to Wallace. Lyell believed in special creation for humans; William Crookes, the inventor of the cathode-ray tube and the discoverer of thallium, was a spiritualist, as was the statistician Francis Galton, one of Darwin's cousins.

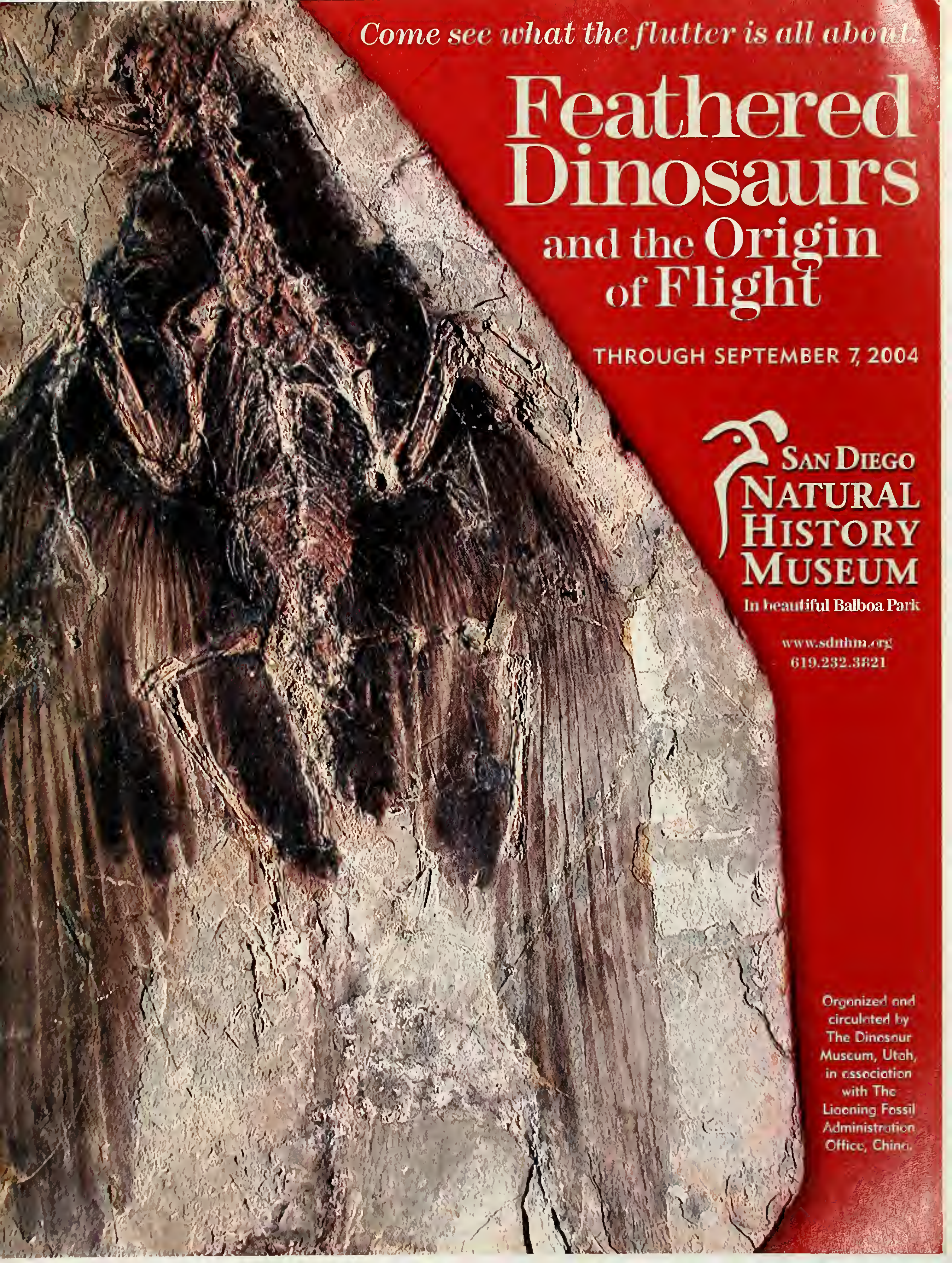
Wallace and spirit: The photograph allegedly captures the famous naturalist, at about age fifty, with a male spirit conjured by a London medium, c. 1872.

Yet I am not entirely convinced that Wallace's "evolutionary teleological theism" is as diligently constructed a theory as Fichman claims it to be. Wallace's posture as a defender of spiritualism, in the face of repeated exposures of fraudulent practices, is that of a believer, not of an objective scientist. Perhaps that is not surprising, considering the role of spiritualism in Wallace's personal life. He credited mediums with bringing him into contact with three dead siblings, including his younger brother, Edward, who had died of yellow fever while assisting Wallace in the Amazon.

Wallace also seems to have reveled in debate, and he often started an argument just for the fun of it. Slotten describes how he casually picked a fight with Darwin over the latter's theory of sexual selection, which Wallace did not accept. Darwin was pained by their disagreement, and he wrote to Wallace to say so. But Wallace seemed to have lost no sleep over the skirmish, and replied to Darwin lightheartedly: "Pray don't distress yourself. . . . It will all come right in the end." Wallace once told a friend, "An uphill fight in an unpopular cause . . . has charms for [me] that [I cannot] resist."

Perhaps the greatest accomplishment of the two new books is to show that there was no "other Wallace." Through the rich sources that inform them, the reader is afforded penetrating glimpses into Wallace's many idiosyncrasies. He emerges as a kind, somewhat naive and gullible man, quietly suffering personal pains—but also as a man of keen intellect. After reading almost a thousand pages of Wallaceana by Slotten and Fichman, I am left with the impression of a sometimes brilliant mind struggling, perhaps not completely successfully, to reconcile the good choices with the bad and forge them into a single life. And what a life it was!

