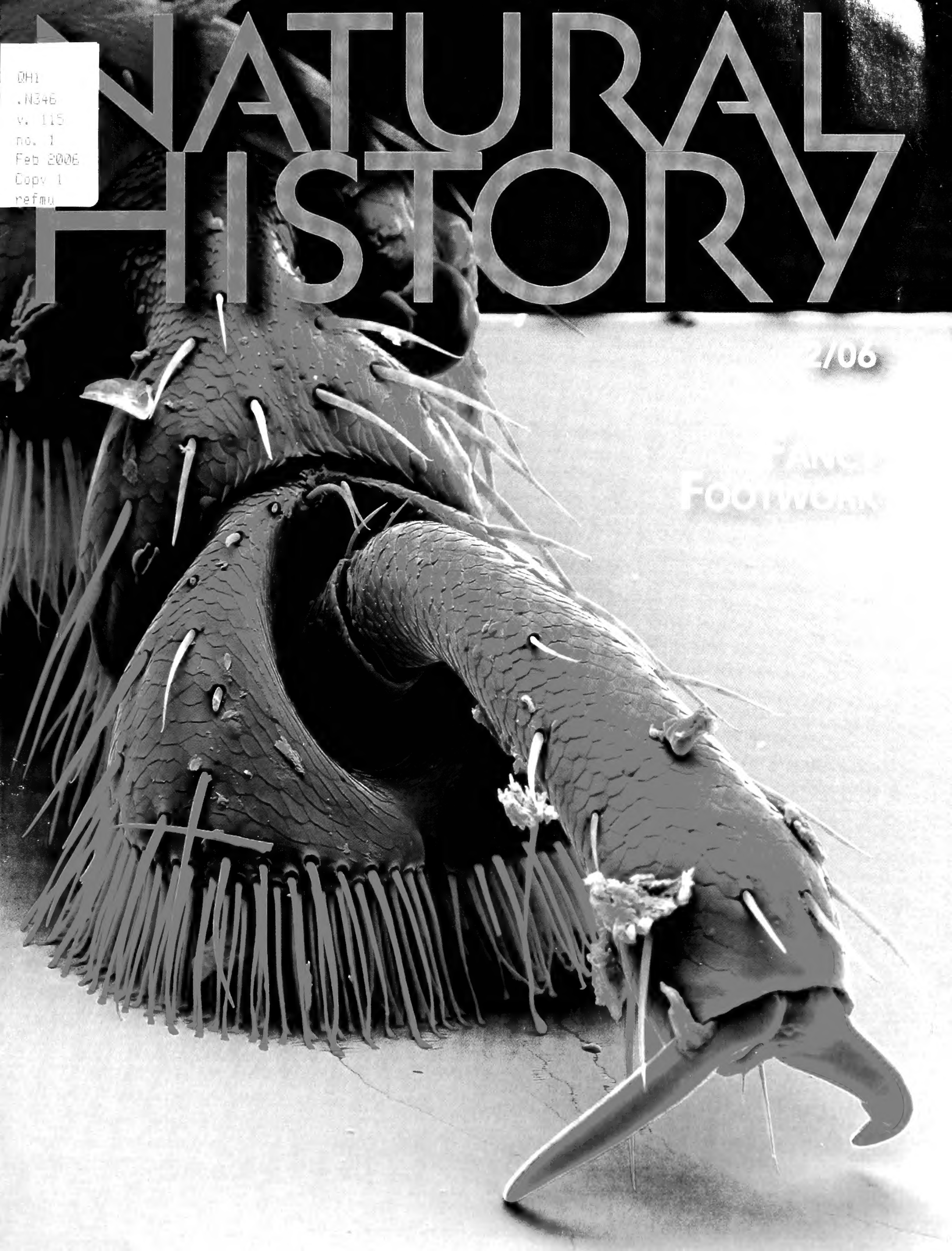
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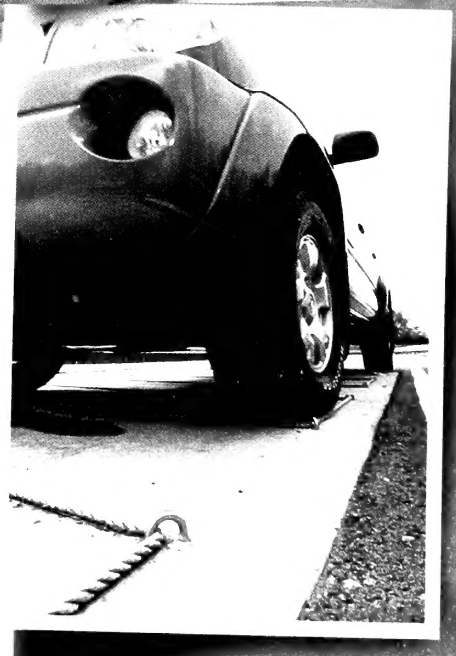

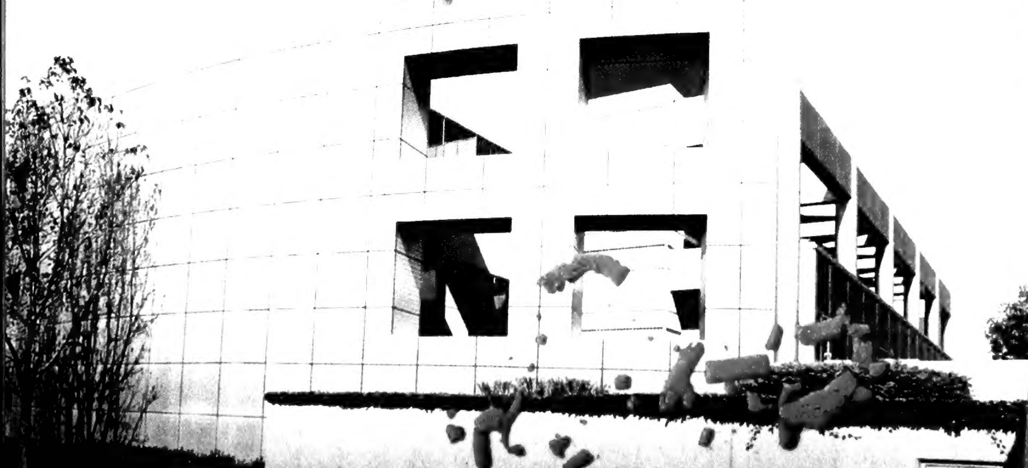

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FEBRUARY 2006 VOLUME 115 NUMBER 1

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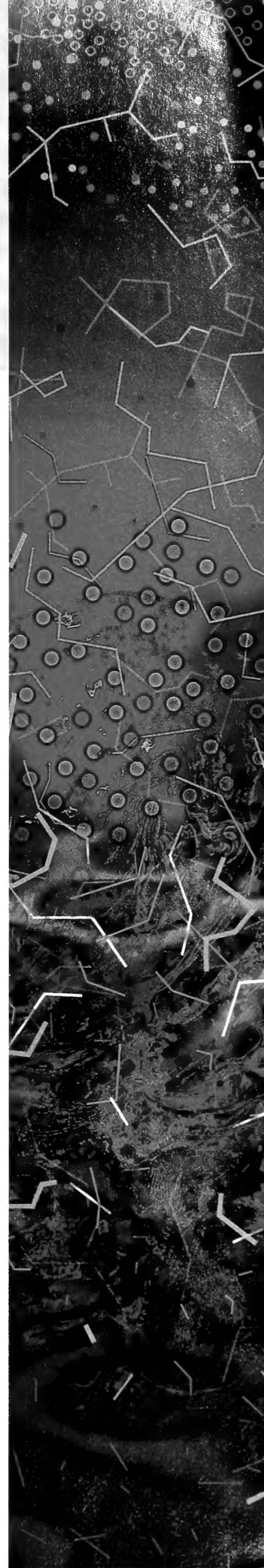

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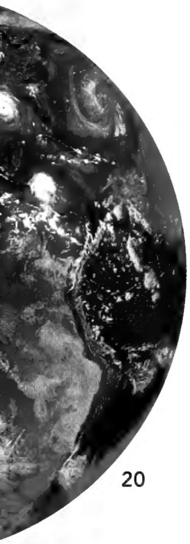
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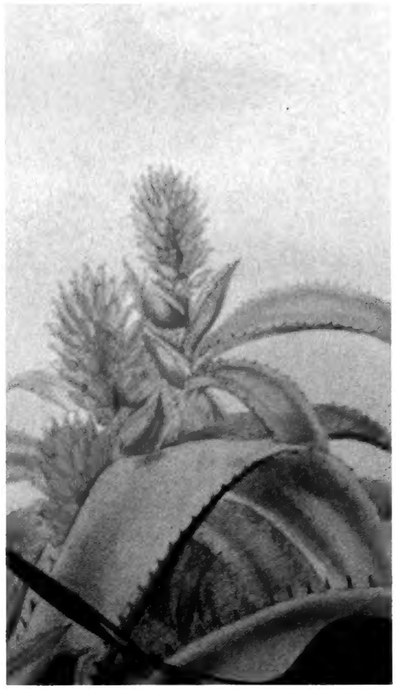
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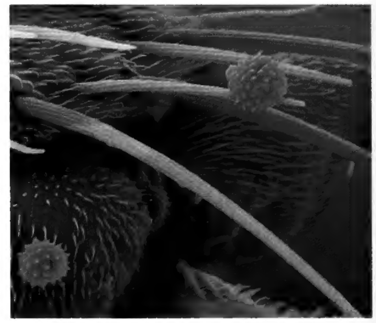
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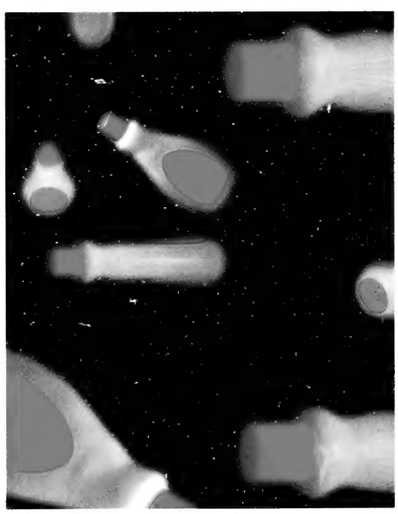
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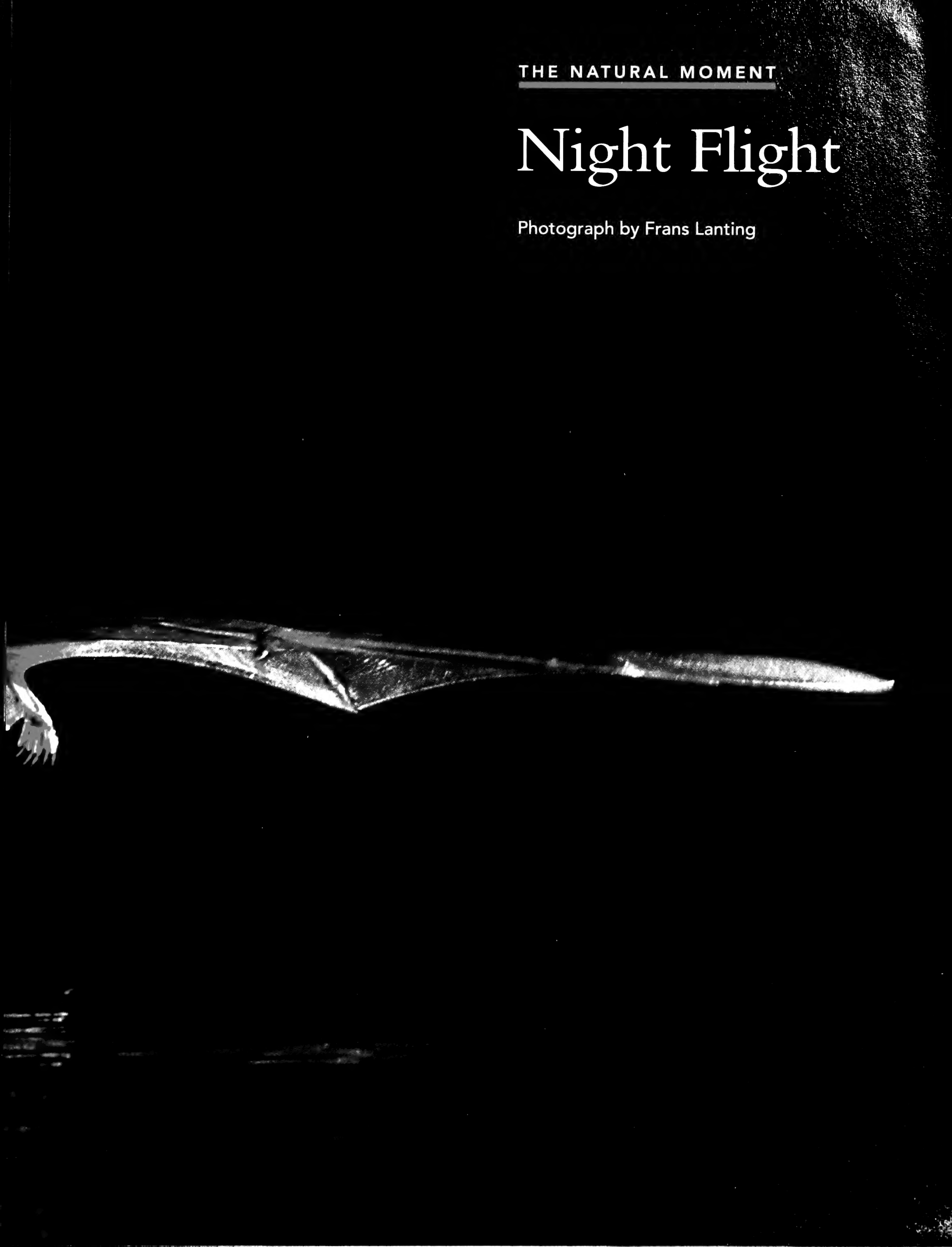
ON THE COVER: False-color scanning electron micrograph of a beetle foot *(Gastrophysa viridula)*, magnified 350×

THE NATURAL MOMENT

Night Flight

Photograph by Frans Lanting



THE NATURAL MOMENT

◄ *See preceding two pages*

Crashing an Oscar afterparty is easier than gaining entrée into Central America's nocturnal world. Above one Panamanian island, some seventy-three bat species dominate the night sky. Yet as veteran photographer Frans Lanting discovered, seeing, hearing, and tracking the bats' active nightlife takes some serious legwork.

To document the comings and goings of the bulldog bat *(Noctilio leporinus),* Lanting began by locating a fish-filled lagoon. Bulldog bats, a.k.a. fisherman bats, hunt for small fish that break the water's surface. The bats also prey on insects, but in the dry season, from December to April, the insect populations plummet, and the bats are more likely to dip into the water for their meals.

Bats chatter in high-frequency pulses beyond the range of human hearing, at a rate of more than a dozen pulses a second. By interpreting the echoes of the pulses, the bats can "see" in the dark. When a fish jumps, for instance, it gives away its position to any bulldog bat on the prowl; all the bat then has to do is estimate where the fish is headed underwater, and grab it.

Bats can swoop down at more than sixty miles an hour, so lighting one up for a photograph takes some incredibly fast reflexes. With help from scientists on Panama's Barro Colorado Island, Lanting found a solution. Six strobe lights were set up to fire automatically when a bat-size creature triggered their infrared sensors.

All of Lanting's preparation obviously paid off, but he still credits his glimpse of the bat world to a bit of serendipity. —*Erin Espelie*

UP FRONT

Fly on the Wall

The alien body part pictured on our cover is nature's answer to gravity. Note the hairlike structures bristling from the base of the large green hemisphere in the center. Each little hair exudes a spot of fluid, the better to cling to surfaces pitched at impossible angles. Marvel at the two-pronged claw attached to the appendage projecting in the front—not, it turns out, a weapon for tearing into the flesh of prey, but a fulcrum or pivot point for prying the sticky hairs off a surface and moving on. Adam Summers reveals all the exotic details in his "Biomechanics" column this month, titled "Shoe Fly" (page 28).

Summers, by your responses, writes two of the most intriguing pages we print in *Natural History* every month. His beat is the living world, but his take on that world is all about leverage and linkage, hydraulics and aerodynamics—in short, the mechanical principles that come, well, naturally, to any living thing trying to make its way in nature. That includes any creature that has mastered the ability to run, fly, breathe, pump blood, or, as in the case of the highly magnified foot of the green dock leaf beetle in our cover image, cling to walls and ceilings.

• • •

Neil deGrasse Tyson has a more figurative take on the phrase "fly on the wall" in his "Universe" column, "Exoplanet Earth" (page 20). In Tyson's fancy, the observant but unseen "fly" is an altogether different kind of alien: a civilization from another star system. What could such aliens learn about our planet if they turned powerful instruments on . . . us?

If you're like me, the answers will surprise you. They probably couldn't see the Great Wall of China, any more than astronauts can see the structure from the *International Space Station.* But if the aliens were smart enough to sort the colors of our light output into a spectrum, they would certainly detect an atmosphere far out of equilibrium—a pretty good signal that something down here is strange enough to be alive.

That brings me to the biggest question in this month's issue—one of the biggest questions I can imagine: How did life arise on Earth? Antonio Lazcano has pondered that question in molecular detail for most of his career as a biologist, and in his article, "The Origins of Life" (page 36), he presents a masterful account of the state of the discipline.

• • •

Many readers were inspired to voice their opinions about our special issue on "Darwin & Evolution" (November 2005)—so many, in fact, that even after we expanded our "Letters" department this month, we still had many more thought-provoking responses than we could squeeze into just one issue. The first installment begins on page 11.

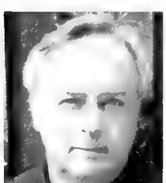
—PETER BROWN

CONTRIBUTORS

An expert nature photographer, **FRANS LANTING** prides himself on making the unseen visible. He began taking pictures while hiking through national parks in the United States, then developed his craft by photographing wildlife in a park near his home in the Netherlands. A remarkable example of Lanting's skill can be seen in his image of a Panamanian bulldog bat in midair ("The Natural Moment," page 6). For the past few years, Lanting has been at work on a book documenting the evolution of life on Earth. Among his eight previous books are *Jungles* (Taschen, 2000) and *Living Planet* (Crown, 1999). More of his work can be seen on his Web site (www.lanting.com).

ROBERT W. JONES ("March of the Weevils," page 30) studied entomology at the University of Massachusetts–Amherst. After college he joined the Peace Corps and traveled to Honduras, where he became hooked on the tropics. Jones completed his master's degree and doctorate at Texas A&M University in College Station. His work on boll weevils began twenty years ago, when he was given a truck and two years to locate the insect's host plants in the Mexican state of Tamaulipas. Since then, he has traveled throughout Mexico and Central America in search of weevils and their preferred domiciles. He is a professor of biology at the Universidad Autónoma de Querétaro in central Mexico.

ANTONIO LAZCANO ("The Origins of Life" page 36) was trained as both an undergraduate and a graduate student at the Universidad Nacional Autónoma de México in Mexico City, where he is now professor of the origins of life. After working for some time on the prebiotic synthesis of organic compounds and the role of extraterrestrial molecules in shaping the primitive environment on Earth, he has become increasingly engaged in comparative genomics as a tool for understanding the origin and early evolution of metabolic pathways. Lazcano has just been re-elected president of the International Society for the Study of the Origins of Life (ISSOL).



Raised in Iowa and California, **VERLYN KLINKENBORG** ("A Shell with a View," page 42) earned a Ph.D. in English literature from Princeton University. He is a member of the editorial board of *The New York Times,* and has taught literature and creative writing at Bennington College, Fordham University, Harvard University, and St. Olaf College. His books include *The Last Fine Time* (Knopf, 1991), *The Rural Life* (Little, Brown, 2002), and *Timothy; or, Notes of an Abject Reptile,* which is being published this month by Alfred A. Knopf, and from which his article has been adapted. His work has also appeared in many magazines. Klinkenborg lives in rural New York State with his wife, Lindy Smith.

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Stupid Design

I am an engineer, not a biologist, but I agree with the point made by Neil deGrasse Tyson in his article "The Perimeter of Ignorance" [11/05]: we are not engineered intelligently. A good engineer would have placed a single ear on top of our heads so we could hear equally in all directions (with proper guarding for rain runoff, of course). Surely we would be able to breathe and swallow at the same time. And wouldn't a tail still come in handy to hold a flashlight when we have one wrench on the bolt and another on the nut?
Bill Schubert
Twin Lake, Michigan

Neil deGrasse Tyson criticizes the eye as an example of poor engineering because it can't detect ultraviolet, infrared, and other wavelengths of radiation. Biologists have another reason to see it as an example of unintelligent design: the retina is oriented backwards, with the sensory cells located at the back. Light must travel through layers of nerve cells in order to reach the sensory cells, which is a most inefficient design.

The arrangement makes sense only if the embryonic development of the optic cup is understood as an outgrowth of the brain. In the vertebrate embryo, the cells that will become the sensory cells of the retina are initially located on the outermost layer of the body. The brain then develops as an "inpocketing" of the outer layer of the embryo. Presumably our distant ancestors developed light-sensing cells on the outside of their bodies, where the light would hit. Evolution is the only way to make sense of the backwards retina.
Judith S. Weis
Rutgers University
Newark, New Jersey

My favorite example to add to Neil deGrasse Tyson's list of "clunky, goofy, impractical" designs is the left recurrent laryngeal nerve. The larynx is supplied by branches of cranial nerve X. Two of those branches are the recurrent laryngeals, which, instead of branching off at the level of the larynx, originate in the chest. Furthermore, the left recurrent laryngeal is nine inches longer than the right one. Because both recurrent laryngeal nerves are so long, they are at greater risk of injury, including (in modern times) from surgery in the neck or upper thorax. Why would anyone design such an arrangement? It's a pure accident of embryonic development.
Jim Peck
Jackson, Mississippi

EDITOR'S NOTE: The following e-mail exchange began as a letter from James Caggegi, a reader in Tustin, California, regarding "The Perimeter of Ignorance." Neil deGrasse Tyson's responses were made as interpolations within the body of the e-mail, and are reproduced here in italic.

JAMES CAGGEGI: Mr. Tyson, the human body's design, though faulty by your standards, is a design nonetheless. And a design presupposes a designer. Now, whether the designer is "time and chance" or an "intelligent designer" is a battleground for debate.
>> NEIL DEGRASSE TYSON: *My opinion is not particularly relevant here. I simply asserted that, by the standards of any sensible engineer, the human body is also faulty or underequipped.*
JC: I am not a scientist, but I know the definition of "science" is knowledge.
>> NDT: *Although I've never been a fan of debates over word definitions, I think it's important to note that science is a process of knowing,*

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In fact, with this level of control and creativity, the only thing the Canon EOS 20D blurs is the line between "professional" and "amateur."

EF 180 f/3.5L 1/500th

And how George Lepp turns those features into photographs.

EF 500 f/4L 1/750th

George Lepp

Nature photography has been my passion for almost 50 years. In that time, I've seen some of the most exquisite wonders of nature, not to mention amazing innovations in the world of photography. And the EOS 20D surely tops that list.

What I love most about the EOS 20D is the creative control it gives me. Take the shot of these Sandhill Cranes taking off.

For fast-moving action like this, the EOS 20D really excels. The 5 frames per second capture rate and the sophisticated DiG!C II Image Processor, combined with the fast EF 500mm f/4L IS USM telephoto, allow me to set a high ISO to stop the action, while still getting in close for all the details. And with the lightning-fast autofocus and unparalleled Image Stabilization, I can concentrate on composition, not camera settings.

It seems to me that the brilliant design I find in nature is matched only by the entire range of EOS cameras and EF lenses.

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not the knowledge itself.

JC: It seems you've forgotten that what you are espousing is not knowledge but theory, or the pursuit of knowledge.

>> NDT: *That's as good a definition of science as any.*

JC: Maybe those who believe in the possibility of an intelligent designer are not "*embracing* ignorance," as you say, but rather have opened their minds to the idea that there might be something (or someone) supernatural revealing itself through nature.

>> NDT: *Those who use nature as a record of an intelligent designer are being highly selective about what evidence they cite in its cause. And while I made that point semicomically, it remains philosophically serious: if there is a higher designer, why do the workings of nature suggest abject stupidity as often as intelligence?*

JC: Is it ignorance to say that nature reveals an intelligent designer and to ask for what purpose we could have been designed?

>> NDT: *You can only think that statement is true if you selectively ignore deep and unlimited evidence to its contrary. In which case, yes, it is ignorance to make such an assertion.*

JC: Maybe you are mistaking ignorance for humility—something hard to find in the scientific community.