MENNO SCHILTHUIZEN is an associate professor of evolutionary biology at the University of Malaysia Sabah. He is the author of Frogs, Flies, and Dandelions: The Making of Species *(Oxford University Press, 2001).*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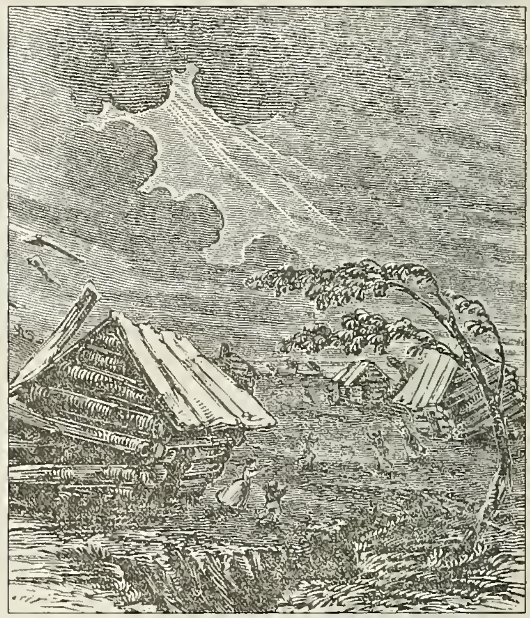
By Laurence A. Marschall

The Big One: The Earthquake that Rocked Early America and Helped Create a Science
by Jake Page and Charles Officer
Houghton Mifflin, 2004; $24.00

Which of the lower forty-eight states has survived the most powerful earthquake ever recorded in the United States? Strange to relate, the answer is not California, but Missouri. In the middle of the night, on December 16, 1811, the residents of the town of New Madrid awoke to a churning in their stomachs and a rumbling in their ears. Stumbling into the darkness, they saw the ground flapping like a wind-tossed sheet, buildings crumbling all around, and, some claimed, the Mississippi reversing itself, flowing toward the north.

Radiating tremors tumbled homesteaders from their beds in neighboring Kentucky and shook church bells in Charleston, South Carolina. Aftershocks continued for months, and two more major temblors shook the Earth again on January 23 and February 7, 1812, finishing off what the December quake had not destroyed and rattling windows in Montreal, a thousand miles away. By the time the entire episode was over, the course of the Mississippi had been changed in many places, and a new landscape of lakes and ridges had been sculpted. Entire towns had disappeared.

At the beginning of the nineteenth century all this was a puzzlement; when and where earthquakes might occur was anybody's guess. According to Jake Page, a science writer, and Charles Officer, a geologist, the scientists of the day had only the faintest idea that earthquakes might be associated with volcanoes or tectonic forces. They had no way of making quantitative records of geologic disturbances, and they knew nothing of the Earth's interior. To those who relied on guesswork and quasi-scientific analogy, earthquakes were traceable to such factors as unfavorable wind conditions, electrical disturbances, and the natural wrinkling of the Earth's cooling crust. To the pious, earthquakes were acts of divine retribution—though why Missouri deserved God's wrath any more than Washington, D.C., or New York City was, then as now, a theological enigma.



The Great Earthquake of New Madrid, anonymous engraving, 1851

Page and Officer take the New Madrid quake as a point of departure for their genial history of modern earthquake science. Seismographs were a key development: a host of clever recording devices were introduced by British, Japanese, and Italian inventors in the mid 1800s. The infant science of seismology made it possible to listen to the "sound" of Earth's interior in response to temblors, just as you can tell whether a tree is hollow by the sound it makes when you tap on its trunk. In time, seismograph recordings enabled geologists to determine that Earth has a dense core surrounded by a slowly flowing mantle and a thin outer crust.

Seismology also led to the mapping of earthquakes all over the planet, and thus to the realization that some regions—the edges of the Pacific Ocean, for instance—are more prone to quakes than others. By the middle of the twentieth century such earthquake-prone zones were recognized as the intersections of tectonic plates, huge rafts of crustal material that float on the mantle and jostle each other ponderously, like giant floes in packs of sea ice. Most earthquakes came to be understood as a natural consequence of the sticking and sudden slippage of crustal plates in contact with each other, the fitful adjustments of continents in motion.

The New Madrid earthquakes, however, remained strange and puzzling, because they were centered far from the margins of tectonic plates: half a continent away from the San Andreas fault to the west, half a continent and half an ocean away from the Mid-Atlantic Ridge to the east. Page and Officer explain how investigators working in the New Madrid area during the past decade have located a fault, known as the Reelfoot Rift, inside the crust, buried several kilometers deep beneath the sediment of an ancient inland sea and, overlying that, the deposits of the Mississippi River and its tributaries. It was the sides of this deep crack that slipped in 1811. Aftershocks continued for several years, and small earthquakes still waggle seismographs in the region.

So when, exactly, is the next "big one" due to hit the nation's midsection? On this point Page and Officer judiciously demur. In spite of two centuries' worth of increasing seismic savvy, earthquake prediction remains almost as much a magic art as it was in 1811. Still, if I were planning a move to Missouri, I wouldn't buy a penthouse condo, no way, no matter how attractive the price.

Sunken Cities, Sacred Cenotes, and Golden Sharks: Travels of a Water-Bound Adventurer
by Bill Belleville
University of Georgia Press, 2004; $29.95

Just about the time that you, dear reader, are pulling out of your driveway, heading for your daily aggression-filled hour on the expressway or inbound commuter train, Bill Belleville is probably tumbling backward off the gunwale of a diving boat into a crystal-blue ocean. An environmental journalist and filmmaker, Belleville has managed to make a decent living, as far as one can figure from these enjoyable essays, out of visiting ecologically engaging underwater sites in the West Indies and in Central and South America, and then writing about it for the folks at home. Nice work if you can get it.

It's not all dog-paddling in a heated pool, though. Belleville is an expert diver whose wanderlust takes him to places few sane people would venture. In one early scene in the book he is dangling in a harness fifty feet above the water level of an overgrown limestone cenote, or sinkhole, deep in the jungle of the Dominican Republic. From that precarious position, a winch will lower him down to an inflatable raft floating on the shadowed waters far below. With a team of scuba-clad archaeologists, he will dive more than a hundred feet farther down into the cenote, to a pinnacle of rock that rises from the pit's bottom (some 250 feet under water). From there, he and the rest of the team will get their bearings as they search for artifacts tossed into the sinkhole by pre-Columbian tribes as a sacrifice to their gods.

It's cold, dark, and claustrophobic down there, with practically no margin for carelessness. But the journey, which leads to the discovery of shards of ancient pottery and the bones of

Diving a cenote in the Mexican state of Quintana Roo, on the eastern Yucatán Peninsula

extinct sloths, makes for a story of great suspense.