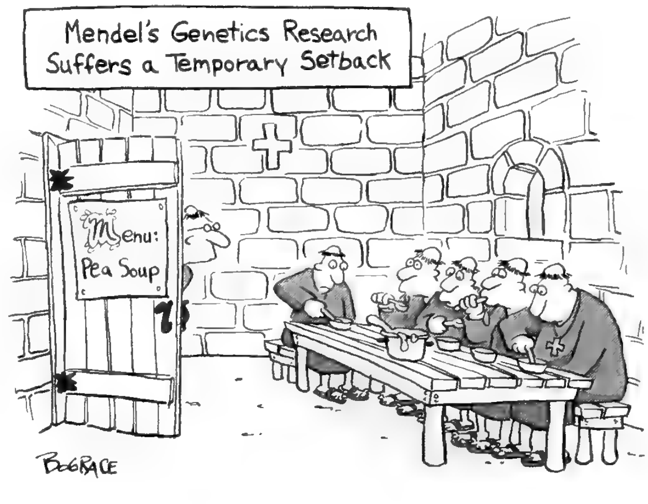
>> NDT: *Again, I do not like arguing word definitions, but if humility, as you use it, means being so deeply moved by what you do not understand that you credit a higher intelligence, thereby abandoning any further investigation into its causes, then yes, there is not a single humble scientist out there. Or rather, if a scientist credits a higher power, then one of two things is true: Either the scientist feels that way about a subject outside his or her research expertise. Or, if the subject does fall within his or her expertise, the scientist will never make discoveries about it.*

JC: You say that intelligent design belongs in the realm of religion, philosophy, or psychology, but "not in the science classroom."

>> NDT: *Yes, because intelligent design and its philosophical predecessors played a significant role in the history of human thought—as a reliable obstacle to the advance of science.*

JC: Could it be that scientists are afraid of being accountable to an intelligent designer, if indeed one exists?

>> NDT: *Given that about 50 percent of scientists are religious, I should think they would welcome such a possibility.*



God of the Gaps

Neil deGrasse Tyson points out the scientific pitfalls of invoking the "God of the gaps" to explain currently unknown features of the natural world. Christian thinkers have also noted the problems of that strategy from a theological perspective.

Sitting in a Nazi prison cell in 1944, the German theologian Dietrich Bonhoeffer wrote:

> How wrong it is to use God as a stop-gap for the incompleteness of our knowledge. If in fact the frontiers of knowledge are being pushed further and further back (and that is bound to be the case), then God is being pushed back with them, and is therefore continually in retreat. We are to find God in what we know, not in what we don't know; God wants us to realize his presence, not in unsolved problems but in those that are solved.

To invoke the "God of the gaps" is bad science and worse theology. It is one reason many American Christians share scientists' concerns about the attempts by some fundamentalists to promote intelligent design in our schools and in our country.

The Reverend Jack V. Zamboni, Rector
Grace–St. Paul's Episcopal Church
Mercerville, New Jersey

Fact and Theory

Richard Dawkins ended his excellent article "The Illusion of Design" [11/05], with an unfortunate terminological twist: "Evolution . . . is not a theory, and for pity's sake, let's stop confusing the philosophically naive by calling it so. Evolution is a fact." But collapsing an elegant and far-reaching theory such as evolution into a raw datum of nature surrenders the word "theory" to its vulgar usage, and it panders to the "philosophically naive" instead of educating them. Instead, let's argue this: Intelligent design is not a theory, but an untestable dogma.

Daniel Jacobs
San Francisco, California

Whale Story

Donald R. Prothero's article "The Fossils Say Yes" [11/05] mentions transitional fossils of whales and other creatures as evidence for evolution. Yet the evidence he mentions can all fit within creationist models. As a creationist, I accept that whales were land creatures that went into the sea after the flood. In fact, many of us accept limited speciation on a fast scale.

Robert Byers
Toronto, Ontario, Canada

DONALD R. PROTHERO REPLIES: It is clear that Robert Byers has not actually looked closely at the evidence and fossils supporting evolution. Transitional whale fossils occur in

strata spanning thousands of meters, and their locations cannot be explained by a single flood. In fact, most of the deposits are not flood deposits at all, but river sediments or gradually deposited marine beds. The same is true of most of the other transitional fossils mentioned in my article. The land animals would have had to evolve incredibly fast by the creationist flood model to turn into whales in just forty days and forty nights. And if Mr. Byers accepts "limited speciation on a fast scale" for such a major macroevolutionary change as the origin of whales, isn't he conceding virtually all of evolution?

Life's Origins

One basic question of evolution was not addressed in your "Darwin & Evolution" issue [11/05]. How did life and the original cell begin?
Charles B. Koons
Houston, Texas

THE EDITORS REPLY: Charles B. Koons's question has spawned a subdiscipline all its own. Antonio Lazcano, one of its leading practitioners, sums up the current state of knowledge in his article "The Origins of Life," on page 36 of this issue.

"Irreducible Complexity"

Your 11/05 issue, devoted entirely to Darwin and evolution, failed to mention the most significant challenge to evolution in decades: Michael Behe's compelling argument against macroevolution, based on the intricacy of subcellular biochemical systems. Using five systems in the body to demonstrate his case, Behe, a biochemist at Lehigh University in Pennsylvania, asserts that macroevolution cannot operate at the microcellular level. Any minute change would render the highly specialized machinery of the cell inoperable. From the subcellular perspective, it is impossible for a bacterium to evolve into an organism with complex biochemical systems, no matter how much time is allowed, because the mechanisms are irreducibly complex.

I am at a loss as to why there was no mention of this in the issue. I understand your casual dismissal of the nonscientific intelligent-design philosophy, but Behe presents a legitimate scientific discussion with specific biological evidence.
Phillip Garding
North Bend, Washington

THE EDITORS REPLY: In April 2002 *Natural History* published a statement by Michael Behe, along with a rejoinder by the biologist Kenneth R. Miller of Brown University to Behe's examples of "irreducible complexity." Both are available on our Web site (www.naturalhistorymag.com).

Insulting and Unfair

As a staunch creationist, I found the tone of your 11/05 issue to range from condescending to insulting. Even a layman like myself can see that there are holes in the Darwinian theory of evolution through which the *Beagle* could sail. The frequent updates claiming, "We used to think this, but now we know that," do little to help. Heavy-handed lectures are unlikely to persuade creationists to swap their faith for such an incomplete and spiritually unsatisfying explanation of our world. The prima facie evidence of the world around us indicates the work of a Creator, and the marvelous workings of nature reinforce this conclusion.
David R. Gee
Van Nuys, California

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Genes for Jaws

The finches Darwin famously encountered on the Galápagos Islands—whose assorted beaks were adapted to a diet of grubs, insects, leaves, or seeds—demonstrate that new species can evolve when subpopulations specialize in particular foods. The myriad perchlike cichlid fishes from Lake Malawi in central Africa make another good example: some have jaws that bite, others have mouthparts ideal for vacuuming plankton from the water. That may sound like a lot of change to attribute to the occasional random mutation in one gene or another. But according to R. Craig Albertson, a biologist at the Forsyth Institute in Boston, and his colleagues, no statistical miracles are needed: much of the fishes' diversity in jawbone shape and function can be traced to variations in a single gene known as *bmp4* (for "bone morphogenetic protein 4").

Lake Malawi's *Labeotropheus fuelleborni*, for instance, is a seven-inch-long biting cichlid. It pries algae off rocks with its stout lower jaw. Albertson's research showed that the embryos of the species have high concentrations of the product of the *bmp4* gene in their developing jaws. In contrast, a smaller cichlid, *Metriaclima zebra*, sucks in waterborne plankton and has a more slender, elongated jawbone; little of the gene product is present in *M. zebra*'s immature jaws. Another suction feeder, the zebrafish,

Larva of the cichlid fish Metriaclima zebra *with red-stained bone and blue-stained cartilage*

Danio rerio, is also low in *bmp4* product. When the biologists injected messenger RNA transcribed from the *bmp4* gene into zebrafish embryos—thus inducing the embryos to make more gene product than they naturally would—the jawbone developed a stouter shape, similar to the biting species' jawbones. (*PNAS* **102**:16287–92, 2005)

—*Stéphan Reebs*

Melodious Mice

When it comes to songs, the ones made by birds, whales, and people usually get most of the attention. But new research suggests that mice should be added to the list as well. Investigators have known for some time that male mice emit ultrasonic calls when they discover signs of female mice nearby. Biologist Timothy E. Holy and computer programmer Zhongsheng Guo, both at the Washington University School of Medicine in Saint Louis, Missouri, have examined those calls in detail for the first time, and they made a surprising discovery.

Ultrasonic mouse calls are inaudible to people, but by recording them and dropping the pitch of the calls several octaves, the investigators were able to hear their true complexity. The calls incorporate two essential features of song: multiple kinds of syllables and a regular temporal pattern. Individual mice even sing their own unique songs, which are far more complex than the simple calls of insects and amphibians. It remains to be seen whether the calls serve as a communication channel between mice. (*PLoS Biology*, 3:e386, 2005)

—*Nick W. Atkinson*

Safe House

Would you trust your beloved heirlooms to an institution that could not ensure their safety or whose environmental conditions were hazardous to their survival? Presumably not. Yet according to a recent study by Heritage Preservation, a nonprofit conservation group based in Washington, D.C., that's precisely what many institutions are asking the public to do with some of the nation's most precious art, historical artifacts, and scientific specimens.

Heritage Preservation examined the "health" of U.S. archives, libraries, and museums—some 30,000 institutions in all—and found that 26 percent of them cannot protect their collections against damage from inappropriate humidity, light, and temperature. Even more alarming, the group learned, only 2 percent of the total annual operating budgets of all collecting institutions is dedicated to conservation. And in the event of a natural disaster or a terrorist attack, only 20 percent of institutions have an emergency plan to protect their collections.

For fans of natural history, however, the news is not entirely bleak. Large institutions, which hold 88 percent of the nation's 820 million scientific specimens, are better prepared. New York's American Museum of Natural History, for instance, has permanent staff dedicated to collections management and a small army of volunteers; moreover, it is working toward a comprehensive emergency plan for all its collections. "We have been working hard—even before 9/11—toward preserving and assessing the needs of our collections in a strategic way," notes Merrily Sterns, the museum's senior director of federal programs. "Despite limited funds, over the past decade we have allocated increasing resources to collections management, preservation, and security. But the needs are great."

Flood at this off-site storage facility in March 2004 damaged many archaeological artifacts belonging to the New Mexico Museum of Indian Arts and Culture, in Santa Fe.

The fact that "federal funding is extremely scarce to almost nonexistent for collections protection," Sterns adds, should sound alarm bells throughout all U.S. museums. That funding is especially critical for small natural history museums, which cannot bear the costs of needed conservation staff and expertise alone. (www.heritagepreservation.org/HHI/full.html)

—*Mary Knight*

Germ Warfare

In spite of their unicellular condition, bacteria can be highly social creatures. Millions of the soil-dwelling bacteria *Myxococcus xanthus*, for instance, live in cooperative swarms, feeding together on detritus and other microorganisms. When food is scarce, 100,000 or so of them gather together and form multicellular reproductive structures that generate stress-resistant spores.

But social interaction does not always imply cooperation. In nature, a single species of *Myxococcus* tends to inhabit a given area. And when brought together in the laboratory, *M. xanthus* and its relative *M. virescens* are known to be fiercely competitive. Each species forms its own reproductive structures and secretes compounds toxic to its rival. Eventually, *M. virescens* invariably dominates *M. xanthus.*

Now it appears that such aggression also takes place between members of the same species of *Myxococcus*. Francesca Fiegna and Gregory J. Velicer, both evolutionary biologists at the Max-Planck Institute for Developmental Biology in Tübingen, Germany, experimentally paired nine strains of *M. xanthus* in all possible combinations. They found that in a nutrient-poor environment the bacteria engage in rampant antagonism, suggesting that the organisms distinguish "us" from "them" even for various genetic strains within their own species. Most strains fared worse and produced fewer fruiting bodies in pairs than they did in isolation. Some even died off altogether (unicellular victims, as it were, of "ethnic cleansing"). A few dominant strains thrived on the competition, however, producing more spores than they did when they grew alone. (*PLoS Biology* 3:1980–87, 2005)

—*Graciela Flores*

Delayed Gratification

Cotton-top tamarin

Given the choice, many animals prefer a small, immediate reward to a larger one in the future. Both common marmosets and cotton-top tamarins, two species of South American monkey, fit that profile—though a marmoset will wait quite a bit longer than a tamarin will. Such behavior actually makes good sense in the wild: a monkey that waits too long risks losing its reward altogether. The food could be snatched up by a competitor, spoiled in the heat, or blown away by the wind.

Now a team of Harvard University primatologists, led by Jeffrey R. Stevens, has discovered a twist to this tale. If the rewards are separated by distance instead of time, cotton-top tamarins switch their preference. Tamarins faced with either a small food reward nearby or a larger one farther away, choose to make the longer trip, even though it takes more time. Common marmosets, however, are less willing to travel for food—they will wait, but they won't walk.

Stevens and his team suggest the reason for the unexpected reversal arises from differences between the two species' foraging habits: tamarins range over great distances to find insects, whereas marmosets rely on more predictable, localized food sources, such as tree sap. (*Current Biology* **15**:1855–60, 2005)

—*N.W.A.*

The Earth Gets Clocked

How old is the Earth's core? You might think such a fundamental question would have long since been settled, yet various geological "clocks" give conflicting birthdays as far apart as 50 million years. That's a big discrepancy and a big puzzle for earth scientists.

One clock relies on the rate at which hafnium-182 radioactively decays into tungsten-182. By that reckoning, the core was formed 30 million years after the origin of the solar system, or about 4.54 billion years ago. But a second clock, based on the decay of two isotopes of uranium into lead, dates the core to 80 million years after the solar system's birth. Now the geochemists Bernard J. Wood of Macquarie University in Sydney, Australia, and Alex N. Halliday of the University of Oxford think they have resolved the inconsistency.

Wood and Halliday maintain that the hafnium-tungsten clock is correct. But, they point out, about 45 million years after the birth of the solar system a Mars-size object hit the young planet. It added its metallic core to Earth's and spun out debris that coalesced into the Moon.

The investigators think the collision sparked a dramatic change in Earth's chemistry, causing lead in the mantle to join the core. That event reset the uranium-lead clock, and so by its estimate the core looks much younger than it really is. (*Nature* **437**:1345–48, 2005) —*G. F.*

Male jumping spider

Too Clever by Half

Many harmless, tasty animals mimic others that are dangerous or poisonous—an evolutionary tactic that affords protection from predators without the metabolic costs of the real threat. Jumping spiders of the genus *Myrmarachne,* for instance, bear a striking resemblance to ants, whose powerful mandibles and stings many predators avoid. More precisely, the adult female and juvenile spiders look like ants; but for the adult males, things are more complicated.

Intense sexual selection—competition between males to mate—has led male jumping spiders to evolve greatly elongated mouthparts. Those mouthparts, which make the male spider look as if it is carrying a large object such as prey, are enticing to female spiders. But such "compound mimicry" has a downside, according to research done at the University of Canterbury in New Zealand by behavioral ecologists Ximena J. Nelson and Robert R. Jackson. Predators that avoid ants are still deterred by the ant mimicry. But predators that specialize in eating ants know that the best time to attack is when the ants' pincers are clamped on something else. Bye-bye, spider! (*Proceedings of the Royal Society* B, forthcoming) —*N.W.A.*

Unleash the Wasps

Cuddly they're not, but trained wasps might one day offer some stinging competition to bloodhounds trained to sniff for corpses. In as little as five minutes, parasitic wasps of the species *Microplitis croceipes* can be conditioned to recognize and respond to certain odors. The training teaches the wasps to associate an odor with food. But how could forensic investigators exploit the talents of trained wasps?

Glen C. Rains, a biological engineer at the University of Georgia in Tifton, and two colleagues have devised a practical answer. Their invention, aptly called the Wasp Hound, is a portable, eight-inch tube with an interior chamber housing five wasps. When air bearing the target chemical blows through the chamber, the wasps cluster inquisitively near the odor's source. A camera transmits a video image of the insects to a computer, which is programmed to recognize wasp behavior that indicates the presence of the chemical—and then signal accordingly. Rains and his team say the wasps could be conditioned to detect not only corpses but also drugs, plant diseases, spoiled food, accelerants used in arson, and even human diseases such as cancer. (*Biotechnology Progress*, forthcoming)

—*Rebecca Kessler*

Sea otter snacks on abalone in California.

Fossil By Proxy

Kelps dominate the reefs of cool seas. They represent most of the biomass in these richly productive ecosystems, yet relatively little is known about their origins. One theory holds that kelps became widespread in the Northern Hemisphere sometime between 5 and 10 million years ago, when northern oceans cooled off and became rich enough in nutrients for kelps to flourish. But evidence supporting the theory is hard to come by, because the fossil record is bereft of kelps—their soft tissue simply does not mineralize well.

So one must approach the question sideways. James A. Estes, a marine biologist at the University of California, Santa Cruz, and two colleagues noted a pattern among species of abalone that grow to more than six inches long. Throughout the world, those larger species live only in cold seas that have plenty of kelp, their preferred food. Unlike kelps, though, abalones leave fossils behind. Examining the fossil record, Estes and his coworkers found that small species of abalone have been around for more than 60 million years, but large ones only 5 million years. That sharpens the time estimate for the kelps' population surge in northern seas.

The work also offers insight into another question: How could large abalones evolve in kelp forests that also harbor otters? Otters dine on abalones and prefer the big ones. Estes and his colleagues think abalones survive in protective crevices on the rocky seafloor; meanwhile, otters prey on other kelp eaters, such as sea urchins. The reduction in predators enables the kelp to grow so lush that the dead bits raining from their rubbery fronds provide the sheltered abalones with food aplenty. (*Paleobiology* **31**:591–606, 2005) —*S.R.*

Birth of the Spud

For every hot, salted, deep-fried bite of potato you've enjoyed, you have Andean farmers to thank. They were first to cultivate the spud (*Solanum tuberosum*), perhaps as early as 7,000 years ago. Today, from western Venezuela to northern Argentina, many primitive cultivars survive, some as weeds in commercial potato fields, others naturalized into the wild flora. The cultivars present a rich variety of shapes, colors, and growth habits. Such widespread distribution and great diversity have long led botanists to think the potato was independently domesticated several times in various places, possibly from different wild *Solanum* species.

Not so, say David M. Spooner, a taxonomist at the University of Wisconsin–Madison, and his colleagues from the Scottish Crop Research Institute in Dundee. After comparing the DNA of 365 specimens of *Solanum* from all over the Andes, including the primitive cultivars and the wild species from which they could have been derived, the team unearthed a pattern that points to a single origin in southern Peru, from the wild plant *Solanum bukasovii* or a close relative. Local farmers along the cordilleras then presumably developed the profusion of potatoes after the original cultivar was exported from its native soil. (*PNAS* **102**:14694–99, 2005)

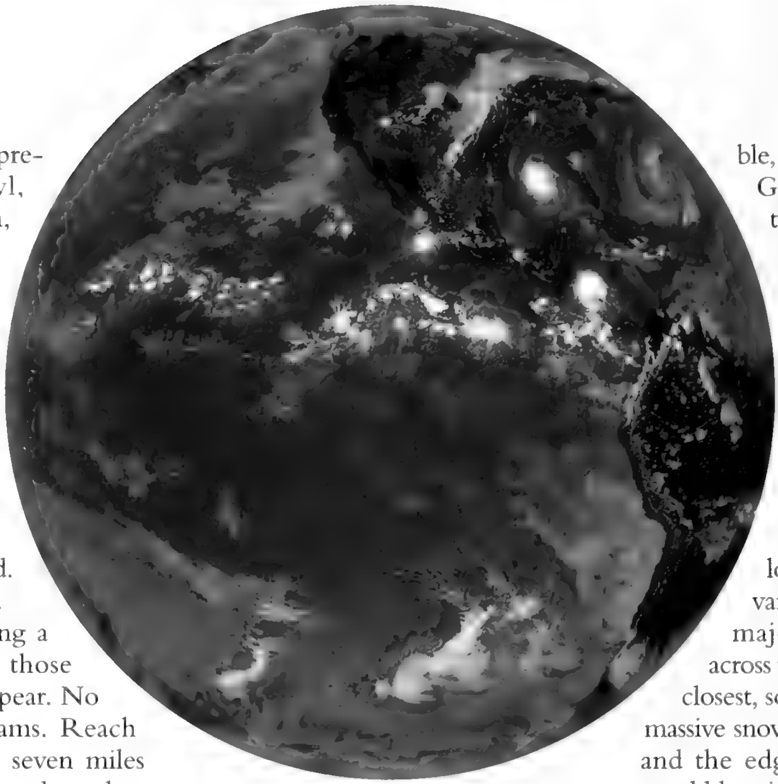
—*S.R.*

South American farmer introduces the potato to Spanish conquistadors.

Exoplanet Earth

What would Earth look like from deep space if inquisitive aliens were scanning for planets?

By Neil deGrasse Tyson



Whether you prefer to crawl, sprint, swim, or walk from one place to another, you can enjoy close-up views of Earth's inexhaustible supply of things to notice. You might see a vein of pink limestone on the wall of a canyon, a ladybug eating an aphid on the stem of a rose, a clamshell poking out of the sand. All you have to do is look.

Board a jetliner crossing a continent, though, and those surface details soon disappear. No aphid appetizers. No clams. Reach cruising altitude, around seven miles up, and identifying major roadways becomes a challenge.

Detail continues to vanish as you ascend to space. From the window of the International Space Station, which orbits at about 225 miles up, you might find London, Los Angeles, New York, or Paris in the daytime, because you learned where they are in geography class. But at night their brilliant lights present only the faintest glow. By day, contrary to common wisdom, with the unaided eye you probably won't see the pyramids at Giza, and you certainly won't see the Great Wall of China. Their obscurity is partly the result of having been made from the soil and stone of the surrounding landscape. And although the Great Wall is thousands of miles long, it's only about twenty feet wide—much narrower than the U.S. interstate highways you could barely see from a transcontinental jet.

Indeed, apart from the smoke plumes rising from the oil-field fires in Kuwait at the end of the First Persian Gulf War in 1991, and the green-brown borders between swaths of irrigated and arid land, from Earth orbit the unaided eye cannot see much else that's made by humans. Plenty of natural scenery is visible, though: hurricanes in the Gulf of Mexico, ice floes in the North Atlantic, volcanic eruptions wherever they occur.

From the Moon, a quarter million miles away, New York, Paris, and the rest of Earth's urban glitter don't even show up as a twinkle (unless you build a large telescope before you take a look). But from your lunar vantage you can still watch major weather fronts move across the planet. From Mars at its closest, some 35 million miles away, massive snow-capped mountain chains and the edges of Earth's continents would be visible through a large backyard telescope. Travel out to Neptune, 2.7 billion miles away—just down the block on a cosmic scale—and the Sun itself becomes embarrassingly dim, now occupying a thousandth the area on the daytime sky that it occupies when seen from Earth. And what of Earth itself? It's a speck no brighter than a dim star, all but lost in the glare of the Sun.

A celebrated photograph taken in 1990 from the edge of the solar system by the *Voyager 1* spacecraft [*see photograph on page 55*] shows how underwhelming Earth looks from deep space: a "pale blue dot," as the late

American astronomer Carl Sagan called it. And that's generous. Without the help of a picture caption, you might not even find it.

What would happen if some big-brained aliens from the great beyond scanned the skies with their naturally superb visual organs, further aided by alien-state-of-the-art optical accessories? What visible features of planet Earth might they detect?

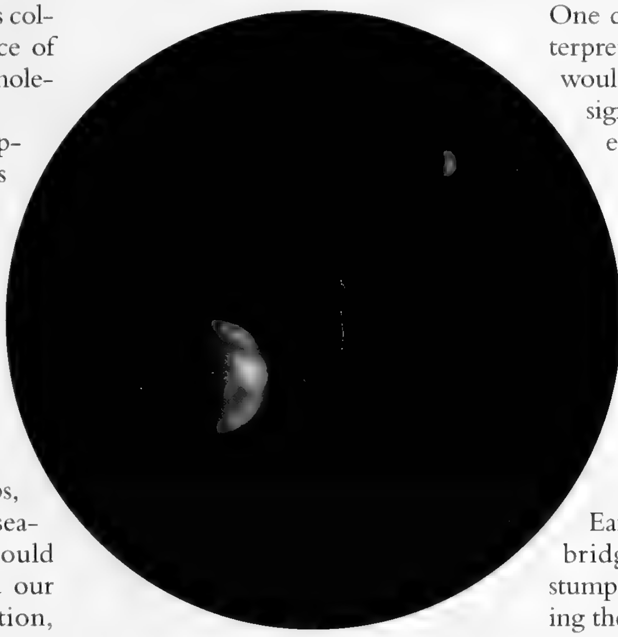
Blueness would be first and foremost. Water covers more than two-thirds of Earth's surface; the Pacific Ocean alone makes up an entire side of the planet. Any beings with enough equipment and expertise to detect our planet's color would surely infer the presence of water, the third most abundant molecule in the universe.

If the resolution of their equipment were high enough, the aliens would see more than just a pale blue dot. They would see intricate coastlines, too, strongly suggesting that the water is liquid. And smart aliens would surely know that if a planet has liquid water, the planet's temperature and atmospheric pressure fall within a well-determined range.