Equally chilling is Belleville's account of a nocturnal dive off the coast of Cuba in search of the rarely seen, bioluminescent flashlight fish *(Kryptophanaron alfredi)*. To spot its soft radiance, Belleville and a companion turn off their lamps before descending into near total darkness, aiming for an underwater cliff top. They can see neither their depth gauges, the research vessel above them, nor even one another. Except for the increasing crush of water pressure, the luminous flashes of the passing marine life, and the glow of their own ascending air bubbles (which roil the abundant plankton in the water), the effect is one of almost total sensory deprivation.

When Belleville finally pulls up, turns on his light, and looks at his digital wrist gauge, he finds that he's dropped almost 110 feet, probably overshooting the target. For a tense ten minutes Belleville wanders around alone searching for his partner, whose light, if it's on, is nowhere in sight. He's afraid to swim very far in any one direction, terrified that, should he be forced to surface too far from the boat, he'll be lost from sight, a helpless dot in the choppy waters that surround Cuba.

Fortunately for Belleville (and for readers with a low tolerance for stress), most of the brief excursions he describes in his book take place in far less threatening, though no less interesting, settings. Short essays describe travels to the interior of central Guyana, where rugged jungle and towering waterfalls become exotic destinations for ecotourism; to the ominously named Mosquito Coast of Nicaragua, where conservationists try to enlist native fishermen in a project to preserve endangered sea turtles; and to the Peruvian Amazon, where a team of biologists is studying the behavior of the boto, an unusual, pink, freshwater dolphin. Belleville's account of the commercial conch farm he visits on one of the Turks and Caicos Islands, an archipelago southeast of the Bahamas, depicts an operation not unlike that of a Midwest cattle ranch—though the conchs, which look like foot-long garden slugs, are destined for soup pots around the Caribbean, not fast-food joints in Tulsa.

Yet such is Belleville's talent that even when he ventures into relatively familiar territory, he brings an unfamiliar perspective, finding adventure and wonderment in little-seen corners of the natural world. In one episode he describes cave-diving on the Suwannee River in northern Florida, and rejoices in "the singular wonder of being inside the living veins of the earth." In another, he and a college friend take a canoe trip into the heart of the Everglades. There, only a few dozen miles from the strip malls and beachfront condos where former commuters go to live out their days, are worlds out of time: transparent channels filled with needlefish, lone ospreys gliding past tangled mangrove shores, flocks of sulfur-winged butterflies.

Vanilla: Travels in Search of the Ice Cream Orchid
by Tim Ecott
Grove Press, 2004; $22.00

What may be the first American recipe for vanilla ice cream, written in the same hand that penned the Declaration of Independence, is among Thomas Jefferson's papers at the Library of Congress. The vanilla flavoring Jefferson used in his kitchen, made from the seedpods of a rare tropical orchid [*see "Age and Beauty," by Kenneth M. Cameron, June 2004*], had already been popular in Europe for nearly three centuries. The Aztecs showed the Spaniards how vanilla could sweeten their chocolate and perfume their cigars, and the long, dark vanilla beans became part of the Spanish empire's rich colonial trade as early as the middle of the sixteenth century.

Privateers from European nations were soon looking for the stuff during their raids of Spanish galleons, and their booty was directly responsible for Queen Elizabeth I's passion for vanilla-flavored desserts. By the end of the seventeenth century such influential Englishmen as Samuel Pepys and Christopher Wren were frequenting coffeehouses where cocoa drinks, flavored with vanilla, were popular menu items. Starbucks, Häagen-Dazs, and the myriad of other food and drink purveyors that rely on vanilla today are thus the beneficiaries of a venerable and pleasant addiction.

Hyping vanilla ice cream, Brighton, England, 1936

The vanilla bean has been prized throughout its long history, not only for its flavor, but also for its great scarcity. Even today only about 2,200 metric tons of beans reach the world's agricultural markets each year, and the going price for the good stuff in 2004 was close to $275 a pound. Such precious commodities breed violence, and Tim Ecott, whose book recounts his travels to the principal growing sites of the vanilla orchid, needed the steel nerves of a war correspondent to cover this story.

Buyers for the major companies that trade in vanilla travel to remote jungle locations in Indonesia, Madagascar, Mexico, and Papua New Guinea, chartering private planes under aliases to confuse competitors. They carry suitcases stuffed with millions of dollars in cash and visit wealthy growers whose warehouses are surrounded by razor wire and armed guards. Stories of extortion, fraud, and murder in the vanilla trade are as brutal as those told of diamond dealers or heroin smugglers.

The vanilla orchid, its essence so easy on the tongue, has not made things easy for the grower. Although its vine flourishes in many tropical climates, the plant produces no seedpods unless it is fertilized. In nature, that work is done—but only rarely—by a species of tropical bee native to Mexico and Central America. The bee preserved the Spanish domination of the vanilla trade for many centuries. Early vanilla-lovers from other countries, hoping to break the monopoly, managed to transplant cuttings to other parts of the globe, but it was not until the middle of the 1800s that a slave named Edmond, on the French colony of Réunion in the Indian Ocean, devised a way to manually inseminate the plants.

Edmond's discovery laid the groundwork for the global trade Ecott writes about, but producing vanilla remains a tedious and time consuming process. It takes months for the seedpods to develop, and months more to cure the seeds. Once the vanilla beans reach the processing factory, extracting the concentrated flavoring can take weeks more, because the dried beans must be steeped in alcohol. Ecott's fascinating travelogue makes it clear that the high price of that little vial of natural vanilla extract is, by any measure, a bargain.

Modern chemists have learned to synthesize the principal ingredient of vanilla, and more than 90 percent of vanilla-flavored foods now contain the artificial stuff. But the real beans contain an estimated 400 trace components that greatly enhance the flavor, and natural vanilla will surely reign supreme for a long time among lovers of good food.

LAURENCE A. MARSCHALL, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

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Slip-Sliding Away

By Robert Anderson

I'm predicting a landslide in November, but not the political kind. I'm talking about the sudden shift of hundreds or thousands of tons of rock and soil, and that kind happens nearly every day. To catch up on the latest tolls in death and destruction from major landslide events, go to the U. S. Geological Survey's (USGS) main site on the subject (landslides.usgs.gov), and click on "Recent Landslide Events."

In some places, such as the San Francisco Bay area, weather and geology seem to conspire with gravity to bring down mountainsides on a regular basis. You can get the details from a section of the USGS Web site dedicated to the causes and effects of El Niño (walrus.wr.usgs.gov/elnino/). Scroll down the page to the "Landslides" section, click on "Potential San Francisco Bay Landslides," then click on "fly-by movies." Download a cross-sectional view of a "slow-moving failure" and watch it undermine a typical California hillside home, or take a virtual flight over Marin County or East Bay Hills to get some idea of how prevalent landslides have always been in the region. Beneath the fly-by features, you'll find movies of two actual slides from the 1996–97 rainy season.

Many things can set critically unstable rock in motion. On May 18, 1980, about a mile below Mount Saint Helens, a magnitude 5.1 temblor triggered the largest landslide worldwide in the past century (see pubs.usgs.gov/publications/msh/climactic.html and click on "Debris avalanche"). The mountain shed 0.7 cubic miles of rock, uncorking the more infamous eruption.

Human activities sometimes set the stage for catastrophic landslides. Logging is a good example. Steep slopes denuded of trees and cut with new roads don't stay put for long. The Sierra Legal Defence Fund has issued a report on the problem in British Columbia, titled "Going Downhill Fast" (www.sierralegal.org/reports/landslide_toc.html). The deadliest and most infamous landslide in Canadian history, the Frank Slide of 1903 in southwestern Alberta, may have been triggered instead by badly regulated coal mining beneath the unstable crest of Turtle Mountain. The resultant landslide brought some 90 million tons of rock down on the sleeping town of Frank, and claimed at least seventy lives (see www.canadiangeographic.ca/Magazine/ma03/alacarte.asp and "The Day the Mountain Fell," at www3.sympatico.ca/goweezer/canada/frank.htm).

The greatest potential for disaster, however, may lie offshore. Enormous blocks of volcanic islands or continental shelf can give way and travel miles underwater. As the landslide material comes to rest on the deep-sea floor, the sudden displacement of a huge vertical column of seawater can kick up deadly tsunamis across wide areas. The Monterey Bay Aquarium Research Institute provides a good explanation of how such submarine landslides have shaped the Hawaiian Islands (www.mbari.org/volcanism/Hawaii/HR-Landslides.htm). To find out more about submarine landslides, visit the site of New Zealand's National Institute of Water and Atmospheric Research (www.niwa.co.nz/pubs/wa/09-1/avalanche.htm).

Earth, of course, is not the only planet where geologic processes combine to tear down and level the surface material. At "Geology of Mars" (www.lukew.com/marsgeo/index.html), a Web site created by Albert T. Hsui, a geologist at the University of Illinois at Urbana-Champaign, you'll learn about the "mass movements" on the Red Planet. Many of them cluster around the huge Valles Marineris, a continent-size canyon that gives gravity some steep cliffs to work with.

ROBERT ANDERSON is a freelance science writer living in Los Angeles.

 (Continued from page 11)

Mr. Ehrlich and I agree that some global warming is highly likely, that we can't know for sure whether that will cause severe damage within our lifetimes, and that we can take steps now that will retard the warming without harm to—even with benefit to—the economy.
Spencer R. Weart
American Institute of Physics
College Park, Maryland

Not Dead Yet

While I enjoyed "Venomous Lizards of the Desert" (7-8/04), by my good friend, colleague, and collaborator Daniel D. Beck, I found it of interest to read that your editors apparently regard me as deceased. I can assure you that I am, thank you very much, among the living.
Brent E. Martin
Tucson, Arizona

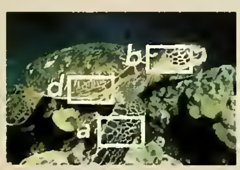
THE EDITORS REPLY: In the sentence in question, the word "late" should have referred only to Charles H. Lowe. We are happy to acknowledge our error.

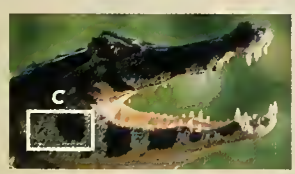
Bad Behavior?

In his review "Brains and the Beast" (5/04), Frans B. M. de Waal bashes a behaviorist straw person. For example, he writes that the "so-called" law of effect states that "all behavior is conditioned by reward and punishment." But the law of effect—a bona fide law of behavior with more than sixty years of solid research behind it—does not state that "all" behavior is determined by reinforcement and punishment: as with all other laws of natural phenomena, it is subject to many limiting conditions. Mr. de Waal is incorrect when he speaks of behaviorism's "two separate languages: one for human behavior, another for animal." In fact, radical behaviorism (so named not because it is extreme, but because it includes private events in its analysis) has always assumed that there is no fundamental, qualitative dividing line between humans and animals. As radical behaviorists, I and my colleagues have not "caved in" and exempted humans from our behavior analysis. On the contrary, decades of experimental research have demonstrated that the laws and principles discovered initially with nonhumans apply even to very complex forms of human behavior, such as language and thinking, that others attribute to mind.
Henry Schlinger
California State University, Northridge
Northridge, California

FRANS B. M. DE WAAL REPLIES: True, a fragment of the behaviorist school adheres to the original notion that all organisms follow the same law of effect, and that thinking is a behavior rather than a mental process. This minority view survives in a particular school of therapy, known as Behavior Analysis. Since this school rarely if ever says much about animal behavior, it was ignored in the present discussion. The vast majority of psychology-trained students of animal behavior take a different stance. They are behaviorists only when it comes to animals, being far more liberal in their interpretations of human behavior. This double standard is reflected in questions, such as Clive D. L. Wynne's, about how we compare with animals. The question itself betrays the historical roots of psychology in philosophy and religion, because no biologist would ever ask such a question. Humans and animals are not separate categories, at least not any more than giraffes and animals are.

Answer to "Cryptic Creatures" puzzle (page 18): c





Mission Impossible

In "No-Fly Zone" ("Endpaper," 4/04), Robert Zimmerman describes in gory detail an experiment showing that even with heroic efforts cosmonauts were unable to keep quail chicks alive at zero gravity. The author makes his point convincingly, then turns around and claims that the cosmonauts' "efforts were for naught" and that their experiment was a "failure." I could not disagree more. The results were as clear-cut as they come: all the chicks died. Then his punch-line: the cosmonauts' "selfless labors illustrate how human efforts to expand into space could make what is now a hostile, barren emptiness into a livable habitat . . . not just for people, but for whatever life we bring along." Come again?
Bernd Heinrich
University of Vermont
Burlington, Vermont

ROBERT ZIMMERMAN REPLIES: As Bernd Heinrich says, the experiment produced a scientifically meaningful result, and in that sense it was not a failure. But for humans to successfully colonize the planets, we will also have to make space livable for many other life-forms besides ourselves. Thus, the failure of the Soviets to devise an environment in which quail chicks could prosper merely means that more experiments have to be done. Moreover, there is ample evidence from later experiments in space that there is nothing inherent in weightlessness or space to prevent our success.