Earth's distinctive polar ice caps, which grow and shrink from the seasonal temperature variations, could also be seen optically. So could our planet's twenty-four-hour rotation, because recognizable landmasses rotate into view at predictable intervals. The aliens would also see major weather systems come and go; with careful study, they could readily distinguish features related to clouds in the atmosphere from features related to the surface of Earth itself.

Time for a reality check: We live less than a dozen light-years from the nearest known exoplanet—that is, a planet orbiting a star other than the Sun. Most exoplanets lie more than a hundred light-years away. Earth's brightness is less than one-billionth that of the Sun, and our planet's proximity to the Sun would make it extremely hard for anybody to see Earth directly with an optical telescope. So if aliens have found us, they are likely searching in wavelengths other than visible light—or else their engineers are adapting some other strategy altogether.

Maybe they're doing what our own planet hunters typically do: monitor stars to see if they jiggle at regular intervals. A star's periodic jiggle betrays the existence of an orbiting planet that may otherwise be too dim to see directly. The planet and the host star both revolve around their common center of mass. The more massive the planet, the larger the star's orbit must be, and the more measurable the jiggle when you analyze the star's light. Unfortunately for planet-hunting aliens, Earth is puny, and so the Sun barely budges, further challenging alien engineers.



Earth and the Moon as photographed from Mars by the Mars Orbiter Camera, 2003

Radio waves might work, though. Maybe our eavesdropping aliens have something like the Arecibo Observatory in Puerto Rico, home of Earth's largest single-dish radio telescope—which you might have seen in the early location shots in the 1997 movie *Contact*, based on a novel by Carl Sagan. If they do, and if they tune to the right frequencies, they'll certainly notice Earth, one of the loudest radio sources in the sky. Consider everything we've got that generates radio waves: not only radio itself, but also broadcast television, mobile phones, microwave ovens, garage-door openers, car-door unlockers, commercial radar, military radar, and communications satellites. We're just blazing—spectacular evidence that something unusual is going on here, because in their natural state, small rocky planets emit hardly any radio waves at all.

So if those alien eavesdroppers turn their own version of a radio telescope in our direction, they might infer that our planet hosts technology. One complication, though: other interpretations are possible. Maybe they wouldn't be able to distinguish Earth's signal from those of the larger planets in our solar system, all of which are sizable sources of radio waves. Maybe they would think we're a new kind of odd, radio-intensive planet. Maybe they wouldn't be able to distinguish Earth's radio emissions from those of the Sun, forcing them to conclude that the Sun is a new kind of odd, radio-intensive star.

Astrophysicists right here on Earth, at the University of Cambridge in England, were similarly stumped back in 1967. While surveying the skies with a radio telescope for any source of strong radio waves, Anthony Hewish and his team discovered something extremely odd: an object pulsing at precise, repeating intervals of slightly more than a second. Jocelyn Bell, a graduate student of Hewish's at the time, was the first to notice it.

Soon Bell's colleagues established that the pulses came from a great distance. The thought that the signal was technological—another culture beaming evidence of its activities across space—was irresistible. As Bell recounts, "We had no proof that it was an entirely natural radio emission. . . . Here was I trying to get a Ph.D. out of a new technique, and some silly lot of little green men had to choose my aerial and my frequency to communicate with us." Within a few days, however, she discovered other repeating signals coming from other places in our galaxy. Bell and her associates realized they'd discovered a new class of cosmic object—pulsing stars—which they cleverly, and sensibly, called pulsars.

Turns out, intercepting radio waves isn't the only way to be snoopy. There's also cosmochemistry. The chemical analysis of planetary atmospheres has become a lively field of modern astrophysics. Cosmochemistry depends on spectroscopy—the analysis of light by means of a spectrometer, which breaks up light, rainbow style, into its component colors. By exploiting the tools and tactics of spectroscopists, cosmochemists can infer the presence of life on an exoplanet, regardless of whether that life has sentience, intelligence, or technology.

The method works because every element, every molecule—no matter where it exists in the universe—absorbs, emits, reflects, and scatters light in a unique way. Pass that light through a spectrometer, and you'll find features that can rightly be called chemical fingerprints. The most visible fingerprints are made by the chemicals most excited by the pressure and temperature of their environment. Planetary atmospheres are crammed with such features. And if a planet is teeming with flora and fauna, its atmosphere will be crammed with biomarkers—spectral evidence of life. Whether biogenic (produced by any or all life-forms), anthropogenic (produced by the widespread species *Homo sapiens*), or technogenic (produced only by technology), this rampant evidence will be hard to conceal.

Unless they happen to be born with built-in spectroscopic sensors, space-snooping aliens would need to build a spectrometer to read our fingerprints. But above all, Earth would have to eclipse its host star (or some other light source), permitting light to pass through our atmosphere and continue on to the aliens. That way, the chemicals in Earth's atmosphere could interact with the light, leaving their marks for all to see.

Among the biomarkers for aliens to ponder in Earth's atmosphere: chlorofluorocarbons, vapor from mineral solvents, escaped coolants, and smog

Some molecules—ammonia, carbon dioxide, water—show up everywhere in the universe, whether life is present or not. But others pop up especially in the presence of life itself. Among the biomarkers in Earth's atmosphere are ozone-destroying chlorofluorocarbons from aerosol sprays, vapor from mineral solvents, escaped coolants from refrigerators and air conditioners, and smog from the burning of fossil fuels. No other way to read that list: sure signs of the absence of intelligence. Another readily detected biomarker is Earth's substantial and sustained level of the molecule methane, more than half of which is produced by human-related activities such as fuel-oil production, rice cultivation, sewage, and the burps of domestic livestock.

And if the aliens track our nighttime side while we orbit our host star, they might notice a surge of sodium from the sodium-vapor streetlights that switch on at dusk. Most telling, however, would be all our free-floating oxygen, which constitutes a full fifth of our atmosphere.

Oxygen—which, after hydrogen and helium, is the third most abundant element in the cosmos—is chemically active and bonds readily with atoms of hydrogen, carbon, nitrogen, silicon, sulfur, iron, and so on. Thus, for oxygen to exist in a steady

(Continued on page 55)

The Butterfly Bird

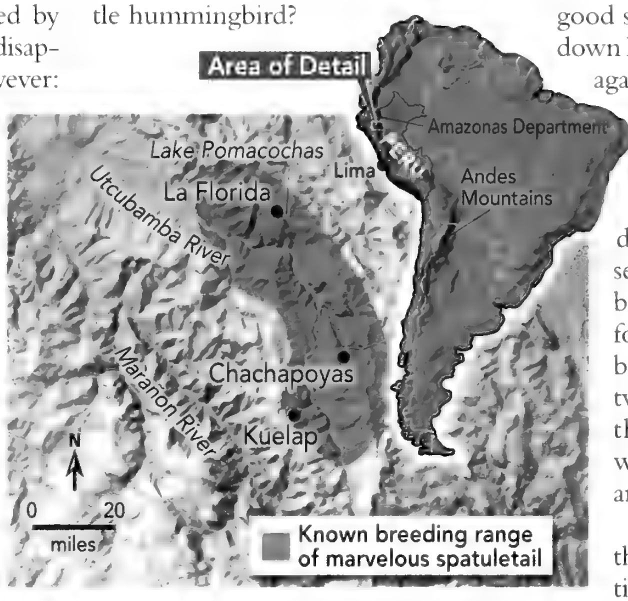
A legendary hummingbird draws bird-watchers to the Peruvian Andes, but the details of its biology and ecology remain largely unknown.

By Noam Shany

Allá está, el colibrí que la mariposa le sigue! ("It's over there, the hummingbird that the butterfly follows!"). The children in the crowded schoolyard shout excitedly, pointing to a tiny hummingbird hidden in the foliage. As I often do, to encourage environmentalism I am visiting a school as I make my way into the Andes of northeastern Peru. The teachers, newcomers to the nation's Amazonas Department and not familiar with its many living creatures, are amazed by their students' knowledge. I am disappointed when I see the bird, however: it is just an immature male, with only a short tail.

Some boys offer to show me a fully developed male, whose unusual tail does indeed make the bird in flight look as if it has a butterfly in hot pursuit. Each boy claims to know a secret spot near his family's plot of cultivated land. Sometimes their tips introduce me to new locales where the bird occurs. This time, though, I decline their offers and, after taking my leave, continue driving farther upland along the winding road, deeper into the range of my quarry.

The Peruvian Andes have long been inhabited. Earlier on my route, I passed a turnoff leading to Kuelap, the ancient fortress of the Chachapoyas culture, a civilization that flourished in northern Peru from A.D. 800 until 1470. But the pace of new settlement is unprecedented. The slopes are a crazy quilt of cloud forests and lush meadows dotted with cattle. When I reach La Florida, a tiny village nestled on the shores of Lake Pomacochas [*see map below*], I notice that since my last visit, makeshift housing has mushroomed along the recently paved road. More forest is being cleared to make room for farming and pastures. Mounds of bags filled with potatoes await pickup; farmers pull donkeys that carry containers loaded with milk for a local dairy. How do all these changes affect my rare little hummingbird?



A legend among ornithologists and bird-watchers, *Loddigesia mirabilis,* the marvelous spatuletail, occurs primarily along an eighty-mile stretch of the east bank of the Utcubamba River. The bird seems content to inhabit the edges of humid montane forest, patches of shrubbery, and second-growth forest. Such habitat appears widely available. Yet for some reason no one understands, the bird's range and numbers are highly restricted.

In the past eight years I have visited the bird's stronghold perhaps twenty times, sharing muddy trails with the farmers' donkeys and oxen. Near the cultivated plots, the only native plants are a few shrubs that mark the borders of properties and a few scattered trees on the edge of the trail. In my search I seek out an area at the forest's margin where I see a suitable hummingbird dining area: some *Bomarea formosissima* vines that are profuse with clusters of bright red, tubular flowers. As I wait, a sparkling violet-ear, a common hummingbird of the Andes, alternates between visiting the flowers and perching atop a tall tree, where he sings his raspy song.

Then a small hummingbird with a long tail whizzes by. Could it be the bird of my quest? No, it is a green-tailed trainbearer, its extremely long streamers glittering in the light. Minutes pass; I grow restless. Perhaps this is not a good spot after all. Then a movement down low catches my eye. In silhouette against the ground, a bird hums like wind through the brush and vanishes into the dense vegetation. That's it! The millisecond sighting rekindles my dampened spirits. I have clearly seen why people would say of the bird that it looks as if it is being followed by a butterfly. Floating behind the hummingbird's body, two specialized tail feathers give the impression that butterfly wings—or even two more birds—are giving chase.

Excluding those two feathers, the marvelous spatuletail is a petite bird, measuring less than three inches from the tip of its beak to the end of its tail. Its bill is black, of medium length, and curved slightly downward. The female's plumage is fairly plain for a hummingbird—green on top, dingy white below. In the male, blue crown feathers make for a rather short crest, the gorget is brilliant turquoise-green, and a black line bisects the whitish underparts. The mature male's most prominent feature, however, is its two outer tail feathers, each a bare, wirelike shaft terminating in a wide, glossy, violet-blue disk: the spatule. Because of their paddle shape, such feathers are known as rackets.

Most hummingbirds have ten tail feathers, but both male and female spatuletails have only four. The racket plumes of females and immature males are short and their spatules are not very wide. The female's other two tail feathers, moreover, are fairly narrow and simple. Those two nonplume tail feathers are also reduced in the mature male to narrow shafts. Two other long, narrow feathers, known as undertail coverts, support the male's exceptional tail. The racket plumes themselves cross each other most of the time a third of the way to halfway down their length, but the bird can also move them independently.

In spite of its beauty, the spatuletail is low in the hummingbird pecking order. It spends much of its day seeking shelter in dense thickets, keeping quiet, and avoiding confrontations (which it is likely to lose) with other species of hummingbird. When it finally emerges to feed, it is apt to move quickly, visiting flowering plants on a route regular enough that the blooms have time to refill with nectar between successive visits. Hummingbirds run on high-octane fuel and, in an unusual display of territorial behavior, defend their energy source from other species of hummingbirds and even from insects. For example, I once watched a male spatuletail feed by perching on some blossoms and hovering at others, but his meal was continually interrupted by an aggressive sparkling violet-ear that darted from above, protecting the blossoms from what it clearly regarded as an intruder.

Mature male marvelous spatuletail, a rare Peruvian hummingbird, sips nectar from Andean blueberry blossoms. The prominent, outsize tail feathers, known as rackets, are a key element of the male's mating dance.

After a successful bird-watching outing in the Peruvian Andes I usually have the luxury of retiring to some comfortable if rather out-of-the-way hotel. Earlier naturalists had to endure long and dangerous expeditions to enjoy a similar experience. Andrew Mathews, a botanist who ventured to northern Peru in 1835, was asked by his friend George Loddiges to collect as many hummingbirds as he could. A letter Mathews wrote to him from Chachapoyas captures the spirit of the time.

> The country has been in such a state of revolution for some time past, that it is very difficult to send large collections from this [place] to the coast. . . . I had heard of the death of poor Douglas from Mr. Maclean, and regret it extremely. Science has lost one of its ablest and most indefatigable collectors. I can assure you that many times whilst travelling in this country my life has been exposed to imminent danger in the [ravines] and bad roads of the Cordillera.

Mathews's words were prescient, for ultimately he, too, perished in the course of his adventures. The fact was recorded in a monograph on hummingbirds published between 1849 and 1861 by John Gould, a gifted artist who, beginning in 1827, worked as a taxidermist at the Zoological Society of London. His scientific description of the marvelous spatuletail accompanies his lithograph of the species [*see illustration on next page*]. Both were based on the specimen in Loddiges's collection, which explains the genus name *Loddigesia*, bestowed by Gould. Working with the dead bird, Gould could only guess at how the male's unusual tail functioned in life:

> It would be very interesting to see this bird on the wing; for I have no doubt that

its greatly developed spatules serve in some way to sustain it in the air; and if so this may account for the very diminutive size of its wings. It is just possible that, when the tail is fully spread, the spatules may be projected in front of its head.

In the next hundred years few biologists even reached the remote mountains, let alone recorded encounters with the extraordinary hummingbird. The species was all but forgotten until the 1960s, when the Brazilian collector Augusto Ruschi managed to add a live male to his aviary. Even then, enthusiasts were reluctant to travel to Peru because of the nation's political turmoil. Not until the early 1990s, when conditions became more stable, did they begin flocking to see what had come to seem a nearly mythical creature. To this day, its nest has not been scientifically described, no major studies of the species have been undertaken, and only a few people have been able to photograph the bird in its native habitat.

Lithograph of the marvelous spatuletail, made by the English artist and naturalist John Gould in the mid-nineteenth century, was based on a single dead specimen. In his scientific description, Gould incorrectly surmised that the tail feathers aided the bird in flight.

I've already noted how hard it is to observe a spatuletail in flight, because the enormous paddles move in different directions, diverting attention from the bird itself. I couldn't help wondering whether the tail evolved because it enabled the bird to avoid predators or harassment from other hummingbird species. But the accepted explanation for the male's tail is that it plays a key role in courtship, and therefore has been shaped through the process known as sexual selection.

In some ways, sexual selection seems perversely at odds with the interests of the bird. To construct its monumental tail, the male must divert valuable resources toward a body part that contributes nothing to its ability to compete for food. Moreover, the tail actually hampers its ability to fly, thereby *increasing* its risk of becoming prey. But if females prefer mates with fancy tails or other seemingly useless attributes, a male with such an attribute is more likely to mate and produce offspring. That is the true measure of the male's Darwinian "fitness." The male peacock's tail is commonly cited as an extreme case of sexual selection.

But why do females—with their own interests in producing offspring—choose such extravagances in looking for a suitable mate? One explanation is that females are on the lookout for evidence of a male's vigor. If a male can devote so much extra energy to decoration or to some special courting behavior, his outlandish distinction may be a fair advertisement of a reserve of energy. But once a pattern is set—say, the females' preference for a larger tail—it tends to take on a life of its own, as males compete from generation to generation for the attention of the opposite sex.

Spatules are not exclusive to this Peruvian hummingbird. Evolutionary forces have shaped them in a number of species belonging to various bird families. In the Americas, tail rackets occur both in other species of hummingbird (booted racket-tail, racket-tailed coquette) and in most species of motmots. Elsewhere, they occur in racket-tailed parrots from the Philippines, in paradise-kingfishers from the Australo-Papuan region, and in a few drongo species from South Asia and Southeast Asia. The pennant-winged nightjar, a nocturnal African species, has a single racket flight feather toward the end of each wing; the feather drops off after the courting season. Among the *Parotia,* a genus of birds-of-paradise from New Guinea, six racket plumes sprout from the head and play an important role in the male's display.

The development of racket feathers is similar in most species. The shaft of a more ordinary feather bears long barbs along two sides, from which branch smaller barbules. In the racket of a spatuletail, except for the disk at the end, the feather shaft bears only short barbs—indeed, it looks almost bare to the naked eye. One exception is the racket in motmots: the feather begins its growth like a normal feather, but the barbules and barbs near the base gradually wear out and fall off, or are plucked off as the bird preens.

In the avian world, it's common for a few adult males to gather in a communal display area called a lek where they strut their stuff before the females. Spatuletail males in a lek usually outnumber the females that come in hope of finding Mr. Right. Young males, still learning the art of courtship, also hang around the lek.

Roger Ahlman, a birder and freelance tour guide who lives in Ecuador, once watched an adult male spatuletail that was perched on a branch, waving his tail feathers from side to side. A second full-plumaged male was perched not far away, and a young male made a brief appearance. A female then entered the stage and sat on the same branch as the first male. In response he launched into full display mode: He flew upward, turned toward her, and hovered a foot away from her, his body in a vertical position that showed off his glittering green gorget. He then lifted his tail plumes and arched them, bringing the disks in front of his head, his body swaying from side to side. The dance lasted about thirty seconds, but failed to impress the female.

During my intermittent visits, which together add up to about six weeks of field observations, I have seen ten or twelve mature males in their territories, and between eighty and a hundred other spatuletails (females and young males). I've also been rewarded with the sight of eleven other species of hummingbird and other sought-after species, such as the chestnut-crested cotinga, the white-capped tanager, and the rare rusty-tinged antpitta. My joy, however, has been tempered by the large scale of habitat destruction, as machetes clear the fragments of surviving primary forest to make way for cultivation.

Although little is known, as I noted earlier, about the ecology of the marvelous spatuletail, the scarcity of the bird suggests it needs a specific combination of plants and environmental conditions to survive. Yet ornithologists don't know what that combination is. All the known populations of marvelous spatuletail lie outside the network of protected areas set aside by the Peruvian government to conserve the country's biodiversity. The risk that the species is losing essential habitat is therefore great.

Yet so iconic is the spatuletail, as a symbol of the wealth and uniqueness of Peruvian nature, that the species was adopted as the logo for the Javier Prado Natural History Museum in Lima. Hence, as a major attraction for ecotourists, the marvelous spatuletail is ideally positioned to serve as a powerful engine for the local economy. My fear is that it may become extinct for the sake of a few bags of potatoes.

Avid birder NOAM SHANY *is the co-author, with James F. Clements, of* A Field Guide to the Birds of Peru *(Ibis Publishing, 2001). Under a grant from Nature and Culture International, he is working with Peru's regional government of Loreto to create a network of protected areas.*

BIOMECHANICS

Shoe Fly

To walk on walls and ceilings, your feet have to stick, but they have to get unstuck, too.

By Adam Summers ~ Illustrations by Tom Moore

My mother is a rock climber, the familial human fly. She practices endlessly on walls and cliffs, refining her ability to stick to vertical surfaces and overhangs. Watching her, I've had plenty of time to contemplate the biomechanics of her gravity defiance. As she glides up a wall and then spiders along upside down across a "roof" section at a local gym, her aerial ballet testifies to the powers of friction and adhesion. In fact, the same interplay of forces enables a real fly to stick to walls. One day human climbers may borrow some of the fly's tricks for holding fast.

Fortunately for the fly, nothing in nature is perfectly flat and smooth; any interaction between surfaces is really a story of bumps hitting lumps. Friction is the force that results when the bumps on one surface smack into and snag on the lumps of another. Adhesion, a close cousin to friction, is the result of the molecular attraction between two materials as they are being pulled apart. Usually, though not always, increasing the adhesion between two surfaces increases the friction, too. Together these forces enable flies to walk just about anywhere.

Stanislav Gorb and his research group at the Max Planck Institute for Metals Research in Stuttgart, Germany, have examined the footfalls of dozens of insect species. With electron microscopy, high-speed video, and clever devices for measuring forces, Gorb's group has looked at how these creepy crawlers attach and detach themselves from surfaces. Flies, beetles, and thousands of other insects depend on a system of hairs to hang on. For all their clinging power, though, sticky feet do exact a cost: the better the fly sticks to a surface, the harder it is to get unstuck.

Fly foot gets a grip with sticky hairs and with claws shaped like a set of bull's horns. In the false-color scanning electron micrograph, the footpads of a syrphid fly (Eristalis pertinax), *depicted in beige, are covered with minute hairs, or tenent setae. The hairs both increase the contact area of the fly's foot and secrete a sticky fluid, enabling the fly to walk upside down. The set of claws can help the fly pry its footpads loose. The image is magnified 120X.*

Under the electron microscope you can see that a fly's foot ends in a soft pad covered with tiny hairs, called tenent setae. Each hair terminates in a delicate spatula that maximizes the contact area of the foot by flattening against the surface on which it stands [*see micrograph at left*]. Increasing the contact area increases the frictional forces that keep the foot rooted down. Rock climbers, too, try to increase surface area for a better hold by "smearing," or spreading the balls of their feet over rocks.

But flies do something even more active and interesting to get a grip, as Gorb's group found. By flash-freezing surfaces where flies had been walking, the researchers highlighted the sweaty little footprints that flies leave wherever they go. Under pressure, the flies' footpads secrete an emulsion that, like ice cream, is a mixture of sugars and oils; the goop coats the tenent setae and creates a strong bond between hair and surface through capillary adhesion. This form of adhesion is familiar to anyone who has ever found an advertising flyer on the windshield: a dry one flutters off, whereas soggy paper clings stubbornly to the glass, even while you drive down the highway.

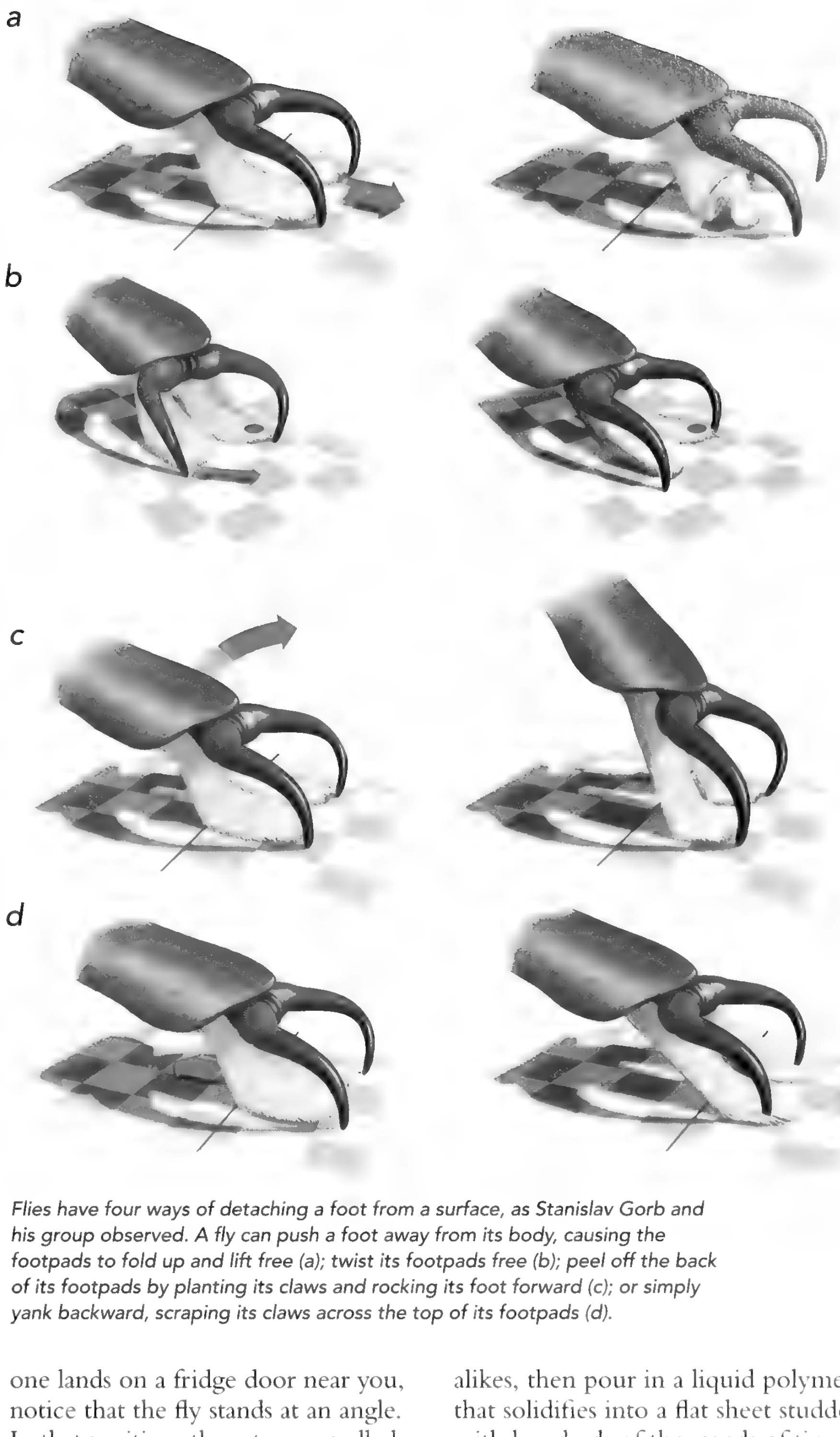
That same stubborn adhesion presents a problem for the fly. If its feet stuck too well to whatever it landed on, it would have to just stay put and order room service. So how does it get unstuck? Gorb watched hundreds of videotaped detachment events at a slow speed. What he found is that the fly has not one strategy, but four, for freeing up a stuck foot. Pushing the foot away from the body tends to scrunch up the footpads, popping them free. The other options are twisting the pads loose, prying them up with the help of two little claws on the end of the foot, or simply yanking them away from the surface with brute force [*see illustrations at right*].