AMENDMENT: A Web site was incorrectly transcribed in the "nature.net" column "Olympian Sites" (7-8/04). Petra H. Lenz's site is www.pbrc.hawaii.edu/~petra/animal_olympians.html

Natural History *welcomes correspondence from readers. Please send e-mail to* nhmag@naturalhistorymag.com *All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

Ablaze from Afar

Astronomers may have identified the most distant "blazar" yet.

By Charles Liu

Imagine standing on a hilltop on a foggy night, with a powerful flashlight in each hand. You point one flashlight forward and one backward, then turn them both on. If a friend is watching from far away, what would she see? It depends, of course, on what direction she's looking from. From either side, she would observe two cones of light—illuminated fog, really—shining from one spot, in opposite directions. Observing from behind or in front of you, though, she'd see a single bright source, aimed directly at her.

Brassaï, *Avenue de l'Observatoire (headlights)*, 1934

This example illustrates the quandary we astronomers face when we study the superenergetic systems known as quasi-stellar objects, or QSOs. According to current theory, all QSOs lie far outside our Milky Way and harbor at their center a supermassive black hole, several million to several billion times the mass of our Sun. All around the black hole are enormous swirling clouds of matter, which the black hole's great mass drags inward. The infalling matter liberates tremendous amounts of energy—often more in a few hours than the Sun will produce in its entire projected ten-billion-year existence.

Much of the energy gets channeled into two powerful, oppositely aimed jets of electromagnetic radiation and subatomic particles, plowing outward at nearly the speed of light. So depending on whether, from our vantage point here in the Milky Way, the jets of a QSO are head-on, sideways, or diagonal to our line of sight, we observe a single powerful beam, two expanding jets of glowing gas, or something in between. Viewing angles may thus account for the observed variety of QSOs. If so, each view—each kind of QSO—affords the chance to study a different aspect of supermassive black holes and their environs.

One member of the QSO menagerie is called a blazar, and it appears to be a QSO viewed right "down the barrel" of one of its jets. Now a research team led by Roger W. Romani of Stanford University has reported the discovery of the most distant blazar ever identified, some 13 billion light-years from Earth.

Regardless of the viewing geometry, all QSOs reside at the centers of distant galaxies. The closest QSOs are about a billion light-years from Earth. (Plenty of supermassive black holes lie closer by, but they and their environments are much less luminous.) The central energy source of a QSO is so bright and concentrated that, from our vantage, it drowns out the light of its host galaxy. That's why, in any typical picture of the sky, QSOs look like ordinary stars.

The resemblance creates a problem for astronomers. With millions of foreground stars for every QSO in the sky, identifying the latter can be harder than finding miniature black pearls in a barrel of peppercorns. The only way to be sure that an object is a QSO is to measure its full spectrum, and that can take a *lot* of telescope time. There aren't enough telescopes in the world to permit astronomers to measure the spectra of every starlike object in the sky, hoping to discover QSOs by chance. So astronomers have to find clever ways to improve the odds of finding these black-hole superengines.

One way is to search for electromagnetic radiation other than visible light. Powered by nuclear fusion at their cores, ordinary stars generally emit most of their energy as visible, ultraviolet, and infrared light in well-known output ratios, determined by their composition and temperature. QSOs, by contrast, are powered by gravity, not nuclear fusion. They emit copious quantities of X rays and radio waves, whereas typical stars produce only minute amounts. So QSO hunters often make X-ray images of large areas of sky, then match them up with radio and visible-light images. If an object shines brightly in all three pictures, it's a good bet that it's a QSO.

Romani and his colleagues added another dimension to this multiwavelength strategy—one particularly suited to identifying blazars. QSOs emit gamma rays, the most energetic type of electromagnetic radiation, near their centers, but this radiation seems to be directed largely along the jet. So if you happen to be staring head-on at a QSO jet—that is, when you're looking at a blazar—the gamma rays should be visible. To pinpoint likely blazars, Romani's team assembled gamma-ray data obtained with the Compton Gamma Ray Observatory, and compared them with X-ray, radio, and visible light data to find probable QSOs. Then, with the 9.2-meter Hobby-Eberly Telescope 450 miles west of Austin, Texas, they measured the spectra of the blazar candidates to confirm their identities.

The technique has enabled Romani and his colleagues to pinpoint a number of blazars, all billions of light-years from Earth. One of them, in an area of the sky off the end of the bowl of the Big Dipper, stood out. With a redshift of 5.47 it is so far away that when the light we now observe left the blazar, the universe was only 15 percent of its present size and "only" about a billion years old. The object thus affords astronomers an unprecedented view of a QSO jet early in cosmic history, and may illuminate how such jets affected the development of the universe.

But the discovery also opens up a new puzzle. Based on their observations, Romani and his coworkers estimate that the central black hole of the blazar may be more than 15 billion times the mass of our Sun. How did such an enormous black hole form so soon after the big bang? If the mass measurement is confirmed, black-hole theorists will have yet another mystery to ponder.

Charles Liu is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.

THE SKY IN SEPTEMBER

By Joe Rao

Mercury makes a brief appearance in the September sky, peeking out from the glare of the Sun in the first week of the month. On the 9th, shining at magnitude −0.4, the swiftest planet reaches its greatest elongation, eighteen degrees west of the Sun, and rises with the break of day. The following morning Mercury is up ninety minutes before the Sun and passes breathtakingly close to the star Regulus. Observed from Europe, the planet almost grazes Regulus, passing just 0.06 degree (about an eighth the diameter of the full Moon) south of the star. For most viewers in the Western Hemisphere, Mercury has already begun to recede from the star by the time the planet rises, though it is still less than half the Moon's disk away. Speedy Mercury is easily visible as late as the 19th; as it nears the Sun on the sky, it brightens to magnitude −1.2. Thereafter, the planet rises invisibly in the glare of the morning.

Venus rises about 3 A.M., some two hours before the first light of dawn, and shines near the much dimmer Saturn as the month begins. For skywatchers at midnorthern latitudes, morning apparitions of Venus, shining at magnitude −4.2, don't get much better than this. The planet glides about three and a half degrees south of the center of M44, the Beehive star cluster in the constellation Cancer, the crab, on the mornings of the 10th and 11th. By month's end Venus has descended to within five degrees of Regulus, on its way to a close encounter on October 3.

Mars is in conjunction with the Sun on the 15th and cannot readily be seen until the end of October.

Jupiter, too, is lost in the glare of the Sun during September and reaches conjunction with our star on the 21st.

Saturn starts the month paired with blazing Venus. On the 1st, look toward the east-northeast soon after 3 A.M.; Saturn is a couple of degrees above and to the left of Venus. Even farther above and to the left of this planetary pair are Castor and Pollux, the bright twin stars of the constellation Gemini. Saturn shines at magnitude 0.2 but pales next to the brilliance of Venus. Indeed, Saturn only appears one-fifty-eighth as bright. Venus gradually moves east as September ages, leaving Saturn on its own in Gemini. The planet's ring system is tipped about twenty-two degrees toward Earth, and provides a spectacular view even in small telescopes.

The Moon wanes to last quarter on the 6th at 11:11 A.M. and becomes new on the 14th at 10:29 A.M. It waxes to first quarter on the 21st at 11:54 A.M. and to full on the 28th at 9:09 A.M. That full Moon is known as the harvest Moon: the full Moon closest to the autumnal equinox in the Northern Hemisphere.

The equinox takes place at 12:30 P.M. on the 22nd. The Sun crosses the celestial equator from north to south as it traces its apparent annual path against the background of stars. Autumn begins in the Northern Hemisphere, spring in the Southern.

All exact times are given in eastern daylight time.

EXPLORER GUIDE

EXPLORER GUIDE

Picturing Planets

P. KNEEBONE

Dr. Oppenheimer (right) and colleague

Strange new worlds. They're out there, but has anyone actually seen a planet beyond our solar system? Ben Oppenheimer, a postdoctoral fellow at the American Museum of Natural History, aims to be the first. He has built a camera, called the Lyot Project Coronagraph, that blots out the blinding rays of stars so their orbiting planets can be directly imaged.

This spring, he and his colleagues installed the camera on a sophisticated U.S. Air Force telescope at the top of Haleakala, a dormant volcano on Maui. The $2 million coronagraph was funded by the National Science Foundation, National Aeronautics and Space Administration, and private donors.

In the past decade, scientists have indirectly detected more than 100 planets by observing their "wobble" effect on their parent stars. Direct images would greatly expand our understanding of these planets, revealing their mass, composition, and whether they have atmospheres that could possibly harbor life there. And Dr. Oppenheimer's camera will be ready for stellar close-ups. That is, it can sift out Jupiter-sized planets as near to their stars as Earth is to the Sun. Previous coronagraphs could only see larger brown dwarfs (a.k.a. "failed stars") and other companions orbiting stars at greater distances.

In the coming months, Dr. Oppenheimer will focus on the parent stars of presumed planets that are within 100 light-years of Earth. Like his Museum colleagues in search of organisms on our planet, he hopes to track down these elusive Earth cousins and explore their horizons. When it comes to strange new worlds, you have to see it to believe it.

The Lyot Project was supported in part by Hilary Lipsitz, Charlene and Anthony Marshall, and Cordelia Corp.


D. FINNIN/AMNH

The transit of Venus—Venus passing in front of the Sun—on Tuesday, June 8, 2004, was visible from the Ross Terrace at the Rose Center for Earth and Space. Several hundred enthusiasts showed up in the very early hours of the morning to don special protective viewing glasses to observe this rare occurrence.

High School Science Research Program

When asked what they did on their summer vacations, the high school interns working at the American Museum of Natural History will have some amazing jobs to describe. For example, instead of serving up fries or ringing up retail sales like some of her classmates, Wendy Guillen, 15, mingled with monkeys this August at the Sedgewick County Zoo in Wichita, Kansas, working with Museum scientists on behavioral and genetic studies involving groups of chimpanzees, orangutans, and gorillas in an effort to analyze their family relationships.

Wendy is just one of the 60 interns participating in the Museum's High School Science Research Program (HSSRP), an early training ground for high school sophomores and juniors, many of them city kids reflecting the great ethnic and racial diversity of New York City, interested in pursuing careers in research science. The HSSRP students work side-by-side with Museum professionals and top scientists on a wide range of exciting projects.

It is a selective, intensive program in which students commit to at least two years, including summers. Students declare a "major" related to an area of Museum specialization, such as genetics, astrophysics, anthropology, or biodiversity, and then follow up with a year of preparation that includes courses in content and research techniques. Most of the students participate in ongoing scientific research, like Lawrence Lin, 17, a junior at Bronx High School of Science who has been analyzing the DNA of gray whales for the last year in the Museum's molecular laboratories. Others are collecting frozen tissue samples for the Museum's Ambrose Monell Collection for Molecular and Microbial Research, updating the online database showing the evolutionary relationships between different bird species, and investigating Mesoamerican artifacts from the Museum's vaults that have never been studied.

The High School Science Research Program is supported in part by the Lita Annenberg Hazen Foundation.

D. FINNIN/AMNH

A young visitor to the special exhibition *Frogs: A Chorus of Colors* gets up close and personal with a bright blue dart poison frog. But she's not in danger—dart poison frogs in the wild are rendered toxic by their diet, and in captivity are fed a controlled diet that makes them harmless. *Frogs* features over 200 live frogs and remains on view at the Museum until January 9, 2005.