No fly in its right mind is going to want to go to all that trouble unless it's absolutely necessary. Usually, when walking on a ceiling or a wall, the fly has a relatively slow gait because four of its feet are attached to the surface at any one time. On the ground, though, flies can save energy by walking like most other insects, with only three feet on the ground. The insect's six legs form alternating tripods, with the body supported by a fore and a hind limb on one side, in concert with the middle limb on the other. The ground gait is the six-legged equivalent of a trotting horse that has two feet planted at a time—and, just as a trot is faster than a walk, the trotting fly is a faster fly.

The damp nature of fly-foot contact has other consequences as well. In high humidity and under strong pressure, the fluid between the tenent setae can act like grease, causing the foot to slide. So flies have adopted a cockeyed strategy for hanging onto walls. If a fly stood vertically on a wall, the forces on its footpads would tend to detach the setae. Next time one lands on a fridge door near you, notice that the fly stands at an angle. In that position, the setae are pulled in the direction of strongest attachment—diagonally. For the same reason, the hardest thing for flies to do is walk headfirst down a wall; they can do it, but they are barely hanging on.

Gorb's group is now working on patterning various materials to scale fly feet up to human size. With photolithography and laser drills they etch a mold of tenent-setae look-alikes, then pour in a liquid polymer that solidifies into a flat sheet studded with hundreds of thousands of tiny, flanged columns. These prototypes have a long way to go before any of them is ready for wall walking. But I'm certain my mom will be first in line for a full set of fly feet.

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



Flies have four ways of detaching a foot from a surface, as Stanislav Gorb and his group observed. A fly can push a foot away from its body, causing the footpads to fold up and lift free (a); twist its footpads free (b); peel off the back of its footpads by planting its claws and rocking its foot forward (c); or simply yank backward, scraping its claws across the top of its footpads (d).

March of the Weevils

How a Mexican beetle launched a hundred-year attack on United States cotton

By Robert W. Jones

More than a hundred years ago, a curious-looking insect appeared in the United States that would dramatically transform the economy and landscape of the cotton-dependent South. The first report from the front lines of the unfolding U.S. invasion came in October 1894. That's when a small vial of insects arrived at the headquarters of the U.S. Department of Agriculture (USDA) in Washington, D.C., sent by a pharmacist named Charles W. DeRyee from Corpus Christi, Texas. In those days, farmers made insecticides from chemical ingredients they bought at a local drugstore. When a new and perplexing pest had appeared on cotton farms near Corpus Christi, local farmers had naturally turned to DeRyee for help. The pharmacist, in turn, sent the offending insects off to the USDA, accompanied by a troubling note that described damage to the fruits growing at the top of the area's cotton plants:

> The "Top" crop of cotton of this section has been very much damaged and in some cases almost entirely destroyed by a peculiar weevil or bug which by some means destroys the squares and small bolls. Our farmers can combat the cotton worm but are at a loss to know what to do to overcome this pest.

An insect taxonomist at the USDA, Eugene A. Schwarz, identified the "peculiar weevil" as *Anthonomus grandis,* a member of the Curculionidae, or "snout beetle" family, so-named for its members' unique, elongated snouts. When Schwarz and, independently, C.H. Tyler Townsend, an entomologist from New Mexico College of Agriculture and Mechanical Arts (now New Mexico State University) in Las Cruces, went to Texas to observe the weevil and the damage it caused, they quickly realized the animal's destructive power and alerted the world to the threat it posed to cotton production.

What those investigators saw is characteristic weevil activity. Adults pierce the flower buds, or "squares," with their long snouts and eat the pollen within. They also puncture the immature fruits, or "bolls," to consume the developing cotton fiber. More important, the females bore holes deep into both squares and bolls to deposit their eggs. After hatching, the larvae consume the innards of the plant's reproductive structures. Damaged squares are then severed from the plant, never to become bolls. And most of the damaged bolls fail to produce their trademark fluffy fibers. *Anthonomus grandis,* a modest, quarter-inch-long insect, soon became known as the notorious cotton boll weevil.

The appearance of a field heavily infested by weevils is a depressing sight to any cotton farmer, but it must have been devastating to those who first witnessed the destruction. When weevils are finished with a cotton plant, the plant retains its lush, green foliage, but it has none of its distinctive large, white and pale-pink flowers or fiber-producing fruits. Yellowed, weevil-infested buds are scattered over the ground like confetti.

Yet even for the cotton farmers who first surveyed such depredations, it would have been hard to imagine the sweeping trajectory of the weevil's invasion. From their fields it marched across the South, leaving massive agricultural and economic disruption in its wake. Even today the cost of the pest in crop losses and control measures in the U.S. is estimated at around $150 million a year, and the cumulative costs of the invasion exceed $22 billion. Fortunately for U.S. cotton growers, the war on the boll weevil, begun more than a century ago, is finally being won. The insect has been eradicated

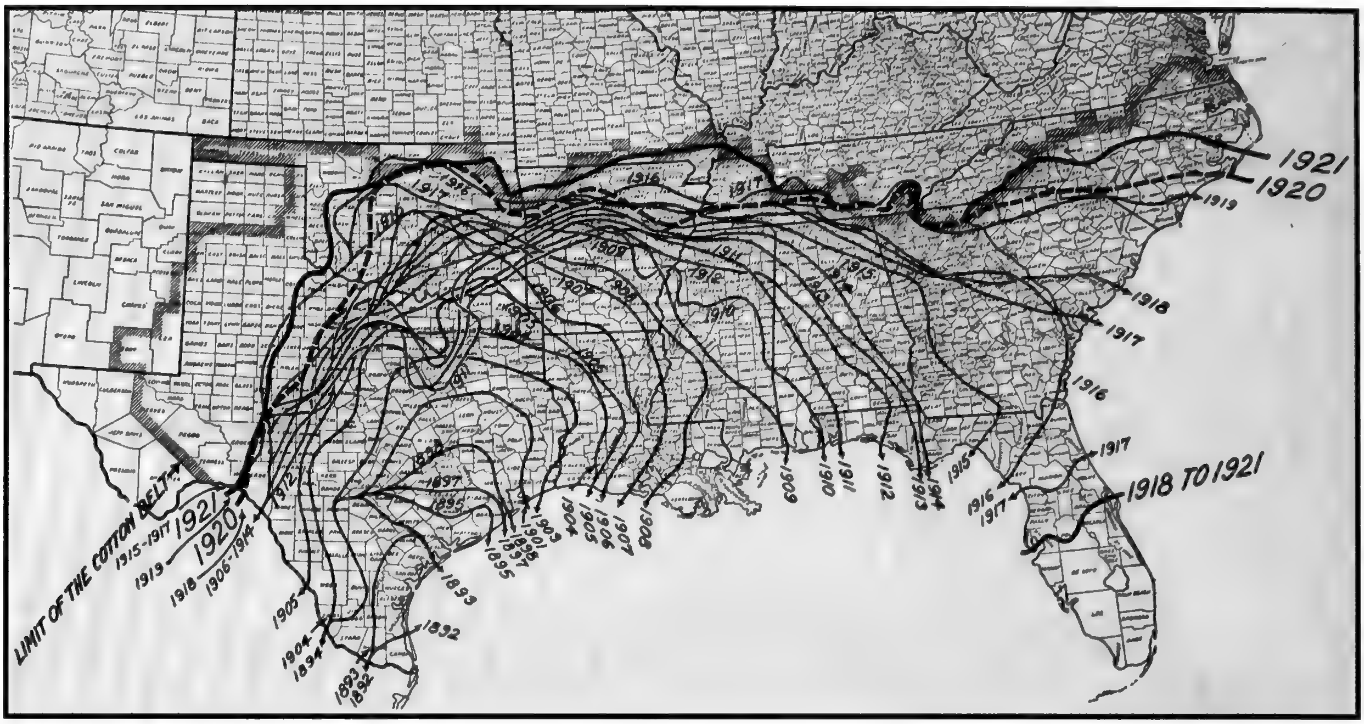
Boll weevil prepares to feed on a "square," or bud, of a cotton plant. Females deposit eggs within cotton squares and immature "bolls," or fruits, which the weevil larvae consume and ultimately destroy.

from ten states, and it is in retreat in seven more. Unfortunately, the principal weapons in this war have been chemical insecticides, some of which, especially initially, have left toxic residues that are likely to persist for many years.

A second unfortunate reality is that much of the war against the boll weevil had to be fought without knowing the biological history of the enemy—where it came from or why. The mystery can be traced to an obscure taxonomic error. Correcting that error eventually led to a vastly improved understanding of the weevil's natural history, but that understanding came too late to have much impact on the U.S. eradication effort. In fact, the success of the eradication effort led to cuts in spending on research into alternate methods of weevil control. Does that mean the enhanced knowledge is of no more than academic interest? Quite the contrary. The boll weevil may be in retreat in the U.S., but it remains a key cotton pest in Mexico and Central America. In those countries the presence of the weevil's wild host plants may make it futile to apply U.S. eradication methods. More worrisome is that the insect has opened a second front in South America. That invasion continues mounting to this day. Understanding the boll weevil's origins, its natural enemies, and the defenses that relatives of cotton might have evolved against its ancestors may one day help reduce the need for pesticides to control it.

As early as 1862, some thirty-two years before Charles DeRyee's alert, the boll weevil had already been reported destroying cotton plants in what were then wild and isolated regions of Mexico's northern states. That earlier report caused little stir in the U.S. By 1900, however, the weevil was well entrenched in southern Texas and plainly displaying its destructive potential. A growing alarm was spreading among cotton growers throughout the South.

And with good reason. Between 1892 and 1922 the boll weevil advanced relentlessly by 40 to 200 miles a year [*see map on next page*]. By 1916 it had reached the Atlantic seaboard, and five years later it had spread throughout the Cotton Belt, from west



Spread of the boll weevil between 1892 and 1921 is plotted on this map from the Farmer's Bulletin, *February 1922.*

Texas to North Carolina and as far north as southeastern Missouri. The beetle eventually settled virtually everywhere cultivated cotton grew.

Three or four years after an invasion, crop losses caused by the boll weevil often exceeded 80 percent, bringing financial ruin to many farmers. The destruction led to the abandonment of numerous marginal cotton-producing areas. Many farmers switched to crops other than cotton. Scholars often list the resulting economic hardship as one cause of the massive migration of farmers and farm laborers—particularly African-Americans—from the rural South to northern cities in the early twentieth century. In spite of the upheaval, however, the forced diversification away from a one-crop economy has been called a blessing in disguise, because it ultimately led to greater economic stability throughout the South.

The efforts to fight back against what became a hundred-year plague also led to innovations in chemistry, agricultural practice, and mechanical design. Many southern universities established entomology departments to study ways to combat the boll weevil. But success was halting. In 1903 the Texas Legislature offered a $50,000 cash reward—a huge sum for its day—to anyone who could devise a way to control the insect. No one collected. And many of the early responses to the boll weevil, particularly chemical treatments, created problems of their own.

Compounds of arsenic were first used against the boll weevil in 1919, with some success. Just two years later, U.S. cotton farmers were applying calcium arsenate dust to their fields at a rate of ten million pounds a year. It remained the principal control method until after the Second World War, when DDT and its derivatives came into widespread use. But calcium arsenate is toxic to invertebrates, fish, birds, and mammals, and it is a known human carcinogen. Its residue is still present in many southern soils.

DDT and the chemical insecticides that were subsequently developed initially offered hope of curbing the boll weevil for good. But the pest resisted control and heavy chemical use added economic and environmental costs to cotton production. The boll weevil remained the most important cotton pest throughout most of the South as the twentieth century closed.

Yet today the boll weevil is on the run in the U.S. A massive eradication program, funded by growers, afflicted states, and the USDA, began in 1978. Traps baited with synthetic boll-weevil pheromone indi-

An Invasion Unfolds

1843 Swedish entomologist Carl H. Boheman scientifically describes the boll weevil *(Anthonomus grandis)* from Mexican specimens.

1862 Farmers in northern Mexico first report boll weevil destroying cotton crops.

1892 Boll weevil enters the United States.

1894 U.S. Departme[nt] the first report cate whether a field is infested; infested fields are then treated with carefully timed, low doses of the insecticide malathion.

As a result, the pest has been eradicated from Alabama, Arizona, California, Florida, Georgia, Kansas, New Mexico, North Carolina, South Carolina, and Virginia. Weevil populations are also declining in the other cotton-producing states: Arkansas, Louisiana, Mississippi, Missouri, Oklahoma, Tennessee, and Texas, as well as in the adjacent Mexican states. The USDA expects the boll weevil to be eradicated from the U.S. by 2009. Nevertheless, the eradication program has been controversial because of its high cost and, again, its continuing heavy reliance on insecticide, which has reportedly triggered outbreaks of other, insecticide-resistant pests.

Meanwhile, undeterred by impending defeat in the north, the boll weevil remains on the march in South America. It was apparently introduced into the northern part of the continent during the late 1940s and, in a mirror image of its U.S. invasion, has moved steadily southward. The insect has now invaded all the major cotton growing regions of Brazil and Paraguay, and has entered northern Argentina. Fortunately, this time pest managers have a much greater range of management options to choose from. Eradication programs in parts of South America are underway.

Two obvious questions arise from the story of the boll weevil's U.S. invasion: why did the insect appear when it did, and where did it come from? The answer to the first question is historical, and relatively straightforward. The arrival of the pest in the U.S. can be traced to economic changes wrought by the Civil War. The Union's naval blockade of the Confederacy prevented Confederate States from shipping cotton to European textile mills, sending cotton prices skyrocketing worldwide. Mexican farmers, who retained access to European markets, responded by planting more cotton, particularly in northern Mexico. In the years before the Civil War, U.S. cotton farms had been separated from their Mexican counterparts by the wide, cotton-free region of northeast Mexico. But shortly after the war, the northward expansion of Mexican cotton farming had narrowed that region substantially, bringing the cotton fields of the two nations within weevil-flying distance. Increased trade between the blockaded South and Mexico may have also helped the weevil cross the border.

But answering the first question only underscores the lack of an answer to the second: where did the boll weevil originate? Entomologists agreed from the very first that, because the weevil was previously unknown in the U.S. or South America, it must have come from southern Mexico, where it was first collected, or perhaps from Central America. They also concurred that the boll weevil, like many other plant-eating insects, restricts its reproduction to a narrow range of host plants. Hence cotton and its close relatives, all members of a group known as the cotton tribe within the family Malvaceae, were the only plants from which the boll weevil could have come. Entomologists and botanists all concluded that the insect's origins must be closely linked to the diversity and geographic range of the cotton tribe.

The USDA expects the boll weevil to be eradicated from the United States by 2009.

Those two clues prompted many investigators to search Mexico and Central America for the cradle of the boll weevil. At first, biologists discovered boll weevils only on wild or cultivated cottons—all species of *Gossypium*—so they assumed the insect was restricted to that genus. Searches for close relatives of cotton in Mexico and Central America later turned up two more genera from the cotton tribe, *Thespesia* and *Cienfuegosia,* that host boll weevils. But hosts from these two genera invariably had few weevils, which occurred only when the plants grew near fields of cultivated cotton, suggesting that neither genera was likely to have been the boll weevil's ancestral host.

So cotton remained the prime suspect. Then, in the 1960s, Paul A. Fryxell, a botanist who specialized in the Malvaceae family at the USDA Cotton Laboratory in College Station, Texas, realized that a relatively obscure but diverse genus of small, tropical trees by the name of *Hampea* had been assigned to the wrong plant family. Other botanists had classified *Hampea* solely on the basis of male specimens, which lack the distinctive tube of fused stamens that surrounds the female flower parts in members of the

of Agriculture (USDA) receives the boll weevil on U.S. soil.

1919 Compounds of arsenic first sprayed on cotton fields to combat boll weevil.

1922 Range of boll weevil reaches its maximum extent in the U.S.

1924 Airplanes first dust cotton with arsenic compounds to control boll weevil on a large scale

1939 DDT's utility as an insecticide discovered, launching the development of an arsenal of synthetic insecticides.

Malvaceae. Fryxell had both male and female specimens and easily recognized that *Hampea* belonged in the Malvaceae. Even more, it was a member of the cotton tribe.

Taxonomy is often thought of as a descriptive science with a lot of name shuffling that yields no testable hypotheses. But Fryxell's seemingly minor taxonomic change turned out to be the most important clue in the search for the boll weevil's origins. For if *Hampea* is closely related to cotton, might some species of *Hampea* also have boll weevils?

The question was answered in 1966, when Fryxell and his colleague, the late Maurice J. Lukefahr, discovered boll weevils on a common, but at the time undescribed species of *Hampea* growing far from commercial cotton farms in the Gulf Coast region of Veracruz, Mexico. On the basis of the large, apparently well-established populations of boll weevils they discovered, Fryxell and Lukefahr concluded that *Hampea,* not cotton, is probably the boll weevil's ancestral host. Fryxell named the species *Hampea nutricia,* for its role in providing nutrition and shelter to the boll weevil and another cotton pest, the cotton leafworm.

Farmer dusts a cotton field against boll weevils in Scott, Mississippi, in 1919. Dusting with calcium arsenate was the principle means of weevil control until after the Second World War. Arsenic residue from the pesticide persists in soils throughout the South to this day.

Evidence gathered in subsequent years has bolstered their conclusion. In 1979 Horace R. Burke and James R. Cate, both entomologists at Texas A&M University in College Station, discovered a previously unknown weevil species *(Anthonomus hunteri),* living exclusively on another species of *Hampea* in the Yucatán Peninsula. The discovery was important because the boll weevil had always been something of an orphan within *Anthonomus,* its megadiverse genus. More than 300 species of *Anthonomus* are recorded in Central and North America alone, yet no close relative of the boll weevil had ever been found.

In the past six years Burke and I have filled in more of the boll weevil's family tree. We have described three more species of *Anthonomus,* closely related to the boll weevil, which also live on various species of *Hampea* in southern Mexico and Central America. The fact that the boll weevil's closest relatives are restricted to *Hampea,* whereas the boll weevil alone lives on cotton, suggests that *Hampea* and its associated weevils have had more time than cotton and the boll weevil to co-evolve. *Hampea* is thus a more likely original host than cotton.

If the boll weevil first evolved on *Hampea,* when did it shift to cotton? The question remains an open one, but it is intriguing to note that Mexico's Gulf Coast region along the border between the states of Tabasco and Veracruz is most likely where cotton was first domesticated in the Americas. That region corresponds precisely with the distribution of *H. nutricia.* The plant is a vigorous colonizer of disturbed soils, and so it is common near agricultural fields. The boll weevils that feed on it almost certainly had intimate and sustained contact with cotton plants cultivated

1950s Boll weevil and other insect pests grow increasingly resistant to certain insecticides.

1962 Rachel Carson publishes *Silent Spring,* sparking public concern over insecticide use.

1969 USDA investigators isolate boll weevil sex pheromone and use it to design the first effective weevil trap.

1971 First pilot eradication program begins in Alabama, Louisiana, and Mississippi.

1978 Nationwic traps dete malathio

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Female parasitic wasp Catolaccus grandis *attacks a boll weevil larva developing under plastic film in a laboratory. The wasp may be able to help control the boll weevil in tropical regions.*

by indigenous farmers. Boll weevils would thereby have had plenty of chances to adapt to the newly domesticated and increasingly plentiful crop.

As I noted earlier, knowing the identity of the boll weevil's ancestral host is of more than academic interest. Botanists have long searched for cotton plants that are resistant to the pest. Although some cultivated varieties are attacked to a lesser degree than others, none is sufficiently resistant to produce a decent yield without pesticides or some other tactic of weevil control. That makes evolutionary sense; the boll weevil and cotton have apparently had only a short period of association. Cotton has simply not had time to evolve an effective way to reduce the damage caused by the pest. The affected species of *Hampea,* however, have several successful tactics for avoiding weevil damage. Further research may lead to the discovery of *Hampea*'s chemical and genetic resistance mechanisms, which may be transferable to cotton.

Likewise, knowing the boll weevil's original host holds the potential for finding its natural enemies, which might control the pest without chemicals. The long association of the boll weevil and its close relatives with various species of *Hampea* gave parasites and predators time to target the association. More than fifteen parasites attack weevils hosted by *Hampea.* The most promising of them is a parasitic wasp, *Catolaccus grandis* [*see photograph at left*]. The female *C. grandis* lays an egg in the cavity occupied by a boll weevil larva, and the emerging wasp feeds on its weevil host. Although research on *C. grandis* has been sidelined by the present success of the U.S. eradication program, the wasp may still be an option for boll-weevil control in tropical regions where abundant wild host plants make eradication difficult.

The natural history of the boll weevil and its host plants illustrates how the loss of tropical biodiversity has effects far beyond the equatorial latitudes. With the destruction of tropical habitats, not only plant and animal species, but also valuable information is lost. Many of the insect pests in the U.S.—including the potato beetles, the pepper weevil, and stem borers that feed on rice and corn—likely come from tropical regions, particularly regions in Mexico where crops were domesticated. Wild populations of those insect species and their close relatives continue to survive on wild hosts, many of which remain poorly studied or even unknown. If those species are lost, biologists also lose clues to their evolutionary history and relations with their host plants and natural enemies.

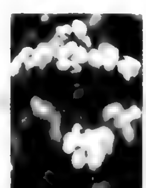
Several of the boll weevil's relatives and their host plants have been identified only in secluded, threatened habitats in southern Mexico. At one of my research sites in the beautiful lake region of Montebello, in the highlands of Chiapas, the habitat of *H. montebellensis* and the only known population of its weevil parasite were destroyed in a 1998 forest fire. The region's growing human population exerts enormous pressure for land; within the next few years any remaining populations of this *Hampea* species and their weevils will almost surely be gone. Not only will their extinction be a further blow to the planet's biodiversity, but it will also irrevocably limit understanding of the boll weevil and reduce our options in developing ecologically sound management tools against an important insect pest. □

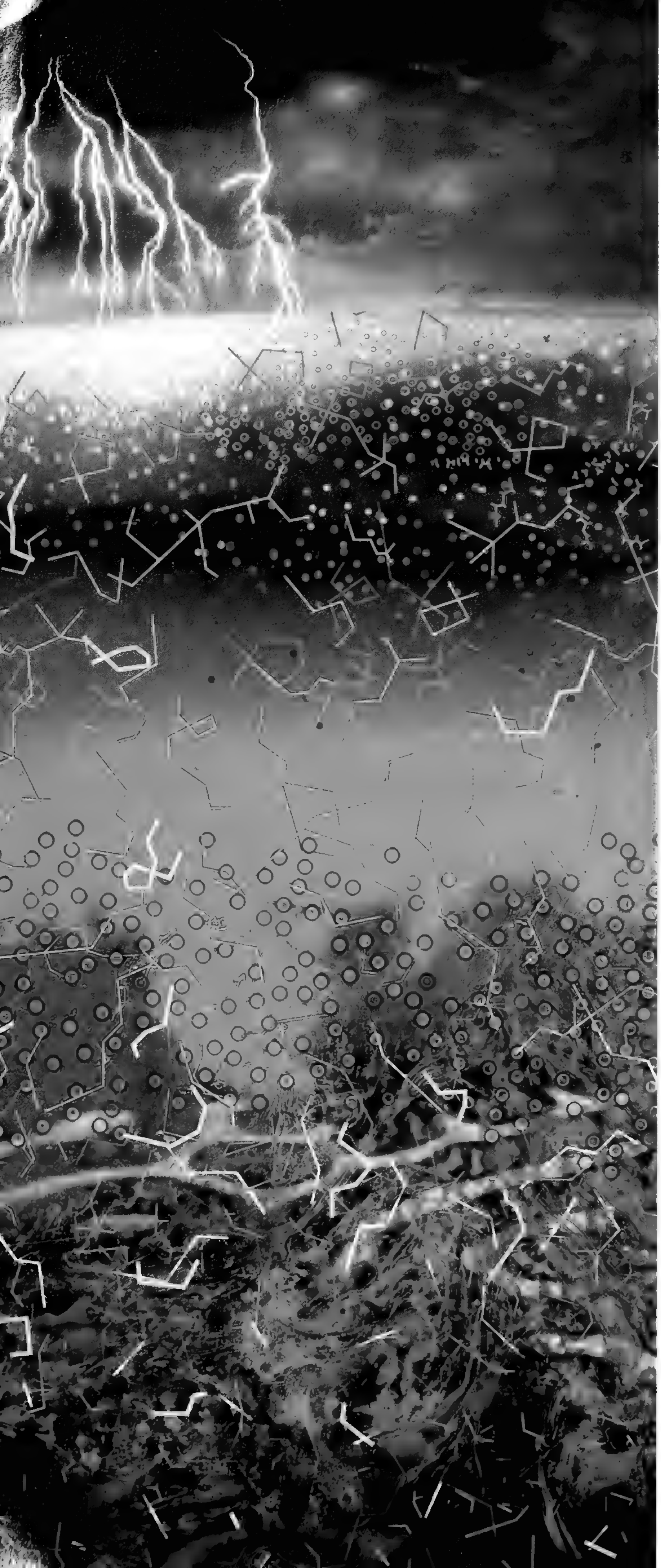
adication program begins; pheromone
fested fields, and the insecticide
eats them.

ginia becomes the first
ate declared weevil-free.