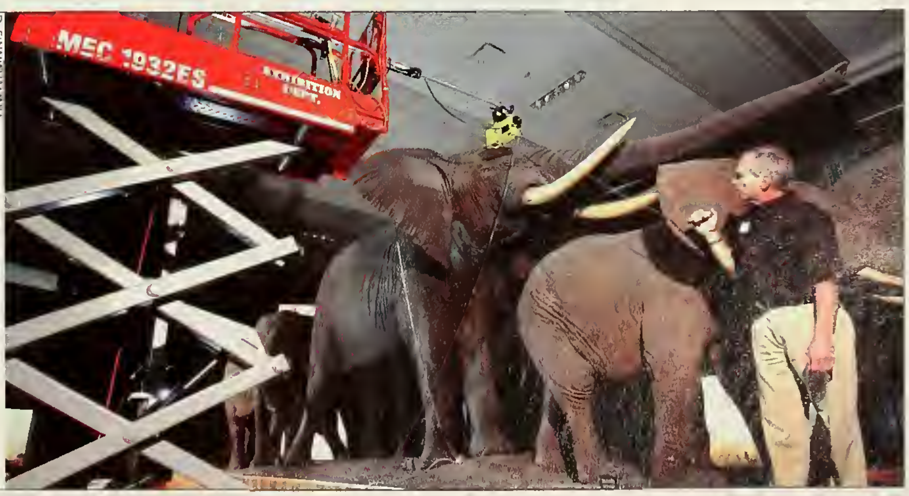
The Earth Machine

One hundred sixty-eight imposing rock specimens greet visitors to the Museum's Gottesman Hall of Planet Earth. Gaze upon towering sulfide chimneys from the deep ocean, a striking 2.7-billion-year-old red and black banded iron formation that records a distant era when the atmosphere contained no oxygen, and a massive specimen of shiny black volcanic obsidian. Run your hand across giant pieces of polished rock that resemble fancy kitchen countertops but tell the story of Earth.

Then, delve into *The Earth Machine: The Science of a Dynamic Planet* (Columbia University Press), by Edmond A. Mathez, Curator in the Museum's Department of Earth and Planetary Sciences, Division of Physical Sciences, and James D. Webster, Chairman and Curator in the same department. The book is based on and extends the science presented in the Gottesman Hall of Planet Earth, which was curated by Drs. Mathez, Webster, and other Museum geologists. Full of photographs and interspersed with tales of how rock samples were brought from the Juan de Fuca Ridge in the northeast Pacific Ocean; Mauritania; Hawaii; and "Rockopolis," California, to the Museum, the book describes for the general reader how Earth works, from its core out to the far reaches of the atmosphere.

So if you're the type who wonders what climates were like in times past, why some volcanoes erupt explosively while others just simmer along, how ancient microbes influenced the evolution of our planet, or why there are oceans on Earth but not on Mars or Venus, this book is your engaging and scientific tour guide, escorting you from the Gottesman Hall of Planet Earth to the corners of the globe.

In June 2004, using the latest digital x-ray technology, scientists peeked under the skin of the African elephants in the Akeley Hall of African Mammals to see how the interior scaffolding of wood and metal is holding up, in the last phase of an extensive conservation survey of the hall funded by a Getty Conservation Grant.



D. FINNIN/AMNH

Museum Events

AMERICAN MUSEUM OF NATURAL HISTORY

© JOE MCDONALD, CLYDE PEELING'S REPTILAND

Mexican dumpy frog

EXHIBITIONS

Frogs: A Chorus of Colors
Through January 9, 2005
This delightful exhibition introduces visitors to the colorful and richly diverse world of frogs, with over 200 live specimens thriving in re-created habitats. The exhibition explores the biology of these popular amphibians, their importance to ecosystems, and the threats they face in the world's changing environments.

Frogs: A Chorus of Colors is presented with appreciation to Clyde Peeling's Reptiland.

Fall Colors across North America
Opens September 25
The fiery colors of autumn come to life in these images by Anthony E. Cook, taken as he journeyed from the northern tundra of Alaska and Canada to the deep southern bayous of Louisiana.

Art for Heart
Through September 26
Paintings by children who lost loved ones in the attacks on New York City's World Trade Center on February 26, 1993, and September 11, 2001, create a powerful and poignant memorial.

Made possible by/thanks to: Lower Manhattan Development Corporation; White & Case LLP; Toys'R'Us; 92nd Street Y; Jewish Community Center Metro West; Sid Jacobson Jewish Community Center; Family and Children's Agency, Inc.; Stamford Jewish Community Center.

Art in Nature: The Photographs of John Daido Loori

Arrows © DHARMA COMMUNICATIONS, 2004; PHOTOGRAPHER: JOHN DAIDO LOORI

Through January 9, 2005
These striking abstract photographs reveal hidden treasures and explore notions of scale in the dramatic land- and seascape of Point Lobos State Reserve in California. The photographer, John Daido Loori, is the abbot of Zen Mountain Monastery, which he founded in 1980 in Mt. Tremper, New York.

Vital Variety: A Visual Celebration of Invertebrate Biodiversity
Through Spring 2005
Invertebrates, which constitute more than 80 percent of Earth's known species and play a critical role in the survival of humankind, are the subject of these extraordinarily beautiful close-up photographs.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

LECTURES

Secret Life of Lobsters
Tuesday, 9/21, 7:00–8:30 p.m.
Journalist and former fisherman Trevor Corson paints an intimate portrait of a Maine lobstering community struggling to save both its way of life and the lobsters it depends on.

NOVA: Origins
Wednesday, 9/22, 7:00 p.m.
This PBS miniseries explores the origins of the universe, our solar system, and life on Earth. Clips from the show and a discussion are hosted by Neil deGrasse Tyson, Frederick P. Rose Director of the Hayden Planetarium.

Dawid Kruiper
Sunday, 9/26, 2:00 p.m.
Dawid Kruiper, traditional leader of South Africa's Xhomani Bushmen, shares the story of his trip across the United States and its mission—to raise awareness of the threats his people face from the encroachment of mining and cattle ranching.

FIELD TRIP

Fall Bird Walks in Central Park
Eight weekly sessions start September 7, 8, and 9.

S. QUINN

WORKSHOP

Animal Drawing
Eight Thursdays, 9/7–11/18, 7:00–9:00 p.m.
Dioramas, dinosaurs, and more provide the inspiration for this intensive drawing class.

FAMILY AND CHILDREN'S PROGRAMS

Signed Tour: Hall of Asian Mammals
Saturday, 9/11, 1:45 p.m.
A simultaneously signed and spoken tour for the whole family.

Space Explorers: Constellations of the Fall Sky
Tuesday, 9/14, 4:30–5:45 p.m.
(Ages 10 and up)
An in-depth look at the stars of autumn in the Hayden Planetarium.

Dr. Nebula's Laboratory: Light and Optics
Sunday, 9/19, 2:00–3:00 p.m.
(Ages 4 and up, each child with one adult)
Dr. Nebula's apprentice Scooter "illuminates" the mysteries of light and optics.

HAYDEN PLANETARIUM PROGRAMS

A glowing aurora on Jupiter

NASA/ESA, JOHN CLARKE (UNIVERSITY OF MICHIGAN)

TUESDAYS IN THE DOME

Virtual Universe
The Lives of Stars
Tuesday, 9/7, 6:30–7:30 p.m.

This Just In. . .
September's Hot Topics
Tuesday, 9/21, 6:30–7:30 p.m.

Celestial Highlights
Morning Planet Parade
Tuesday, 9/28, 6:30–7:30 p.m.

COURSES

Matter and Motion
14 Thursdays, 9/2–12/9, 6:30–8:30 p.m.
A college-level introduction to the cosmos that explores the basic physics of the universe and how it applies to the frontier of modern astronomical research.

NASA's Eyes on the Universe
Six Mondays, 9/21–10/19, 6:30–8:30 p.m.
With telescopes observing across the spectrum—optical, X-ray, and infrared—NASA has opened up the heavens to researchers around the world.

Which End Is Up? Telescopes for Beginners
Four Wednesdays, 9/29–10/20, 6:30–8:30 p.m.
Learn which binoculars or telescope is right for you and your needs in four easy sessions.

PLANETARIUM SHOWS

SonicVision
Fridays and Saturdays, 7:30, 8:30, and 9:30 p.m.
Hypnotic visuals and rhythms take viewers on an unforgettable ride through fantastical dreamspace.

SonicVision is made possible by generous sponsorship and technology support from Sun Microsystems, Inc.

Passport to the Universe
Narrated by Tom Hanks

The Search for Life: Are We Alone?
Narrated by Harrison Ford

Made possible through the generous support of Swiss Re.

LARGE-FORMAT FILMS

LeFrak Theater

Bugs!
This live-action rain forest adventure follows the dramatic lives of a praying mantis and a graceful butterfly and ends with their inevitable encounter.

Lewis & Clark: Great Journey West
Relive the historic journey of Meriwether Lewis and William Clark through the uncharted West.

JOHN LIVZEY © NGT&F

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.

All programs are subject to change.

STARRY NIGHTS *Live Jazz*

Friday, 9/3
5:30 and 7:00 p.m.
Rose Center
for Earth and Space

Eric Reed Ensemble

TAR

Starry Nights is made possible by Lead Sponsor Verizon and Associate Sponsors CenterCare Health Plan and Constellation NewEnergy.

ENDPAPER

Mixing It Up

How I Become a Scientist

By Lynn Margulis

To survive my parents' squabbles, I invented a multiplicity of escapes. From age five, when my family moved to the South Side of Chicago, I would lie in the cool grass patch that extended from the traffic-ridden South Shore Drive to our cracked sidewalk. In that tiny natural green belt, with a view of the glorious Lake Michigan, I studied the frenetic conformity of ants on a sugar trail in the grass, and sow bugs hidden under rocks. On my belly on the turf, I plotted my escape into nature.

From age ten, summer camps on Wisconsin lakes enchanted me. At twelve I became infatuated with science itself, when my seventeen-year-old camp counselor began talking about amoebas. Boy crazy as I was, I asked, "How can you tell males from females?"

The author, aged about twelve

"You can't," she said. "It's a single cell. It has no sex."

"Then how does it reproduce?"

"It splits in half," she said.

Splits in half? How did she know? How could that be? Wouldn't it hurt? But in her answer I suspected right then, right away, that my love of nature could be augmented by inquiry.

Hating the reign of terror at Hyde Park High School, I switched to the College of the University of Chicago at age fourteen, as soon as I found out about their policy of equality based on test scores, regardless of creed, race, or age above fourteen.

Two factors converted me to science: the University of Chicago and Carl Sagan, who later became my husband.

The College of the University of Chicago was unique, as was its academic beacon, a course called Natural Science 2. Tests were optional. So was all attendance in classes and laboratories. What counted were the six- to nine-hour final examinations in June. Also unique to Chicago was the lack of textbooks, which were replaced by direct readings of the great scholars and their commentators. In Nat. Sci. 2, that meant reading the work of Charles Darwin, Gregor Mendel, J.B.S. Haldane, Julian Huxley.

I was sixteen when I met Sagan, and he was nearly five years my senior. Tall, handsome in a sort of galooty way, with a shock of brown-black hair, he captivated me. I literally ran into him one day as I was bounding up the steps of Eckhart Hall, the math building. "Aren't you Lynn?" he asked. "Aren't you Carl Sagan?" I answered.

At the time he was a graduate student in physics, poised to launch his stratospheric career. Although I was a mere girl and our attraction was the usual erotic one, his love for science was contagious. I caught his passion.

I accompanied Carl north to Wisconsin in September 1957, on the eve of *Sputnik 1*. There, as an astronomy graduate student, he worked at the University of Chicago's observatory in Williams Bay. I sought a life-sciences education seventy miles away, at the University of Wisconsin-Madison, where I studied the inheritance of organelles. The mitochondria and plastids reproduced on their own, outside the cell's nucleus. Were they somehow separate? Did they have their own genes, their own natural history?

My interests in the margins of the cell were complemented by reading interests in the margins of biology. There I found that my predecessors—some of them, like the American Ivan Wallin, maligned and ignored, and others, such as Konstantin Merezhkovsky, taken seriously, but only in the Soviet Union—had previously postulated that organelles had evolved from bacteria that became trapped in larger cells. Now with my own eyes I could see that they were right.

Each cell in your body resembles an amoeba. But the oxygen-using parts, the mitochondria, derive from bacteria. The ancient naturalists speculated about mixed-up animals—chimeras, mermaids—that combined parts of fish, reptiles, birds, and mammals. Far more amazing than those imagined creatures are the hybrids of our own bodies. Each of us is a colossus of nanobeasts, a coordinated bestiary with abilities more diverse and precise in the aggregate than those of any machine.

LYNN MARGULIS is Distinguished University Professor in the department of geosciences at the University of Massachusetts, Amherst. This essay was excerpted from Curious Minds: How a Child Becomes a Scientist, *edited by John Brockman, which is being published this month by Pantheon Books.*