2009 USDA projects boll weevil will be eradicated from the U.S.

2006 Ten states have declared the boll weevil eradicated, and the pest is declining in the seven remaining cotton-producing states.





The Origins of Life

Have too many cooks spoiled the prebiotic soup?

By Antonio Lazcano

Twenty-five years ago, Francis Crick, who codiscovered the structure of DNA, published a provocative book titled *Life Itself: Its Origin and Nature.* Crick speculated that early in Earth's history a civilization from a distant planet had sent a spaceship to Earth bearing the seeds of life. Whether or not Crick was serious about his proposal, it dramatized the difficulties then plaguing the theory that life originated from chemical reactions on Earth. Crick noted two major questions for the theory. The first one—seemingly unanswerable at the time—was how genetic polymers such as RNA came to direct protein synthesis, a process fundamental to life. After all, in contemporary life-forms, RNA translates genetic information encoded by DNA into instructions for making proteins.

The second question was, What was the composition of Earth's early atmosphere? Many planetary scientists at the time viewed Earth's earliest atmosphere as rich in carbon dioxide. More important, they were also skeptical about a key assumption made by many chemists who were investigating life's origin—namely that Earth's early atmosphere was highly "reducing," or rich in methane, ammonia, and possibly even free hydrogen. In a widely publicized experiment done in 1953, the chemists Stanley L. Miller of the University of California, San Diego, and Harold C. Urey had demonstrated that in such an atmosphere, organic, or carbon-based, compounds could readily form and accumulate in a "prebiotic soup." But if a highly reducing atmosphere was destined for the scientific dustbin, so was the origin-of-life scenario to which it gave rise.

In Crick's mind, the most inventive way to solve both problems was to assume that life had not evolved on Earth, but had come here from some other location—a view that still begs the question of how life evolved elsewhere.

Crick was neither the first nor the last to try to explain life's origin with creative speculation. Given so many difficult and unanswered questions about life's earthly origin, one can easily understand why so many investigators become frustrated and give in to speculative fantasies. But even the most sober attempts to reconstruct how life evolved on Earth is a scientific exercise fraught with guesswork. The evidence required to understand our planet's prebiotic environment, and the events that led to the first living systems, is scant and hard to decipher. Few geological traces of Earth's conditions at the time of life's origin remain today. Nor is there any fossil record of the evolutionary processes preceding the first cells. Yet, despite such seemingly insurmountable obstacles, heated debates persist over how life emerged. The inventory of current views on life's origin reveals a broad assortment of opposing positions. They range from the suggestion that life originated on Mars and came to Earth aboard meteorites, to the idea that life emerged from "metabolic" molecular networks, fueled by hydrogen released during the formation of minerals in hot volcanic settings.

This flurry of popular ideas has often distracted attention from what is still the most scientifically plausible theory of life's origin, the "heterotrophic" theory. The theory holds that the first living entities evolved "abiotically"—or from systems of nonliving organic molecules present on the primitive Earth. (The term "heterotrophic" was originally coined to describe a kind of metabolism in which "nutrients" such as carbon and nitrogen must be obtained from nature as complex organic molecules such as amino acids, rather than from extremely simple compounds such as carbon dioxide.) According to the theory, organic molecules such as amino acids were chemically combined in a prebiotic soup and "cooked" by various sources of energy. True, some of the details of Miller and Urey's recipe for prebiotic soup presented difficulties, such as the ones Crick highlighted. But abandoning the premise of a prebiotic soup when new findings largely support its account of life's origin is to "throw the baby out with the bathwater."

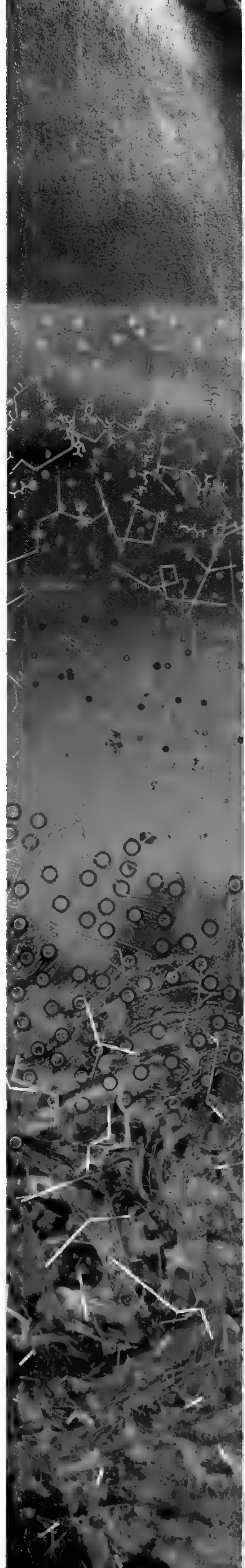
One strong argument in favor of the heterotrophic theory is the surprising variety of biochemical constituents that emerge in laboratory simulations of Earth's prebiotic environment, and the remarkable similarity between them and the constituents of some carbon-rich meteorites. On September 28, 1969, for instance, a meteorite landed in Murchison, Australia, carrying nearly eighty kinds of amino acids. Among them were several amino acids that occur in proteins. Also embedded in the Murchison meteorite were purines, pyrimidines, carboxylic acids, and compounds derived from ribose and deoxyribose, the sugars present in RNA and DNA. (In fact, ribose is the "R" of RNA, deoxyribose the "D" of DNA.) Such relics of the early solar system provide insight into the kind of organic chemistry that took place some 4.6 billion years ago.

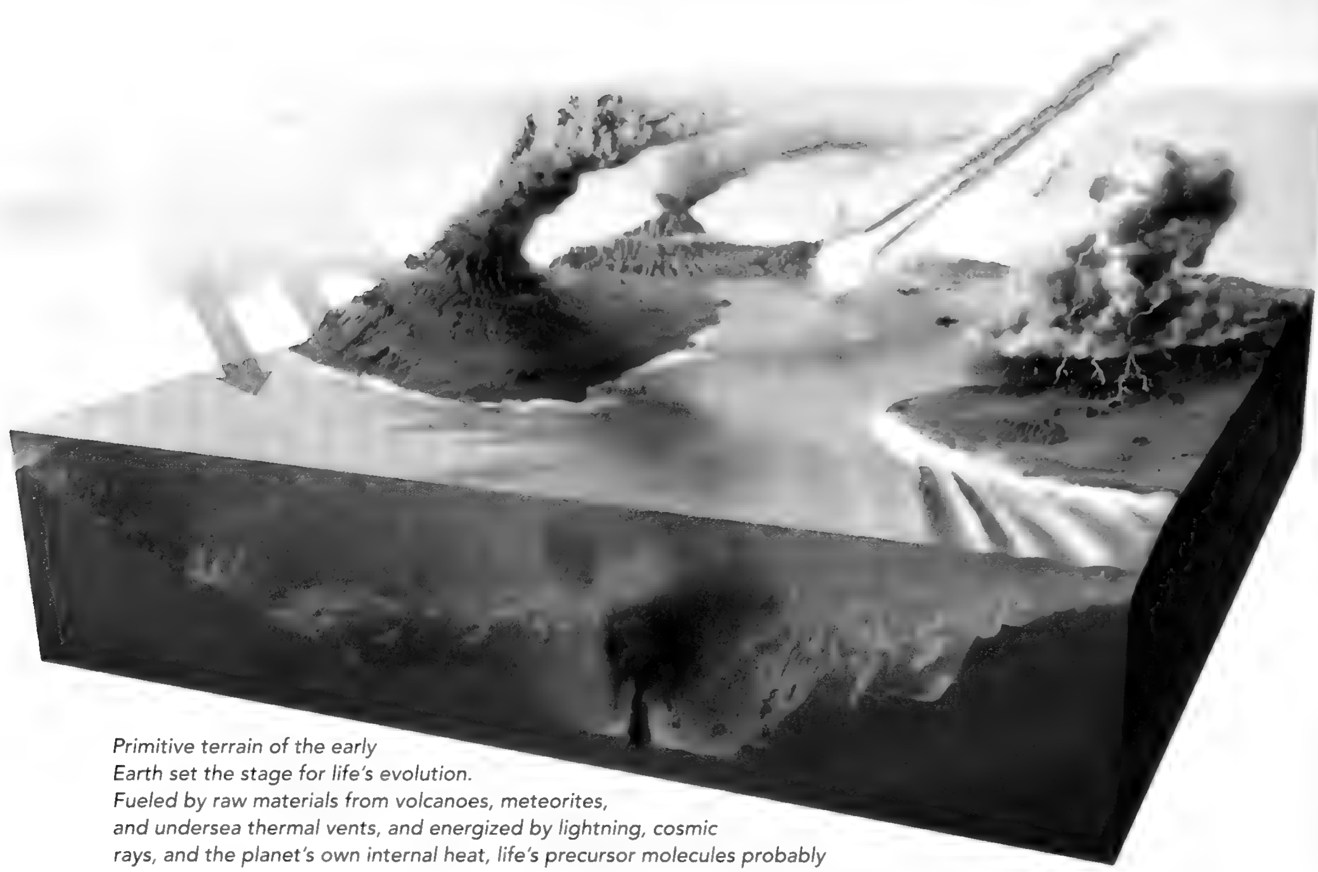
The similarity between the products of laboratory synthesis and the components of the meteorite seems more than accidental. In fact, it offers strong justification for bringing the study of the possible reaction pathways of prebiological molecules into the laboratory. Perhaps reactions such as the ones Miller and Urey simulated were common throughout the solar system, or at least in a prebiotic soup on Earth.

What about the criticisms that the highly reducing atmosphere in the Miller-Urey experiment was unrealistic? The hydrogen in such an atmosphere, according to the critics, would have escaped into space too quickly to have played any role in atmospheric chemistry. But the critics may have overstated their case. Recent theoretical models by Feng Tian, an atmospheric chemist at the University of Colorado, Boulder, and his colleagues suggest that hydrogen in the atmosphere of the early Earth may have escaped more slowly than planetary scientists previously assumed. So although Earth's primitive atmosphere may not have been as strongly reducing as Miller, Urey, and their followers have assumed, it may not have been lacking in hydrogen, either. The hydrogen would have coexisted with carbon dioxide. The presence of both gases would have helped forge hydrogen-rich molecules, which would have transformed into organic compounds.

Certainly, the classical recipe for prebiotic soup requires updating. It must take into account such additional, newly recognized factors as extraterrestrial organic compounds, minerals such as combinations of iron and nickel with sulfur that act as chemical catalysts, and organic molecules synthesized in hydrothermal vents. None of those factors threatens the plausibility of a heterotrophic theory as an explanation for the origin of life.

The heterotrophic theory has also gained support from studies of the capabilities of RNA,





Primitive terrain of the early Earth set the stage for life's evolution. Fueled by raw materials from volcanoes, meteorites, and undersea thermal vents, and energized by lightning, cosmic rays, and the planet's own internal heat, life's precursor molecules probably formed in a "soup" of prebiotic organic compounds about 4 billion years ago.

which have shown that RNA may have played a far broader role during life's evolution than it does in life today. In 1982 the molecular biologists Thomas R. Cech, now at the Howard Hughes Research Institute in Chevy Chase, Maryland, and Sidney Altman of Yale University independently discovered that RNA molecules can act not only as messengers and repositories of information, but also as enzymes, which catalyze chemical reactions. The discovery of such "ribozymes" gave strong support to the idea that RNA might have both stored information and catalyzed reactions in the first living organisms—a hypothesis first put forth independently in the late 1960s by Carl R. Woese of the University of Illinois at Urbana–Champaign, Leslie Orgel of the Salk Institute for Biological Studies in La Jolla, California, and Crick himself.

If true, the hypothesis suggests that an "RNA world" may have preceded life as it occurs today. In such a world, RNA would have performed many functions that other molecules, including DNA and proteins, have now assumed. If such an RNA world preceded life's development, it would help explain how such biological functions as protein synthesis and genetic information storage and replication may have begun.

The history of modern thinking about the origins of life begins with the eighteenth-century naturalist Jean-Baptiste de Monet, chevalier de Lamarck, Charles Darwin's most distinguished predecessor. Darwin himself was reluctant publically to address the question of life's origin. But the idea that living organisms evolved from lifeless matter became widespread soon after the publication of Darwin's *Origin of Species* in 1859. Darwin expressed his private views on the matter in 1871, in a letter to the English botanist J.D. Hooker. Life, Darwin famously wrote, may have started in a

> warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc. present, that a proteine compound was chemically formed ready to undergo still more complex changes.

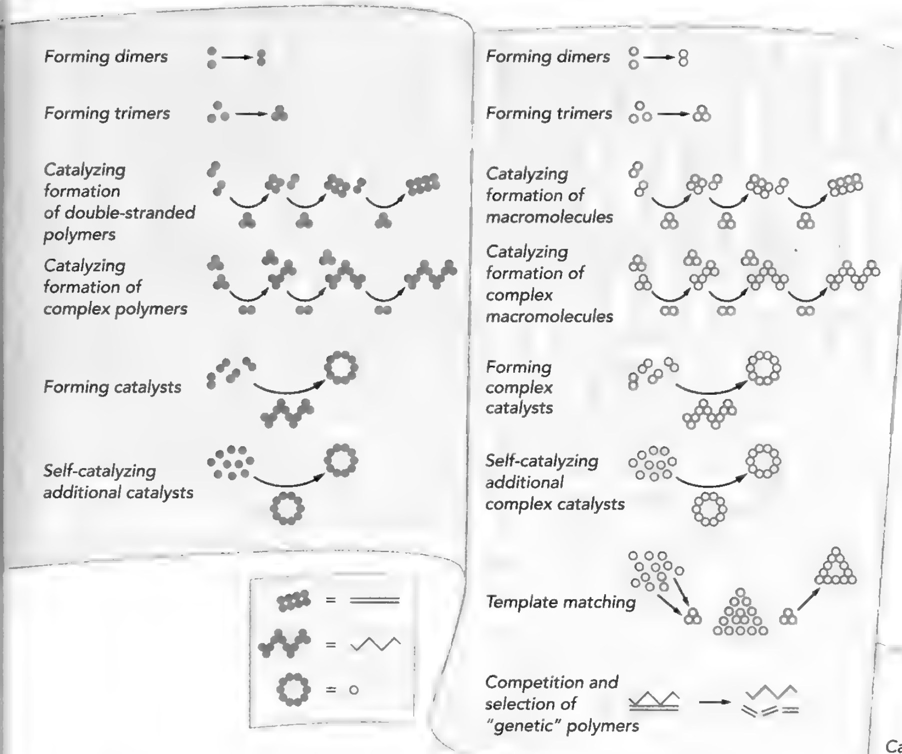
The nineteenth-century German zoologist and evolutionist Ernst Haeckel perhaps best epitomized the leading scientific beliefs after Darwin. The first life-forms, he contended, had been plantlike microorganisms, capable of photosynthesis, that had evolved directly out of nonliving matter according to physical laws.

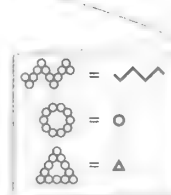
In 1924, the Russian plant biochemist and evolutionary biologist Aleksandr I. Oparin questioned Haeckel's scheme. Oparin could not reconcile his Darwinian view—that simple organisms had gradually evolved into more complex ones—with the prevalent belief that life had suddenly appeared on Earth with a self-sustaining metabolism. So he proposed an alternative scenario. He posited that a long period of abiotic synthesis on early Earth had caused organic compounds to accumulate in a prebiotic soup, which had preceded life. Oparin then described how organic molecules could have evolved, via simple, ubiquitous fermentation reactions, into precellular systems on the primitive Earth. Such systems, he maintained, could then have led to cells that survived without oxygen and fed on the prebiotic soup.

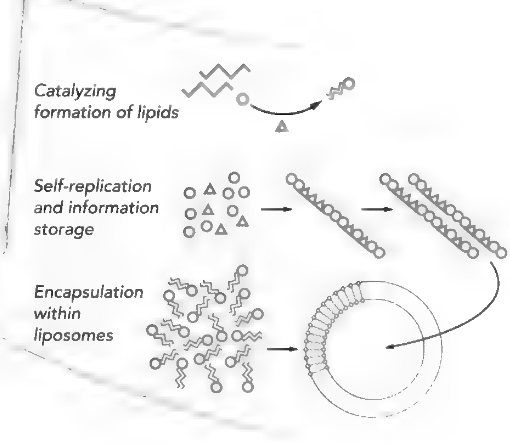
Not too surprisingly, that line of thinking has sparked disagreement. As recently as 1988, the German chemist Günter Wächtershäuser, now a patent attorney in Munich, proposed an alternative "iron-sulfur" hypothesis. Wächtershäuser's core insight was that when iron sulfide (FeS) mixes with hydrogen sulfide (H_2S) to form pyrite (FeS_2), the reaction releases copious quantities of hydrogen gas (H_2). With the release of the hydrogen, on Wächtershäuser's view, organic compounds could form from carbon dioxide in the atmosphere. Life began when self-catalyzing molecular systems emerged from the organic compounds. Experiments confirm that the formation of pyrite can indirectly yield a few organic compounds as well as ammonia (NH_3).

But compared with the variety of biochemical compounds synthesized in simulations such as Miller and Urey's, the process Wächtershäuser described gives rise to only a limited range of molecules. Moreover, the Miller-Urey apparatus sought to simulate Earth's real environment shortly after our planet formed from the primordial solar nebula. In contrast, there is little empirical support for Wächtershäuser's hypothesis.

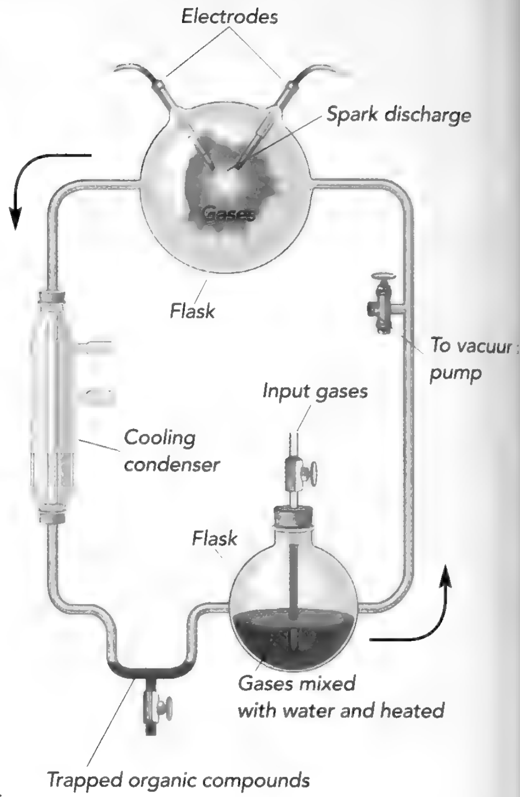
Unfortunately, since the Earth's geologic record from those early times is so sparse, the rocks cannot answer the kinds of questions raised by the Miller-Urey and Wächtershäuser experiments. Most rocks that are more than three billion years old have so thoroughly metamorphosed that life's precursor molecules are no longer detectable. There is no direct evidence of Earth's environmental conditions at the time of life's origin, either. No one knows the temperature of the early Earth, its ocean acidity, the composition of its atmosphere, or any other factors that







Life's precursor molecules built up over at most a few hundred million years. The schematic diagram indicates several kinds of chemical reactions that led, over perhaps several "generations" (blue, red, and green, respectively) to increasingly elaborate molecular complexes. (As the keys beneath the two leftmost panels indicate, the products of one generation become the building blocks for the next.) Among those complexes, some began to carry out functions associated with the basic molecules of life. At some stage, complex polymers emerged that could store and transfer information via template matching. Such "genetic" polymers ultimately became encapsulated within cell-like membranes formed by lipid molecules. The resulting cell-like complexes thereby housed self-replicating molecules capable of multiplying—and hence evolving—genetic information. Many specialists consider the emergence of genetic replication to be the true origin of life.



Stanley L. Miller is pictured above with his experimental apparatus that sought to simulate Earth's primordial conditions during life's molecular evolution. The apparatus, shown schematically at right, blended ammonia, hydrogen, methane, and water—thought at the time of the experiment to be the primary constituents of Earth's early atmosphere—inside a sealed loop of glass tubes and flasks. The gases, mixed with water vapor in the lower flask, flowed into the upper flask, where electrodes, simulating lightning, sparked the vapor. The circulating vapor then condensed and trickled into a collecting trap. After one week, Miller and Urey found that between 10 percent and 15 percent of the system's carbon had formed organic compounds, including many of the amino acids needed to make proteins. The photograph was made in the mid-1950s.

may have substantially affected early life. Nor is there any fossil record of entities predating the first cells.

In a sense, Miller and Urey were also heirs to a second tradition of scientific thought, distinct from that of Darwin, whose aim can be understood today as an attempt to synthesize molecules of prebiotic significance. Such experiments date back as far as 1807, with the work of the French chemist Joseph Louis Proust, as well subsequent chemists, including the Swede Jöns Jacob Berzelius, the Germans Friedrich Wöhler and Adolph Strecker, and the Russian Aleksandr Mikhaylovich Butlerov. All of them attempted to synthesize biologically related molecules under what today would be called primitive conditions—though they were not the conditions Darwin imagined in his "warm little pond."

True prebiotic simulations began with Miller and Urey, and others have followed in their wake. All of them confirmed that amino acids, purines, and pyrimidines—all molecules of biological significance—readily formed under atmospheric conditions thought to be similar to the ones present on the early Earth. Most likely, those molecules would also have formed in the prebiotic soup, along with many other biologically related compounds: urea and carboxylic acids, sugars formed from formaldehyde, and various hydrocarbons, alcohols, and fatty acids, including some known to develop into bilayered membranes—the probable precursors of cell membranes. In addition to all those molecules, other, extraterrestrial molecules may have spiced the prebiotic soup. They would have arrived on Earth aboard fragments of comets, meteorites, and interplanetary dust, as the chemist Juan Oró of the University of Houston first suggested in 1961.

Yet exactly how those simple organic compounds assembled themselves into more complex molecules, or polymers, and then into the first living entities remains one of the most tantalizing questions in science. Earth's primitive broth must have included a bewildering array of organic compounds, a virtual chemical wonderland that synthesized, disintegrated, and absorbed a wide variety of molecules, in ongoing cycles of transformation.

One feature of life, though, remains certain: Life could not have evolved without a genetic mechanism—one able to store, replicate, and transmit to its progeny information that can change with time. That condition, of course, does not imply that nucleic acids (the stuff of RNA and DNA) wriggled in the primitive oceans, ready to serve as primordial genes. Nor does it suggest that RNA arose completely assembled from simple precursors in a prebiotic soup. Rather, precellular evolution likely resembled a branching tree of chemical transformations. Some of the branches would have become evolutionary dead ends. Others would have grown in fits and starts toward the earliest living entities. It is also likely that Darwinian-style natural selection winnowed entire populations of molecules and chemical systems. From that perspective, the first entities that could replicate, catalyze, and multiply would have truly marked the origin of life and its evolution.

Surely, RNA meets all those requirements. But RNA is also highly unstable. A self-catalyzing, self-replicating RNA molecule is unlikely to have arisen spontaneously. So where did it come from?

The answer is not so clear. This difficulty has led to the suggestion that a pre-RNA world of primordial living systems predated and gave rise to the RNA world. Such a pre-RNA world would have spawned the first "genetic polymers" capable of encoding and perhaps transmitting information. If that view is correct, the denizens of a pre-RNA world may actually have initiated what is now called heredity. They, in turn, would have subsequently evolved through natural selection toward RNA.

To explore the possibilities of such reactions, Albert Eschenmoser, an organic chemist at the Eidgenössiche Technische Hochschule in Zurich, and his colleagues have modified nucleic acids to include various versions of ribose and other simple sugars. Still other investigators have synthesized similar polymers without ribose or phosphate. Did systems of such polymers predate the RNA world? The answer to that question remains unknown.

Precisely how the first genetic machinery evolved also persists as an unresolved issue. The hypothesis of a pre-RNA world does not presume that genetic polymers could evolve only from simpler genetic polymers, in a never-ending succession of molecular takeovers. But it does point toward a need to simulate, under plausible prebiotic conditions, the pathways that simple monomers and genetic polymers might have taken to become evolutionary precursors of RNA. Perhaps the best way to comprehend life's emergence is through the molecular dynamics, and evolution, of systems with "replicating entities," endowed with polymers that can store genetic information and replicate differentially.

Whether or not membranes enclosed such entities is also not yet clear. But as I mentioned earlier, lipids and other fatty acids were almost certainly present in the prebiotic soup. Thus cell-like enclosures may have been present as well. Nevertheless, it is reasonable to assume that protein synthesis and the encapsulation of machinery to replicate information did not originate until the RNA world emerged. As the molecular biologists Gerald Joyce of the Scripps Institute, Jack W. Szostak of the Howard Hughes Research Institute, and David Bartel of the Whitehead Institute for Biomedical Research in Cambridge, Massachusetts, among others, have shown, ribozymes alone can perform the reactions needed to construct key chemical bonds.

Taking into account the latest experimental evidence, it seems likely that abiotic synthesis generated the raw materials needed to assemble the first self-maintaining molecular systems capable of replicating. Even if the first living systems had little capacity to synthesize their own compounds, their primary sources of raw materials would have been organic molecules synthesized in the prebiotic soup. Perhaps the energy needed to enable these primitive systems to grow and reproduce came from cyanamide or other high-energy compounds.

Yet by the time RNA-based life appeared on Earth, the supply of raw materials needed to sustain life had probably become exhausted. This famine, so to speak, would have favored the natural selection of simple metabolic-like pathways that could supply materials needed to sustain simple living beings. Ribozymes may have helped maintain some metabolic pathways, until they eventually gave way to protein-based catalysts—that is, enzymes.

Extraterrestrial molecules may have spiced the prebiotic soup.

In spite of all of the scientific debates, the hypothesis that a prebiotic soup fostered an RNA world that then spawned life still offers the most coherent framework to explain life's evolution. The exact pathway for life's origin may never be known. Many gaps in understanding persist.

Yet, however imperfect it may be, today's evolutionary framework is rich enough not to require any appeal to the supernatural or to religious accounts such as those based on "intelligent design." Evidence of scientific incompleteness is not evidence for creationism. Although healthy disagreements on this subject will continue, scientists see such debates as challenges, not as reasons to abandon reason or data. The fact that people can reconstruct life's emergence at all, albeit with imperfect precision, should be cause for celebration: an intellectual achievement of the first rank in shedding so much light on one of the fundamental questions of existence. □

A Shell with a View

It takes a cool blood to feel the earth's warmth.

By Verlyn Klinkenborg

I was gone for more than a week before they found me. A rustling in the bean-field, heavy steps nearby. A shout—a boy's voice—more shouts. Thomas the gardener catches me up in his hands with sickening haste. I weigh six pounds thirteen ounces. He lifts me as though I weigh nothing at all.

Ground breaks away. May wind shivers in my ears. My legs churn the sky on their own. I look down on bean-tops. Down on the blunt ends of sheep-bitten grasses. Over one field, into the next, into the hop-garden beyond. Past thatch and tiles, past maypole, past gilded cock on the church tower. All in my eye, all at once. So far to see.

My week gone in two-score of their strides. Through the meadow. Past the alcove and down the brick-walk. Wicket-gate clicks shut behind us. Thomas sets me down beside the asparagus. All feet square on the ground again. Ferns just joining in a canopy above. Print of Thomas's warm fingers on my tiled belly, smell of tar and damp mould. The fuss the humans made when they found me. Escape of the Old Sussex Tortoise! Eight Days' Pursuit! Captured in Hampshire Bean-field!

"Out!" the boy shouted when they found me, stumbling over his heels. "Timothy got out!"

The boy is mistaken. There is no Out! Humans believe the asparagus forest is In! Fruit wall, laurel hedge. Melonground. They prey upon the distinction. But I am always Out. Among the anemones. On the grass-plot. In the shade of the Dutch-currant trees. Under young beans a week away.

And I was In there, too, as always. In, under unhedged stars, dark of the moon. Among chiding of field-crickets, stirring of long grasses, gleaming wind. Clap of thunder and din of hail. The honeyed smell of maples and sycamores in bloom. Beyond sight of humans. Within my beloved shell.

Great soft tottering beasts. *They* are Out. Houses never by when they need them. Drab furrows of person-scented cloth hang about them. False head of hair or kerchief or hat. Contrivance of hide or wood on the feet, or none at all. That mass of body and brainpan to heat and cool with their internal fires. Fleece, hide, feathers, scales, and shell all denied them.

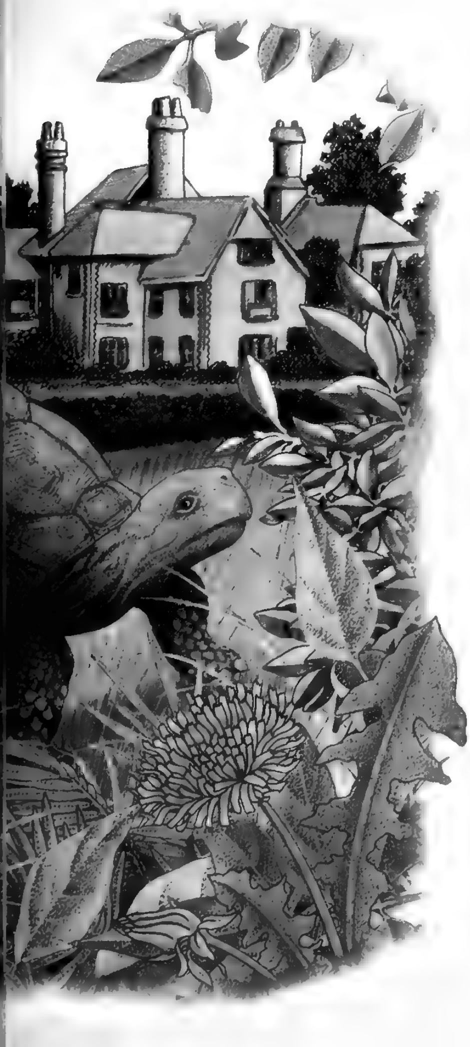
Humans of Selborne wake all winter. Above ground, eating and eating, breathing and breathing, talking and talking. Huddled close to their fires. Never a lasting silence for them. Never more

than a one-night rest. When they go down in the ground, they go down in boxes, for good, and only with the help of others standing round. Peering into the darkness of the cold earth they fear.

To humans, in and out are matters of life and death. Not to me. Warm earth waits just beneath me, the planet's viscous, scalding core. It takes a cool blood to feel that warmth, here at its circumference. The humans' own heat keeps them from sensing it. I drift for months—year's great night—floating on the outer edge of Earth's corona. The only calendar my blood, how it drugs me.

When autumn pinches, I dig. Stroke on one side. Stroke on the other. Slow as the hour-hand and just as relentless. Swimming in place, burrowing my body's length and depth. Ease in, out, adjust the fit. No rush. No rush. A last fitting. Air hole open. Stow legs. Retreat under roof of self. Under vault of ribs and spine.

Loose earth covers my back. Laurel leaves, walnut leaves, chalk soil, Dorton mould. I wait, then cease to wait. Earth rolls repeatedly through day and night. Layer of rime. The frost binds. Then snow, that friendly meteor. Kindly mantle of infant vegetation. Insulating all of us who cling to the soil. Who have not got too upright, too far from the native horizontal.



I rouse before I know I'm rousing. Hatched from the great egg of Earth. I blink and blink. Surprised to come up always just where I went down. To be the only hatchling. Surprised to find myself in the parish of Selborne, county of Southampton, garden of Mr. Gilbert White.

In this place, I am considered a sign of spring. Year after year Mr. Gilbert White notes the occasion. Records the date, the weather. Conjunction, at my arrival, of a bat, a redstart, a daffodil, a troop of shell-snails.

"Timothy the tortoise begins to stir," he writes; "he heaves up the mould that lies over his back."

Yes, the mould sometimes clings to my back as I rise in April. Mr. Gilbert White writes to nephew Samuel Barker.

"When a man first rouses himself from a deep sleep, he does not look very wise; but nothing can be more squalid and stupid than our friend, when he first comes crawling out of his hibernacula."

Who watches Mr. Gilbert White the curate wake? How wise does he look at bed-break?

Late on summer nights he comes into the garden. To see if the bat still flies. To observe by candle-light what moths and earwigs do in the dark. He clasps together the waist of a coat thrown over his open shirt. Hiding the animal within. Bare calves beneath, spindles of flesh. He does not look very wise, tossing stones into the hedge to make the sedge-bird sing its night song.

The humans talk to me. Talk and talk! They say what they think I'll understand. Hail me from a distance as though I were an unexcitable dog. Ask my thoughts about the barley, the wheat, the hops. About the weather down here. Forget themselves and keep talking. Remember themselves, pretend not to be talking. I keep my words hidden in the prow of my skull.

Mrs. John White crops vegetables for the kitchen. The curate's widowed sister-in-law. Cuts flowers for the table. Apologizes if she comes upon me meditating in the foliage. Stoops beside me. Lays a warm hand on my shell. A gentle touch. If I look up at her and say, "Now, then"—what comes next?

Mr. Ralph Churton, rector of Middleton Cheney, pays a summertime visit.

"Behold, the philosophic Timothy!" he says in passing. Raising an arm in salutation.

"Behold, the philosophic Churton!" I might say in return.

My voice would shatter his human solitude. The happiness of his breed depends upon it. The world is theirs to arrange. So they tell themselves. A word or two from me— "Now, then"—and they have all that arranging to do over again.

Can I trust Mr. Gilbert White with a syllable or two? He keeps his countenance turned toward the wild. Tunes his ear to nature's sounds. On foot or horseback every day, over the parish.

Hears the inward melody of a black-cap. Titlark as it feeds in a nearby pasture. Notes the songs down. Chamois linings to his breeches pockets. Seven pockets to his jacket. Papers in each of them. Sermons, carefully docketed receipts. Most recent letters. Scraps with dates and birdsongs. Halves of a broken plover egg in pocket.

> *The humans talk to me. They say what they think I'll understand.... My voice would shatter their solitude.*

Mr. Gilbert White rears the cucumber. Coddles the melon. Improves the polyanth and hyacinth. Wages endless war to keep peaches and nectarines and apricots whole and unblemished. Mellow wall fruit. Catches hornets with half-glasses of his own strong-beer. Birdlime on the end of a hazel twig. Treacle in a bottle. A bounty for wasps' nests and the capture of queens. Fifty thousand wasps destroyed in a single summer. Plundering invaders. "Felon race," he calls them. "Worthless souls"—a harsh judgment even from one who loves apricots. Nothing to be done about the humans who steal his wall fruit in the night.

Sixpence he offers for stories of the bird of many names: goatsucker, churn-owl, fern-owl, eve-jar, puckeridge, *Caprimulgus.* The Selborne boys deliver. What they saw, where and when. Neighbors, strangers, carry curiosities to him. Young snipe, three snipe's eggs. Common sea-gull still alive. Barnacle goose shot on a Bramshot pond. Butterflies, land-rail, half-fledged fern-owls. Three-pound trout, fine pike. Hairball from the stomach of a fat ox. Male otter, twenty-one pounds, taken in the rivulet below Priory Longmead. Last of its kind ever found in the parish.

Mr. Gilbert White visits the farmers to see what carcasses they nail to the ends of their barns. The countryman's museum. Two albino rooks, a peregrine falcon. Takes up the corpses in his Norway-doe gloves. Runs his fingers against the grain of the feathers. Death-clasped feet, sunken eye, flightless wings.

Sunday comes and he stands before the village in the stone shade of St. Mary's. The Reverend Gilbert White of Selborne in the County of Southampton. Curate for an absentee vicar. Clean white surplice. Plain, unaffected voice, learned accent. A gentle tone for climactic words. Easter.

"Let us therefore rejoice," Mr. Gilbert White says, reading from his own handwriting, "& be glad on this day of Christian triumph; for our last & most formidable enemy is now destroyed. All his attempts upon the Captain of our salvation were weak & vain; and all the power of Hell cannot now prevail against them that fight under his standard."

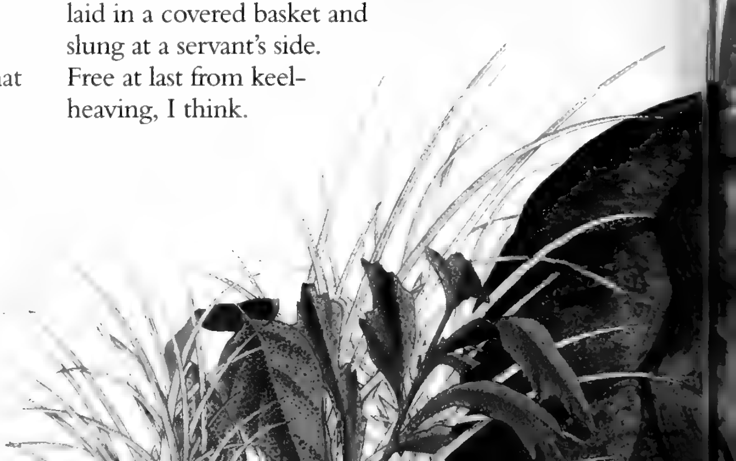
Death—the most formidable enemy—he says is now destroyed. "The lamb who was slain now liveth again," he believes. And so he says aloud to his parishioners. Though on this earth, the lamb who is slain is supper.

I met Mr. Gilbert White when he was twenty years old. The human year 1740, and I just come to England. Stolen from the ruins I was basking on. Jut of wall that had stood forever in sight of the Mediterranean Sea. In earshot of its mild tides. Thrust into a heavy bag by hand unseen. Stowed in darkness. Forgotten.

Then the wind set up a groaning in the ship's bowel where I lay. Keel rising and falling. Months perhaps, many days and weeks certainly. Plummeting toward somewhere unsurmisable. Toward England, as it happened.

Mr. Henry Snooke was the vicar of Ringmer. A churchman, like his nephew, Mr. Gilbert White. Business in the diocese of Chichester—a ballot—took Mr. Henry Snooke down to that sea-town one day. Chance encounter with a drunken sailor. Disconsolate tortoise wrapped in a scrap of soiled huckaback.

Half a crown swapped hands. One pair rope-chafed, salt-bitten. The other as smooth and white as Mr. Gilbert White's writing paper. I was laid in a covered basket and slung at a servant's side. Free at last from keel-heaving, I think.



Only to suffer a swift, brutal trot. Jouncing against the servant's hip for forty miles.

Arrived at a clot of houses on the shoulder of the downs, almost within scent of the sea. There to spend forty years. As Timothy! As Tortoise! Name bestowed by Mr. Henry Snooke. Exclamation by Mrs. Rebecca Snooke, his wife.

Brick-loam in the courtyard and clay beneath. Like living in a china basin. Tiny, miserable kingdom of one. I lived under a tuft of hepaticas. To hibernate was merely to daub myself in mire. Whole winters bare-backed, no soil stiff enough to cover me. Wrenched out of the proper seasons. Preposterous rain. Murderous frosts. Weather gone utterly awry. Blood with it. When to dig and when to rise. When to forget.

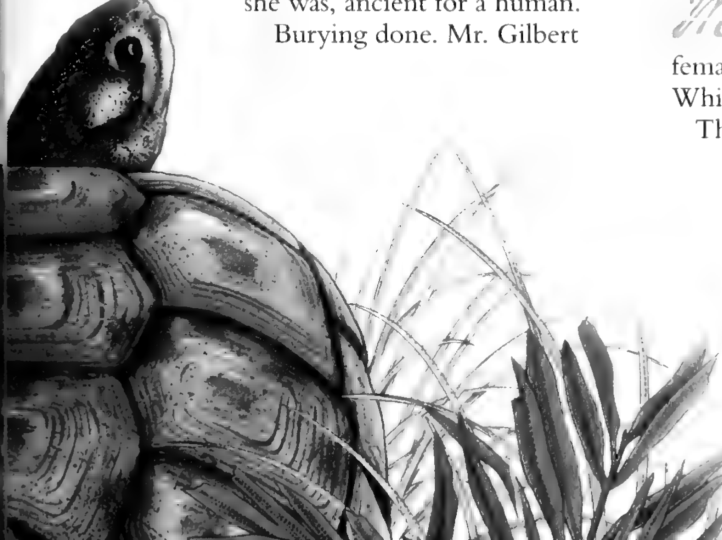
Great events of those years? Drought that undermined buildings and walls. Black spring of barren cows, whole dairies out of calf. Death by lightning of a coach-horse at grass. Dog-plague that killed them moping. Cannon of the King's review at Portsmouth—firings at Spithead— thundering about the house. Shaking the very earth.

And the demise of Mr. Henry Snooke. Twenty-three years of ignoring me after a chance purchase. A few obvious witticisms among friends. I was perhaps not discursive enough for his tastes.

Mr. Gilbert White was always struck by the fact that I recognized Mrs. Rebecca Snooke. She comes into the courtyard waving a lettuce-leaf. Calling from on high, "Timothy! Timothy!"

Who else could it have been? Only a few humans ever entered that courtyard. Was Mr. Gilbert White never struck by the fact that Mrs. Rebecca Snooke recognized me? If another of my kind had walked up to her on that pebbled path, could she have told the difference? Or would that tortoise have been *Timothy* too?

She died, late one winter. Early March. Earthed in still I lay. Aged nearly eighty-six she was, ancient for a human. Burying done. Mr. Gilbert White, nearly sixty years old, pries me out of my winter's depression in Mrs. Rebecca Snooke's brick courtyard. Not the picture of resurrection he preaches from the pulpit. He places me in a wooden box filled with earth and moss. Shipboard again for me, I think. Sea-borne back to the Cilician coast, to my antique city. Great wrong set right at last.



But no. Eighty miles in post-chaises. Not to the sea but to another clot of houses. To this place, to Selborne.

Mr. Gilbert White is a man of system. Naturalist, physico-theologist. He lives in inches and ounces and hours and degrees. Weather on March 20, 1780, the day I was first set loose in Selborne? Dark, moist, and mild. Fifty degrees. Southwest wind. Full moon. Crocuses in high bloom. A matter of record.

Mr. Charles Etty, newly returned from a sea voyage, and Mr. Gilbert White place the female tortoise upon the grass-plot. Mrs. John White at their side, garden shears in hand.

Thomas finds me among the poppies and sets me beside the stranger. Sunlight embraces her and everyone around her.

"A very grand personage!" Mr. Gilbert White says, stooping in admiration. "Very grand!" says the young sailor, who has seen her, far grander, where she naturally belongs.

I stand beside her. Nearly of a size, though her shell rises like a haystack above me. Not kin, not even kind. Yet near enough in nature to know that she is on the point of death. Pupils as dark as mine, as reflective, as pooling. I cannot say that she sees me. Already looking far within. A bright film comes over her eye. A fall of cobwebs against the sun. Legs arch and tense, and in the grass behind her she posits a single egg. Then dies. Sinking to rest on her tiled underbelly.

The egg lies inanimate. The limbo of her breed. On that African island, far away, it might have hatched some months from now, if it had survived predations of the nest. Here it can only spoil. Misguided by the aberrations of this climate.

Just another small corpse. Ten and a quarter pounds when weighed. What makes her different isn't her beauty or her scarcity or the distance she traveled in order to die here. It is this. The humans meant her to live.

Mr. Gilbert White, better than anyone, could guess what a probable surfeit of life lay before her. At his work-table, he clears the contents of her body. Any faint regret undone by the habit of the knife, the disassembly of such an interesting creature. Finds thirty eggs waiting. Cleans the carapace in the water-tub. Dries it carefully. Daubs the interior with one of his preserving concoctions and sets it on a shelf to dry. Then tea.

What will become of her shell? For a time it will stand for the whole tortoise—that lustrous being—in the memory of those who saw her living. In a Madagascar clearing. On a sunny Hampshire grass-plot in the month of July in the very last moments of her life. Then the shell becomes a curio, an uncommon object of unusual beauty or interest. Separate from the identity of the creature who grew it and wore it. Testimony to a type, not an individual. Perhaps it enters one of the grand apothecary shops that humans call museums. Exhibited to the curious at half a guinea a head.

In dying her sex became manifest. Not by comparison to the male of the species. My own case is far less unequivocal. Nest-making devoted to personal hibernation. No eggs buried under the monk's rhubarb or hidden at the foot of the muscadine vine. No seasons of the kind the mares enjoy, heat of the bitches, fervor of the gilts coming into their own.

And so Mr. Gilbert White has always *supposed* that I am male. Perhaps *she* would sound awkward for a tortoise. For the *Timothy* that Mr. Henry Snooke bestowed upon me so long ago in Chichester. A foolish assumption, a giving in to alliteration. Perhaps Mr. Gilbert White is also misled by the extravagance of my adventures. Perhaps a sympathetic assumption of companionship between us.

Timothy I have been this half century and more. *Timothy* I shall be forever after, thanks to Mr. Gilbert White's scribbling. But female I am and have always been since that moment in the egg decades ago. Female I was in that ancient country. This climate, this England, has neutered me.

Wicket-gate stands open. No one by. What is there to deter me? No surtout to pack. No mare to saddle. No instructions to Mrs. John White. No guineas or bank-notes to tuck into my tiled waistcoat. *Out* I go. Leaving only questions behind me.

"How?" The wicket-gate.

"Where?" The bean-field just short of the Pound Field.

"Why?" Above all, why?

Why is two questions. How could I leave such a paradise? After everything we gave you. Needs provided for. Immoderate safety. Kindness, even affection of its humans.

But also: what impels me? What spurs me on?

What is my motive in venturing forth? Mr. Gilbert White imagines only one.

Thomas catches me up in his hands. Returns me to the asparagus. Calm comes over the garden.

That evening Mr. Gilbert White takes up the pen to summarize *why.* Timothy, he writes, "had conceived a notion of much satisfaction to be found in the range of the meadow, and Baker's Hill; and that beautiful females might inhabit those vast spaces, which appeared boundless in his eye. But having wandered 'til he was tired, and having met with nothing but weeds, and coarse grass, and solitude, he was glad to return to the poppies, and lettuces, and the other luxuries of the garden."

He, indeed. The fable that humans love to tell. One bright morning the prodigal tortoise sallies forth. Rich in notions. Wealthy in prospect. But the world is an unrelenting place. Lonely. Coarse grass. Weeds. Imaginary females. Alas the comforts of home. Luxuries of the garden. Old settled ways. Rejoicing over the lost sheep. Fatted calf. A mammals' tale told to the sound of a crackling fire. Never leave home unsure of your next good blaze.

Mr. Gilbert White offers another version in that book of his. "The motives that impel him to undertake these rambles," he notes, "seem to be of the amorous kind: his fancy then becomes intent on sexual attachments, which transport him beyond his usual gravity, and induce him to forget for a time his ordinary solemn deportment."

Humans have their motives. As many as they care to name. Reason is a warehouse full of motives. But only two—says the naturalist—can belong to the viper and the owl. Only love and hunger to drive the swifts and martins and all the beasts of Selborne. The urge "to perpetuate their kind." And "to preserve individuals."

How, the naturalist begins to understand, after years of study. He records the *when* and *where* and *which* of the birds of passage, beasts of the field. Those are the very questions that system is poised to answer. But *why* will never be solved by system. No number of small corpses, dissected, tagged, and preserved, will ever begin to answer *why.*

How the nightingale sings. Pitch of the notes. Melody of the song. Structure of the voice box. But never fully the nightingale's *why.*

Today. Cold dew, louring clouds. Warming, softening. Iron going out of the ground at last. Sun less reluctant. Summer promising and overdue. Men wash their sheep. One by one. Ready the fleece for shearing. Ewes and wethers flow past dogs and men in the fields. Flat nasal peals shoal over the parish. Whistles of men. The very voice of mid-June.

Mr. Gilbert White. In his bed-shirt at the window above the kitchen. There for only a moment a few days past. Face washed by illness.

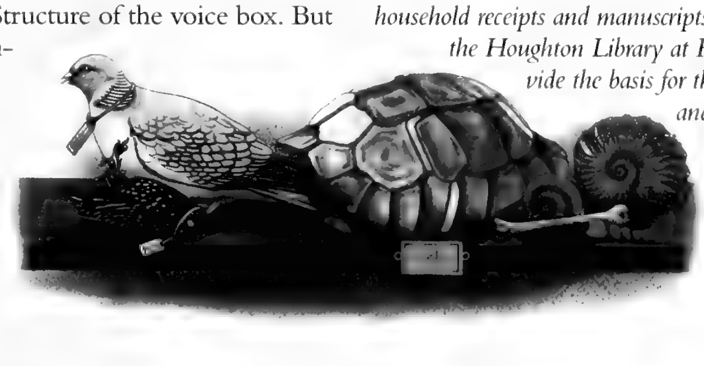
His plans are laid. To lie in his bed a little longer. To be borne from St. Mary's by six day-laboring men with families to raise. Six shillings each for a short morning's service. To be placed in a grave in the natural ground in the shade of the church-walls. Simple stone. "G. W." and the numeral of a day in June in the human year 1793.

The naturalist in Mr. Gilbert White will watch as closely as the cleric in him for the approach of that interesting moment. Quiet dissolution of self. Mrs. John White at his bedside. Warm, strong hands on his. And Thomas. Man, servant, and gardener to him these forty years. Standing beside the window. Looking now at the garden and the Great Mead and Hanger beyond it. Now at the form in the bed. Outside, the whetting of a mower's scythe on an early, dewy morning. Sound his master rejoiced in.

In their presence, the answer to one of Mr. Gilbert White's lifelong questions comes upon him. Merely human at last. One earthly parish only.

HISTORICAL NOTE: *This is a true story. Timothy was a tortoise from the Turkish coast, a member of a subspecies of* Testudo graeca *that still lives near the Byzantine ruin called Anemurium. Timothy died a year after her owner did, having lived in English captivity for sixty-four years. Her shell is preserved in the Natural History Museum in London (its shape shows that she was indeed female).*

Born in 1720, Gilbert White was the curate of Selborne, a Hampshire town about forty miles southwest of London. From 1768 until his death, in 1793, he kept a spare but detailed natural history journal. An edited version was first published in 1931. He also wrote The Natural History and Antiquities of Selborne, *published in 1789. These and other documents, including White's household receipts and manuscripts of his sermons held at the Houghton Library at Harvard University, provide the basis for this portrait of Selborne and the life around it.* □



This essay is adapted from Timothy; or, Notes of an Abject Reptile, *by Verlyn Klinkenborg, which is being published this month by Alfred A. Knopf.*

Going with the Flow

An underground stream links two scenic spots.

By Robert H. Mohlenbrock

Bussell Branch streambed, at times dry, leads to a cave in Grand Gulf, Missouri. Stream waters that vanish underground here re-emerge at Mammoth Spring, more than seven miles away.

As natural attractions "worth a detour" (as the guidebooks have it), Grand Gulf and Mammoth Spring live up to their names. They also share a physical connection, though they lie miles apart in two different states. But more on that connection later: my travels took me first to Grand Gulf State Park, in southern Missouri. Standing on the edge of a rocky limestone bluff, I surveyed a canyon 135 feet deep, nearly a mile long, but nowhere more than 200 feet wide. This was Grand Gulf, whose narrow proportions have earned it the nickname "Missouri's Little Grand Canyon."

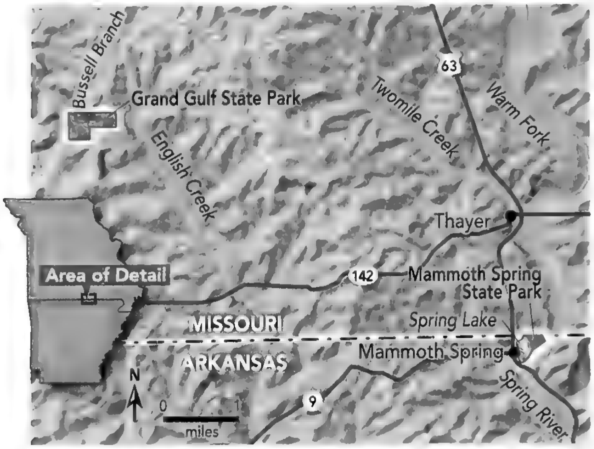
Grand Gulf is a feature of the Ozark Plateau, a 50,000-square-mile region of low mountains, caves, dry upland forests, clear rocky streams, and sinkhole ponds that extends across central and southern Missouri, northern Arkansas, and neighboring parts of Kansas and Oklahoma. In the region surrounding the canyon most of the rocks are dolomite and other forms of limestone, formed 450 million years ago by deposits at the bottom of a shallow sea. Over the ages, streams carved the surfaces of those porous rocks and trickled through cracks, slowly creating underground passages. At the same time, the limestones underground were gradually being dissolved away, causing the water table to fall and turning the upper passages into air-filled caves. In places, the cave roofs collapsed, leaving sinkholes on the surface. Such depressions, which are usually small, are scattered across the Missouri Ozarks. The ones that lack good drainage fill up to form sinkhole ponds.

Water from Bussell Branch contributes to the output of Arkansas's Mammoth Spring, whose waters cascade over a dam built in 1888 from hand-quarried limestone.

Grand Gulf is kin to these depressions, but its size puts it in a class by itself. It was created when the roof of a huge cave collapsed, apparently in sections, sometime during the past 10,000 years. Chunks of the cave roof are strewn across the bottom of the chasm; one section of rock that did not collapse forms a natural bridge that spans a gap of 200 feet.

The drastic change in topography engendered by the collapse diverted a nearby stream into the canyon, where it was "pirated," or captured, by existing underground passages. Called Bussell Branch, the stream flows through Grand Gulf until it disappears into the mouth of a cave at the lower end of the canyon.

Although bare patches of limestone lie all around the rim, enough soil accumulates in small surface depressions to support low-growing plants; trees and shrubs gain a firm foothold by sending their roots into cracks in the rock. The rim is well exposed to sunlight, so the flora must tolerate dry conditions. Some of the trees and shrubs have thick, leathery leaves covered by a waxy cuticle that prevents excessive loss of water on the hottest days. To my surprise, at one place, clinging tenaciously to the edge of the cliff, I saw a shrub known as ninebark, a member of the rose family. Usually it grows along Ozark streams, and in



VISITOR INFORMATION

Grand Gulf State Park
Route 3, Box 3554
Thayer, MO 65791
417-264-7600
www.mostateparks.com/grandgulf.htm

Mammoth Spring State Park
P. O. Box 36
Mammoth Spring, AR 72554
870-625-7364
www.arkansasstateparks.com/parks/park.asp?id=25

fact it is considered a wetland species.

In 1921 a tornado churned through the area, uprooting trees and blowing some of them into the canyon. Downed trees washed into the entrance of the underground cave, largely blocking it. Nowadays, after heavy rains, additional debris accumulates in the cave entrance, and Grand Gulf can fill quickly with water, sometimes to a depth of nearly a hundred feet. Eventually, though, the ponded water does drain away, and in fact the streambed is often dry. The cave entrance, once open to exploration, remains, by most accounts, impenetrable to human adventurers.

In 1967, Tony Aid, then a high school student from nearby West Plains, placed dye in the water of Bussell Branch where it entered the underground cave. After several days, the dyed water appeared more than seven miles to the south in Mammoth Spring, Arkansas.

Fed in part by the water from Grand Gulf, Mammoth Spring flows at an average of 9.78 million gallons an hour. Emerging with a constant temperature of 58 degrees, the spring is the source for beautiful Spring Lake, a main attraction of Mammoth Spring State Park. Because the spring vent is eighty feet below the surface of the lake, however, there's no bubbling springwater to be seen. From the lake, which was formed by damming, the waters join Spring River, popular with trout anglers.

In the nineteenth century a town called Head of the River (now called Mammoth Spring) arose near the spring. A gristmill was built there to tap the spring's water for power. In 1886 the railroad line came to town. The original train depot is now an added attraction in Mammoth Spring State Park.

ROBERT H. MOHLENBROCK is a distinguished professor emeritus of plant biology at Southern Illinois University Carbondale.

Habitats

Dry forest Several oaks dominate the dry rim of Grand Gulf, including blackjack oak, chinquapin oak, northern red oak, post oak, scarlet oak, and southern red oak. Other trees include black cherry, red cedar, shagbark hickory, and winged elm. Among the shrubs are dwarf hackberry, farkleberry (a kind of blueberry), and (though a wetland species) ninebark. A common low-growing plant is poverty grass, readily recognized by the curled-up leaves at its base. Spring wildflowers include downy phlox, pussytoes, rose verbena, and stiff bluets. Among the summer and autumn bloomers are blue wood aster, goat's rue, pencil flower, scurf-pea, spreading aster, woodland sunflower, and a wiry-stemmed member of the mint family known as dittany.

Where the cliffs make enough shade, the moister conditions support black gum, Carolina buckthorn, flowering dogwood, persimmon, redbud, shagbark hickory, white ash, and white oak.

Canyon bottom If you make it down to the bottom of Grand Gulf (there is a trail with stairs), you'll find American elm, bitternut hickory, black willow, blue beech, box elder, cottonwood, honey locust, pawpaw, and sycamore. Spicebush is the most common shrub; among the more scattered ones is American bladdernut. Wildflowers along the stream include bitter cress, ditch stonecrop, hooked buttercup, pale corydalis, seedbox, small-flowered crowfoot, white avens, and various kinds of smartweed.

Lake The water in Spring Lake is so clear that waterweed, an aquatic plant, is visible floating just beneath the surface. Watercress, a common plant in springwater, is plentiful. Numerous smartweeds, as well as false nettle, nodding beggar ticks, and water purslane grow in muddy areas along the shoreline.

By Laurence A. Marschall

Us and Them: Understanding Your Tribal Mind
by David Berreby
Little, Brown and Company, 2005; $26.95

"The stereotype," as the journalist and political commentator Walter Lippmann wrote in his 1922 book, *Public Opinion,* "saves time in a busy life," enabling all of us to quickly establish how we should relate to others. Does the woman in the maroon coat mean well or ill? Is she an employee or a customer, a student or a teacher, a police officer or a shoplifter? A second's glance often suffices to tell. The downside, of course, is that people are not always what they seem at a glance: the tattooed man in the motorcycle jacket may well be chairman of the board; that earnest, clean-cut chap may be a serial killer. In its worst form, stereotypical thinking leads to hate crimes and acts of terrorism. At its very least, writes Lippmann, the stereotype "tends to preserve us from all the bewildering effects of trying to see the world steadily and see it whole."

David Berreby's book is an eloquent effort to view the world steadily and whole. Human "kind-mindedness," as Berreby sees it, however strongly it may seem linked to social and political experience, is ultimately rooted in behavioral genetics. No animal can survive for long without being able to distinguish members of its own species from predators, and nature rewards individuals that can effortlessly tell the nutritious bugs from the poisonous ones. Socially speaking, natural selection favors the ability to distinguish kin ("our family") from strangers, because our genes profit from helping our blood relatives survive.

That tendency is particularly apparent in primates, whose social world is notably convoluted and complex. The seminal work of Frans B.M. de Waal, a primatologist at Emory University in Atlanta, for instance, has demonstrated that chimpanzees have elaborate protocols for dealing with unfamiliar individuals. Not only do the chimpanzees react to apes outside their social group, but when they interact with people, they also view with suspicion any person they don't recognize as part of the group they see every day. When we humans divide the world into "us" and "them," we're just doing what comes naturally.

Jews and non-Jews alike wear yellow stars at a protest against a neo-Nazi desecration of Jewish graves in Carpentras, France. Among the protesters, the yellow stars were intended to mock and subvert a well-known symbol of the Nazi effort to create divisions between "us" and "them."

Berreby suggests that a little science might help people overcome such primate tendencies toward Manichean thinking. By its strict rules of evidence and its insistence on expressing differences not as yes-or-no statements but as degrees of confidence and uncertainty, science provides an effective antidote to false perceptions of "us" versus "them." For example, according to Berreby, DNA analysis gives the lie to commonsense ideas about race:

> Genetically, almost all variations in human DNA are found in all races. As the chemistry of ink on your money gives no clue to its economic value, so human genetics doesn't support today's notion of race.

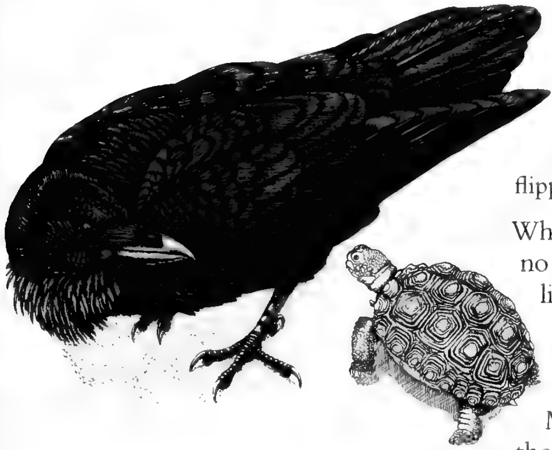
Nor does science recognize any genetic or physiological basis for divisions of people by nation, class, ideology, or religion—a fact that perceptive individuals have known for centuries.

Berreby argues for diversity and tolerance, hardly a novel position, but one resonant with the insights and sentiments of wise men since the dawn of civilization. What makes his argument powerful is the wealth of information he has marshaled, from disciplines as diverse as molecular genetics, neurobiology, quantitative history, and social psychology. But what makes his book so poignant is that despite the wealth of data pointing in his direction, so much political capital is being spent these days in accentuating and perpetuating our differences, instead of in trying to understand, accommodate, and eventually overcome them.

In the Company of Crows and Ravens
by John M. Marzluff and Tony Angell
Yale University Press, 2005; $30.00

Crows and ravens, among the commonest of birds, command our attention more insistently than do any of our other flying friends. Sparrows hardly enter our peripheral vision, pigeons annoy us, but the black-feathered corvids surprise us, instruct us, and intrigue us.

The human fascination with crows and ravens has deep roots in history. They are the tricksters of Native American myth, the inscrutable specters of Poe's midnight reverie, and the wisecracking comedians of such children's



Raven encountering a desert tortoise, from In the Company of Crows and Ravens

classics as *Dumbo.* "We know of no other animal that so consistently and thoroughly has affected our art, religion, and science," write John M. Marzluff and Tony Angell, with a conviction that borders on obsession.

What makes crows and ravens so special? Corvids have more brain mass per unit of body mass than any other bird group except the macaw, a ratio more in line with that of primates than with that of their less well-encephalated cousins. They engage in complex social interactions, teaching their young survival skills beyond the ones acquired by instinct and communicating with an expressive system of more than eighty distinct calls. If trained properly, crows and ravens, like macaws and parrots, can mimic human speech with startling effectiveness.

Corvids can even do math. In one convincing experiment, an animal behaviorist trained western jackdaws, close cousins of crows and ravens, to turn over boxes covering food rewards until five rewards had been retrieved. That the birds were actually counting became apparent when one of the birds turned over boxes that revealed one, two, one, and zero items in succession. After obtaining these four rewards it returned to its cage, an apparent failure. But it quickly returned to the box line, sidled up to the original first box and bowed once, then went to the second box and bowed twice, and then bowed once in front of the third box. After these four bows, which seemed to represent a mental recounting of the previously obtained rewards, the bird went to the fifth box, flipped it over, and got the last tidbit.

Where there are crows and ravens, no doubt, you'll also find avid fans like the authors—at least one of whom, to judge by the pictures in the book, sports a "CORVID" vanity plate on his Corvette. Marzluff, a wildlife biologist at the University of Washington in Seattle, is the scientific heavyweight of the pair, but Angell, a freelance artist and writer and an avocational birder, has contributed dozens of exquisite ink drawings of the black birds in a variety of circumstances, admirably complementing the descriptive text. If corvids could read—and it seems they can do damn near everything else—they would surely find this book as entertaining and instructive as this human does.

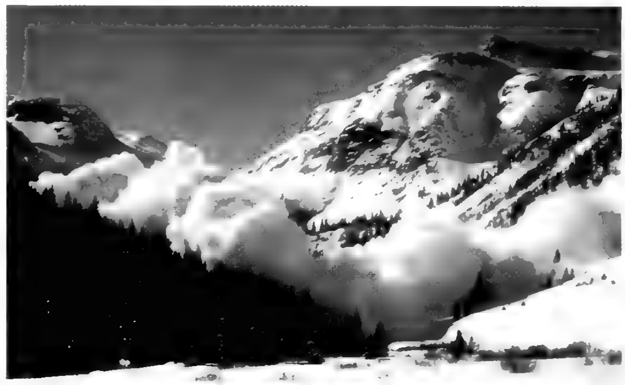
Snowstruck:
In the Grip of Avalanches
by Jill Fredston
Harcourt, Inc., 2005; $24.00

Snowstruck, a kind of sequel to Jill Fredston's book *Rowing to Latitude,* answers a question her earlier knuckle-biter may have left hanging. Why would any sane person spend her summers rowing a small boat through heavy seas along thousands of miles of desolate Arctic coastline? The answer: because, compared to what she does in the winter, a summer dodging icebergs and polar bears is pure relaxation.

Fredston and her husband, Doug Fesler, live in the mountains just outside Anchorage, Alaska. Their cabin is so exposed to the elements that when they aren't enjoying the view, they are battling hurricane winds and blinding snowstorms. For the past eighteen years the couple has run the Alaska Mountain Safety Center, an institution devoted to training alpinists, assessing avalanche threats, and helping out with rescues. They bring to their work a set of unique

and complementary talents: Fredston must be one of the few people in the world with a master's degree in polar and ice studies from the University of Cambridge. Fesler seems to be a self-taught avalanche guru who can look at a snowdrift and immediately visualize the internal stresses and strains that hold it in place; "thinking like an avalanche" is what Fredston calls it. Both are skilled winter mountaineers, as comfortable in crampons and climbing harnesses as most people are in La-Z-Boy recliners.

Snowstruck tells the stories of the rescues they have taken part in and the avalanches they have analyzed. Much of what Fredston recounts is pretty grim—experienced skiers who push themselves a tad too close to the edge of an unstable slope, homesteaders buried by a collapsing mountainside. In eighteen years, Fredston confesses, she has "chiseled dozens of bodies from avalanche debris and never . . . dug a single person out alive."



Controlled avalanche, triggered by explosives, harmlessly releases dangerous accumulations of snow near a highway in Colorado before the snow gives way without warning.

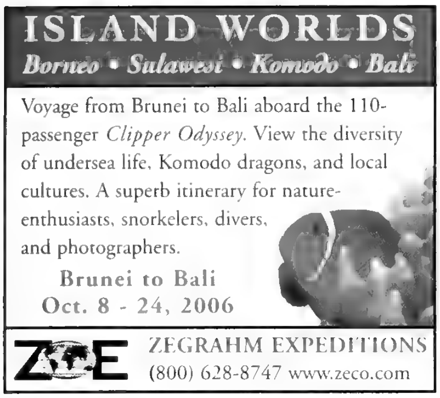
Understanding these tragedies, however, is a way of predicting the avalanche perils of the future and, one hopes, of preventing prudent Alaskans from taking unexpectedly high risks. Avalanches, Fredston knows, start when slabs of dense snow detach from the layers beneath them, most often on slopes angled at between thirty and forty-five degrees. What happens next depends on the track taken by the detached slab as it accelerates. How much more snow does it pick up as it slides? Does it run out into a wide area or a narrow gulch? The leading edge of the avalanche can stir up a billowing powder blast so powerful that the few trees left standing after the snow passes will bear deep scars of pebbles that were blown, forty feet above the ground, like shrapnel in the snow-driven wind.

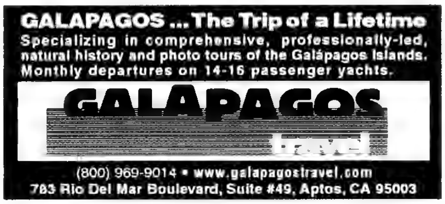
Fredston and Fesler can predict avalanches not only because they know the snow so well, but also because avalanches tend to recur in the same spot. The couple is often called in to create their own avalanches, removing dangerous snowpacks to make roads safe for traffic or to clear the backcountry for rescue parties or recreational activities. The author, who grew up in a placid suburb of New York City, now finds herself hanging out the open door of a helicopter, tossing sticks of dynamite into threatening snowdrifts while a blizzard rages below. "A colleague once lit a charge and threw it out the open door of a helicopter, only to have a blast of wind sling the bomb back in," she writes. A mad scramble to find the dynamite ensued, and the fuse had only seconds to burn when it was tossed back out into the storm.

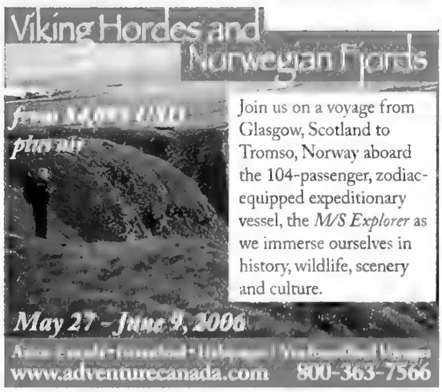
Fredston doesn't hide her opinions about the forces of nature and the follies of humankind, but I wouldn't read her book for its uplifting thoughts. If you have loved ones, you don't have to live in avalanche country to know that life is fragile. Having a free winter evening, a warm fire, and a hot drink is reason enough to curl up with a rousing adventure book like *Snowstruck*.

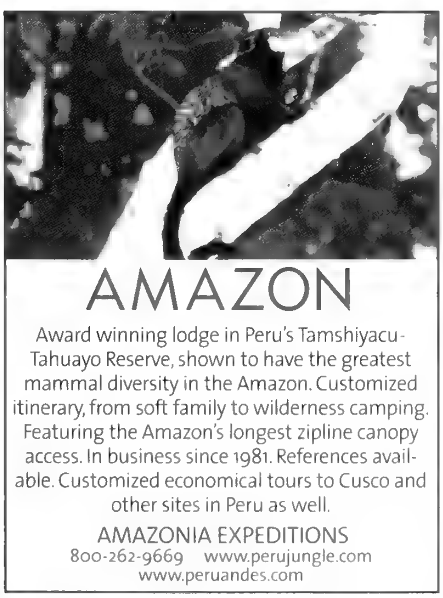
LAURENCE A. MARSCHALL, author of The Supernova Story, *is W. K. T. Sahm Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy. He is the 2005 winner of the Education Prize of the American Astronomical Society.*

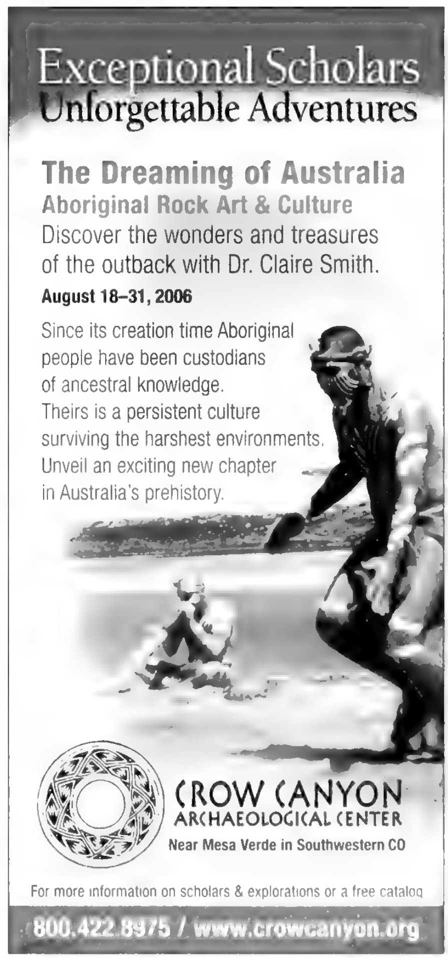
EXPLORER GUIDE











Wave Files

By Robert Anderson

For anyone not affected by the Indonesian tsunami, memory of the catastrophe has begun to fade. Nevertheless, a year later, it's worth remembering the tragedy and asking what's being done to save people from future killer waves. The tsunami of December 26, 2004—triggered by one of the largest earthquakes recorded since 1900—spread outward at nearly 500 miles per hour, leaving nearly 300,000 people dead across the Indian Ocean.

Space-borne cameras recorded the destruction in remarkable detail. Go to DigitalGlobe (www.digitalglobe.com/tsunami_gallery.html) for before-and-after images of coastland that turned brown as the waters swept them clean of vegetation. Scroll down to the images of Kalutara, in Sri Lanka, where swirling floodwaters surged in violent retreat from the beaches. The Center for Remote Imaging, Sensing and Processing at the National University of Singapore has more satellite images (www.crisp.nus.edu.sg/tsunami/tsunami.html). Another site at NASA has *Landsat* 7 images of the hard-hit Sumatran coast, where monster waves plowed inland for a mile or more (www.nasa.gov/vision/earth/lookingatearth/Landsat_Tsunami.html). A variety of sites inventoried at serc.carleton.edu/NAGTWorkshops/visualization/collections/tsunami_other.html give a feel for how the waves propagated through the ocean. Click on "Tsunami Visualization Collection" in the box near the top for an array of animations that show how the catastrophe unfolded. For example, scroll down to "Tsunami Generation" near the bottom for a QuickTime video showing how slippage in the Earth's crust can lift huge volumes of water to form the destructive waves.

By chance, the Indonesian event was the first major tsunami detected from space as it took place. Unfortunately, it's not practical to rely on satellites to detect tsunamis, primarily because a huge orbiting fleet would be needed for appropriate coverage. Future systems are more likely to deploy an array of pressure sensors on the ocean bottom, which have already proved capable of detecting tsunami waves only half an inch high.

For an animation of that kind of system, go to NOAA's Deep-ocean Assessment and Reporting of Tsunamis (DART) page (www.pmel.noaa.gov/tsunami/Dart/dart_ms1.html), or go to www.ndbc.noaa.gov/Dart/dart_map.shtml for a map of the U.S. system that has been operating in the Pacific since late 2003. The new Indian Ocean warning system, scheduled to become operational this year, is described in *National Defense* magazine (www.nationaldefensemagazine.org/issues/2005/Nov/Indian_Ocean.htm).

A page on the National Academy of Engineering's site (www.nae.edu/nae/bridgecom.nsf/weblinks/MKEZ-6DJKL9?OpenDocument) presents five articles by tsunami experts on what they've learned from the Sumatra wave and prospects for better warning systems. At tsunamilessons.blogspot.com citizen Doug Carlson keeps close track of what the U.S. government is doing to ensure early notification, particularly near his home in Honolulu. And Atlantic-coast dwellers shouldn't be complacent either. Go to Steven N. Ward's site (es.ucsc.edu/ward/) and click on "Computer Simulations." Ward, a geophysicist at the University of California, Santa Cruz, has posted animated movies of waves caused by historic and hypothetical landslides and asteroid impacts, some affecting the East Coast. Under the "Impact Tsunami Simulation Movies" menu, select the movie of the Chicxulub event, and you'll see the behemoth wave that accompanied the end of the age of dinosaurs.

Robert Anderson is a freelance science writer living in Los Angeles.

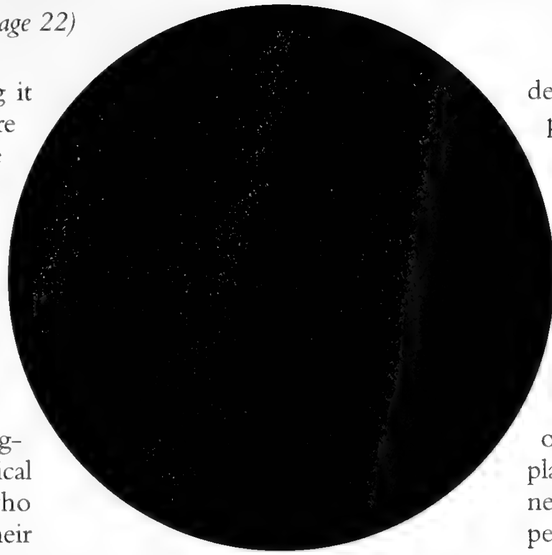
 (*Continued from page 22*)

state, something must be liberating it as fast as it's being consumed. Here on Earth, the liberation is traceable to life. Photosynthesis, carried out by plants and many bacteria, creates free oxygen in the oceans and in the atmosphere. Free oxygen, in turn, enables the existence of oxygen-metabolizing creatures, including us and practically every other creature in the animal kingdom.

We earthlings already know the significance of Earth's distinctive chemical fingerprints. But distant aliens who come upon us will have to interpret their findings and test their assumptions. Must the periodic appearance of sodium be technogenic? Free oxygen is surely biogenic. How about methane? It, too, is chemically unstable, and yes, some of it is anthropogenic. But methane is also produced by bacteria, cows, permafrost, soils, termites, wetlands, and other living and nonliving agents. In fact, at this very moment, astrobiologists are arguing about the exact origin of trace amounts of methane on Mars and the copious quantities of methane detected on Saturn's moon Titan, where cows and termites surely do not dwell.

If the aliens decide that Earth's chemical features are sure evidence for life, maybe they'll wonder if the life is intelligent. Presumably the aliens communicate with one another, and perhaps they'll presume that other intelligent life-forms communicate too. Maybe that's when they'll decide to eavesdrop on Earth with their radio telescopes to see what part of the electromagnetic spectrum its inhabitants have mastered. So, whether the aliens explore with chemistry or with radio waves, they might come to the same conclusion: a planet where there's advanced technology must be populated with intelligent life-forms, who may occupy themselves discovering how the universe works and how to apply its laws for personal or public gain.

Beginning in 1995, my planet-hunting colleagues got busy. Since then, they've discovered more than 150 exoplanets, and there's plenty more where they came from. After all, the known universe harbors some 100 billion galaxies, each with some 100 billion stars.



Earth (pale dot near center of light ray at right) as photographed in 1990 by Voyager 1*, from a distance of 4 billion miles*

The search for life drives the search for exoplanets, some of which probably look like Earth—not in detail, of course, but in overall properties. Those are the planets our descendants might want to visit someday, by choice or by necessity. So far, though, nearly all the exoplanets detected by the planet hunters are much larger than Earth. Most are at least as massive as Jupiter, which is more than 300 times Earth's mass. Nevertheless, as astrophysicists design hardware that can detect smaller and smaller jiggles of a host star, the ability to find punier and punier planets will grow.

In spite of the 150-planet tally, planet hunting by earthlings is still in its horse-and-buggy stage, and only the most basic questions can be answered: Is this thing a planet? How massive is it? How long does it take to orbit its host star? No one knows for sure what all those exoplanets are made of, and only a couple of them eclipse their host stars, permitting cosmochemists to do their thing.

But abstract measurements of chemical properties do not feed the imaginations of either poets or scientists. Only through images that capture surface detail do our minds transform exoplanets into "worlds." Those orbs have to occupy more than just a few pixels in the family portrait to qualify, and a magazine reader should not need a caption to find the planet in the photo. We have to do better than the pale blue dot.

Only then will we be able to conjure what a faraway planet looks like when seen from the edge of its own star system—or perhaps from the planet's surface itself. For that, we will need spaceborne telescopes with stupendous light-gathering power.

Nope. We're not there yet. But perhaps the aliens are.

Astrophysicist NEIL DEGRASSE TYSON *is the director of the Hayden Planetarium at the American Museum of Natural History. His* Natural History *essay "In the Beginning" (September 2003) won the 2005 Science Writing Award from the American Institute of Physics. An anthology of his* Natural History *essays will be published in 2006 by W.W. Norton.*

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Cosmic Cosmetics

Astronomers have found lots of nail-polish remover and sunless tanning lotion in space.

By Charles Liu

It's Earth-year 6526 and you find yourself cruising interstellar space. But—drat!—your nail polish is chipped. And how will you ever restore your earthy, bronze-goddess glow so far from the tanning light of any sunlike star? Great Hubble's ghost, what's a person to do?!

My futuristic scenario is, of course, a space-age joke, but your distress would be short-lived: Drugstore beauty products really do float around in space, sort of, and recent observations by two teams of astronomers—one led by Douglas N. Friedel, the other by Susanna L. Widicus Weaver, both at the University of Illinois at Urbana–Champaign—suggest that you won't have to comb the cosmos for such beauty aids. Nail polish remover—acetone—just what you need before you repaint your nails, is present in abundance, along with its distant chemical cousin 1,3-dihydroxyacetone (DHA), the active ingredient in sunless tanning lotion. The two chemicals have been detected before now, but the new work shows that plenty of both are suspended in the vast clouds of gas and dust that surround newly formed stars.

At first blush, the detection of large amounts of interstellar acetone and DHA may seem like nothing more than amusing curiosities. Actually, finding any complex molecule is serious science, and organic compounds such as acetone and DHA pose a special interest. Learning how much of each species is out there, as well as where they can be found, may be important for understanding the origins of life.

Astrochemists have detected more than 130 molecular species over the years, including alcohol, antifreeze, various hydrocarbons, and even sugar and salt. In spite of the numbers, finding molecules in space is very hard work.

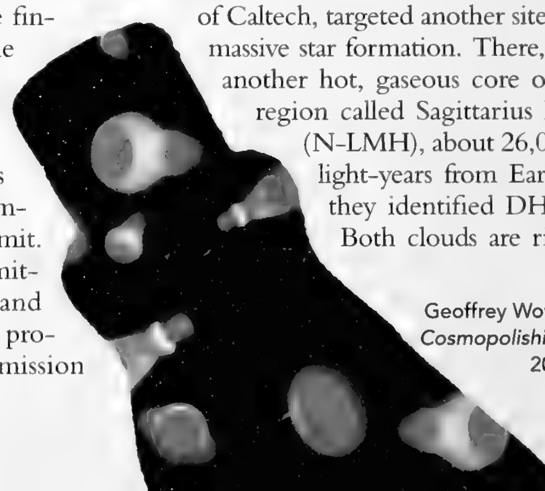
Normally when a gas glows, the glow signals that the gas has been heated, perhaps by a nearby star, perhaps by the gravitational collapse of the cloud of gas itself. When gas particles are heated, they typically absorb energy from their surroundings, then re-emit it as light in a spectrum of distinct colors, or wavelengths, that is characteristic of the gas and identifiable by astronomers.

Unfortunately, though, interstellar nebulae, particularly the ones that harbor molecules, can include dozens or even hundreds of different kinds of gas particles. So sorting through their combined, overlapping spectra to identify one kind of molecule is a little like picking out a single fingerprint on a subway turnstile after rush hour.

As if that weren't challenging enough, the more complicated the gas particles are, in general, the more complicated the spectra they emit. The simplest spectra are emitted by atoms. Hydrogen and helium, the simplest atoms, produce clearly identifiable emission peaks in their spectra, making them relatively easy to distinguish. As soon as you stick two or more atoms together in a molecule, though, things get ugly. Unlike the rigid wooden balls and dowels of college organic chemistry sets, real molecules are more like marshmallows attached to each other with Slinkies—they flip, flop, roll, spin, squish, and vibrate, and every action leads to its own characteristic emission color.

For those reasons, the spectra of acetone and DHA are very complex indeed. The acetone molecule is made up of ten atoms, and DHA is made up of twelve. Their combined motions give rise to spectra with thousands of emission peaks—some isolated and narrow, others mushed together in broad bands of color. Even "color" is a bit of a misnomer; most molecules, including acetone and DHA, emit spectra at wavelengths of just a few millimeters—that is, microwaves and radio waves, invisible to the human eye.

With the recently retired, multi-antenna interferometric observatory of the Berkeley–Illinois–Maryland Association at Hat Creek, California, Friedel's team found interstellar acetone in the hot gaseous core of the Orion–KL region. The site, 1,500 light-years from Earth, is a nursery for massive stars. Meanwhile, at the 10.4-meter single-dish Caltech Submillimeter Observatory on Mauna Kea, Hawai'i, Widicus Weaver, along with Geoffrey A. Blake of Caltech, targeted another site of massive star formation. There, in another hot, gaseous core of a region called Sagittarius B2 (N-LMH), about 26,000 light-years from Earth, they identified DHA. Both clouds are rich



Geoffrey Wowk, *Cosmopolishing,* 2005

in molecular species, but neither acetone nor DHA had been detected in the two clouds before now.

What's exciting about the discoveries is how much of the two chemicals reside in the interstellar clouds. First, each cloud is many times larger than our solar system. Moreover, the measurements suggest that trillions upon trillions of tons of acetone and DHA have collected in the two hot cores. Clearly, conditions there must be highly favorable to the formation and maintenance of the molecules. Yet such conditions are hardly typical of interstellar space.

Okay, so maybe astronauts of the distant future will have no problem sprucing up their fingernails or maintaining perfect skin tone. Acetone and DHA aren't just important grooming aids; both are basic organic molecules, and both serve as key players in many complex biochemical processes on Earth. DHA, for instance, is crucial to human metabolism.

The prevalence of the two chemicals in interstellar space lends support to an idea about the origins of Earth's biology that is becoming increasingly widely accepted. Many complex molecules might not have formed on Earth, but were assembled elsewhere in the early solar system and later deposited here as raw materials for the molecules of life. If conditions in the early solar nebula led to some of the same molecule-making that Friedel and Widicus Weaver have observed in the Orion and Sagittarius cloud cores, organic compounds such as acetone and DHA could have been incorporated into comets and planetesimals. Those bodies might then have collided with Earth millions of years later and dropped their organic payloads onto Earth's surface. If so, the biology of our planet may owe its existence to an interstellar cloud of gas that sowed the seeds of proteins, DNA, and ultimately us—not to mention the stuff that can give us that "bronze-goddess glow."

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 FEBRUARY

By Joe Rao

At the beginning of February Mercury has just passed behind the Sun and sets too soon after sunset to be seen. But by the 9th the speedy planet should be visible to viewers with binoculars, just above the west-southwestern horizon near where the Sun has disappeared half an hour earlier. By the 14th Mercury sets a full hour after the Sun and is easy to see with the naked eye.

The planet reaches greatest eastern elongation (its greatest angular distance from the Sun) on the 23rd, only a day after it passes perihelion (its closest approach to the Sun). That makes for favorable observing in the mid-northern United States, because Mercury is almost directly above the Sun, giving the planet more time to shine in a dark sky before setting at the end of twilight. A slender crescent Moon hangs about five and a half degrees below and slightly to the left of Mercury on the 28th.

Venus rises in a dark sky about half an hour before morning twilight at the beginning of February; it rises nearly half an hour earlier by month's end. The planet is scooting ahead of the Earth as it races around the Sun, so viewers with telescopes will see the crescent of Venus thickening in phase but diminishing in overall size. Venus reaches its greatest brilliancy of the year—a stunning –4.6 magnitude—on the 17th.

Mars soars high in the sky this month. It is near the meridian at dusk and remains visible until about an hour to an hour and a half after midnight. On the evening of the 5th Mars is situated about two to three degrees below the Moon. The planet moves east nearly fifteen degrees this month, crossing from the constellations Aries, the ram, into Taurus, the bull, on the 7th.

If you watch attentively, you may be able to detect changes in the color of the Red Planet. In fact, despite its nickname, Mars usually looks yellow to yellow-orange. During its occasional global dust storms, however, it becomes a lighter yellow.

Jupiter, in the constellation Libra, the scales, rises just after 1 A.M. at the start of February and shortly before 11:30 P.M. near month's end. But for the best views, look before morning twilight begins, when the planet is well up in the south. Soon after midnight on the 20th Jupiter rises about five to six degrees above and to the left of the waning gibbous Moon.

Saturn, just past its opposition of January 27th, is low in the east at dusk and visible for most of the night. The planet begins the month one degree south of Praesepe, the Beehive star cluster in the constellation Cancer, the crab. Soon after darkness on the 10th, the Moon appears to stand high above the planet in the east. On the following evening our satellite shifts below and to the left of Saturn.

The Moon waxes to first quarter on the 5th at 1:29 A.M. and to full on the 12th at 11:44 P.M. It wanes to last quarter on the 21st at 2:17 A.M. and to new on the 27th at 7:31 P.M.

Late on the night of the 17th a waning gibbous Moon occults, or passes in front of, Spica, a bright, bluish, first-magnitude star in the constellation Virgo, the virgin. Unfortunately for most viewers in the United States, the event is unobservable because it takes place before the Moon and Spica rise. In the Northeast, however, Spica will already be hidden when the Moon rises, after about 10 P.M. Soon after 11 P.M., while still low and near the east-southeastern horizon, Spica dramatically pops out from behind the dark part of the Moon as viewed with binoculars or a telescope.

Unless otherwise noted, all times are given in eastern standard time.

Islands Generate Bird Biodiversity

Island life sounds quite appealing in winter months as many of us migrate to warmer and lusher locales. Islands and their flora and fauna also hold a special fascination for scientists and naturalists, as they've discovered islands' rich biodiversity and the large proportion of species found on single islands and nowhere else on Earth.

Now, two American Museum of Natural History biologists have overturned conventional thinking that islands are evolutionary "dead-ends" with a study demonstrating that biodiversity flows "upstream"—from islands to continents, as well as "downstream"—from continents to islands—by showing that birds from widely dispersed South Pacific islands have contributed to continental bird biodiversity in Australia.

This new study of a diverse and brilliantly colored bird family—the monarch flycatchers, found throughout Australasia and the tropical Pacific—by Christopher E. Filardi, biodiversity scientist in the Museum's Center for Biodiversity and Conservation and Department of Ornithology, and Robert G. Moyle, research scientist in the Museum's Department of Ornithology and Ambrose Monell Molecular Laboratory, was published in the November 10, 2005, issue of the journal *Nature*.


C. FILARDI/AMNH

Female *Monarcha richardsii*

Drs. Filardi and Moyle arrived at new estimates of the evolutionary relationships among these birds based on the genetic relatedness among species in an attempt to understand the processes behind the pattern of the birds' geographical distribution. Their analysis shows that a large and diverse array of monarch flycatchers resulted from a single radiation involving nearly every major Pacific archipelago, and that some species with ancestors originating on Pacific islands took hold in Australia and New Guinea at some time in the past.

"Islands aren't just little landforms worth saving as icons of evolutionary quirkiness or symbols of past diversification," Dr. Filardi said. "They are important in a broader sense and may contribute significantly to the future diversity of life on Earth.

Learn more about bird conservation in the CBC's spring symposium, Conserving Birds in Human-Dominated Landscapes, *on Thursday and Friday, April 27 and 28. Visit* **www.amnh.org** *for details.*


R. MICKENS/AMNH

Kids and families enjoy the Museum's annual celebration of **African-American History Month.** This year, over three Saturdays, February 11, 18, and 25, the Museum celebrates the past, present, and future of black theater in the United States with a series entitled Ebony Stages that will include performances, discussions, workshops, and more.


R. MICKENS/AMNH

The Museum's 17th annual **Identification Day** will be held on Sunday, February 12, in honor of the anniversary of Charles Darwin's birth. As in years past, the public is invited to bring their natural-history mysteries—shells, rocks, insects, feathers, fossils, bones, pottery, textiles, or any other natural or cultural objects that have left them puzzled and perplexed—to the Museum, where scientists and experts will attempt to identify them.

Darwin Digital Library of Evolution

Launched in conjunction with the exhibition *Darwin,* the Darwin Digital Library of Evolution (DDLE), at http://darwinlibrary.amnh.org, is the first Web site dedicated to the intellectual genesis and growth of Darwin's theory of evolution. This new project by the Museum's Research Library features the broadest and most complete collection ever assembled of specimens, artifacts, original manuscripts, and memorabilia related to Darwin.

The DDLE features Darwin's chief works, including American, British, and international editions of various titles such as *The Origin of Species* and *Natural Selection;* works by Darwin's intellectual descendents such as Thomas Huxley, Asa Gray, and Herbert Spencer; a well-balanced selection of works exploring critiques of and responses to evolutionary theory; and works that represent key intellectual influences on Darwin.

The DDLE also incorporates the Darwin Manuscripts Project, which provides scholarly transcriptions of Darwin's voluminous scientific notes, notebooks, and drafts, many of which have never been published before.

Since 1999, the Museum's Research Library has focused strongly on integrated digital access to scientific and cultural resources, with a view toward providing free and easy access to the broadest possible audience. Visit http://library.amnh.org.

D. FINNIN/AMNH

A child is captivated by the live iguana featured in *Darwin*. This stunning exhibition, which will be on view until May 29, 2006, appeals to all ages and offers a comprehensive, engaging look at the life and times of Charles Darwin. Other live animals in the exhibition include Galápagos tortoises and South American horned frogs. Visit www.amnh.org/darwin for an overview, curator interviews, videos, behind-the-scenes tours, and a tortoise cam!

PEOPLE AT THE AMNH

Christie Stephenson
Assistant Director for Digital and Special Collections
Research Library

D. FINNIN/AMNH

As Assistant Director for Digital and Special Collections, Christie Stephenson seems thrilled to talk about her new position at the Museum. Bringing years of experience along with master's degrees in library science and art history, Christie's primary responsibility is to digitize and provide online access to the older materials from the Museum's Research Library.

Since her arrival in September 2005, Christie has been exploring Special Collections, which includes film, manuscripts, art and memorabilia, and more than 500,000 photographic images, and documents everything from 19th-century scientific expeditions to the history of exhibition at the Museum. "The process of displaying and communicating scientific information to the public has evolved so much over the years. To see that transition documented visually is really fascinating."

She also serves as technical advisor to the Darwin Digital Library of Evolution, a major project to provide online access to the literature of evolution from the 17th century to the present.

Christie admits that among the greatest challenges she faces is the preservation of information for the future, as film and paper are replaced with "born digital" documentation. She anticipates a future where digital content from the library and the scientific departments can be linked using standard Web protocols, "so that diverse bodies of data can be searched comprehensively."

As the daughter of two geologists, Christie grew up with a love for the outdoors, and eventually became an admirer of the "built environment" and architecture, adding to her appreciation for New York.

Museum Events

American Museum of Natural History

www.amnh.org

EXHIBITIONS

Darwin

Through May 29, 2006

Featuring live animals, actual fossil specimens collected by Charles Darwin, and manuscripts, this magnificent exhibition offers visitors a comprehensive, engaging exploration of the life and times of Darwin, whose discoveries launched modern biological science.

The American Museum of Natural History gratefully acknowledges **The Howard Phipps Foundation** for its leadership support.
Significant support for *Darwin* has also been provided by the Austin Hearst Foundation, Jack and Susan Rudin, and Rosalind P. Walter.
Additional funding provided by Chris and Sharon Davis, Bill and Leslie Miller, the Carnegie Corporation of New York and Dr. Linda K. Jacobs.
Darwin is organized by the American Museum of Natural History, New York, (www.amnh.org), in collaboration with the Museum of Science, Boston; The Field Museum, Chicago; the Royal Ontario Museum, Toronto, Canada; and the Natural History Museum, London, England.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter

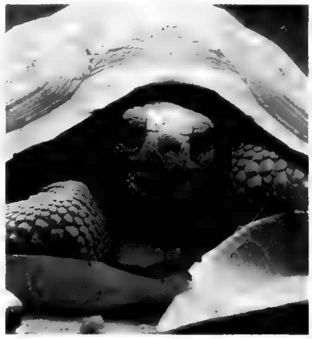
Extended through June 23, 2006

A return engagement of this popular exhibition includes up to 500 live, free-flying tropical butterflies in an enclosed habitat that approximates their natural environment.

This exhibition is made possible, in part through the generous support of JPMorgan Chase.

H DAVIES/AMNH

Julia butterfly *(Dryas iulia)*



HOWARD SNELL, CHARLES DARWIN FOUNDATION, INC

Baby Tortoise

Voices from South of the Clouds

Extended through July 23, 2006

China's Yunnan Province is revealed through the eyes of the indigenous people, who use photography to chronicle their culture, environment, and daily life.

The exhibition is made possible by a generous grant from Eastman Kodak Company. The presentation of this exhibition at the American Museum of Natural History is made possible by the generosity of the Arthur Ross Foundation.

Vital Variety

Ongoing

Beautiful close-up photographs highlight the importance of the immense diversity of invertebrates.

GLOBAL WEEKENDS

African-American Heritage Month

Ebony Stages: Black Theater—Past, Present, and Future

Three Saturdays, February 11–25, 12:00 noon–5:00 p.m.

Drawing on the diversity of the many African communities in the tristate area, this program brings contemporary stories, song, dance, films, and crafts to Museum visitors.

Global Weekends are made possible, in part, by The Coca-Cola Company, the City of New York, and the New York City Council. Additional support has been provided by the May and Samuel Rudin Family Foundation, Inc., the Tolan Family, and the family of Frederick H. Leonhardt.

LECTURES

Why the Galápagos Still Matter

Thursday, 2/2, 7:00 p.m.

Scientists Martin Wikelski, Kenneth Petren, and Gisella Caccone discuss their research on the Galápagos Islands.

What's Out There and What's Really Out There

Tuesday, 2/7, 7:00 p.m.

Ray Villard and Mary K. Baumann tell the stories behind the images in the book *What's Out There: Images from Here to the Edge of the Universe.*

The Best American Science Writing 2005

Thursday, 2/16, 7:00 p.m.

Moderated by Alan Lightman, this event highlights some of the most thought-provoking science writing of the past year. A book signing follows.

JIM AND JAMIE DUTCHER

Jim Dutcher and wolf pup

Living with Wolves

Tuesday, 2/21, 7:00 p.m.

Jim and Jamie Dutcher share their remarkable observations, which defy the storm of controversy surrounding the wolf. A book signing follows.

Art/Science Collision: The Diorama

Tuesday, 2/28, 7:00 p.m.

Naturalist Steven C. Quinn, historian of science Hanna Rose Shell, and photographer Hiroshi Sugimoto discuss the Museum's famous dioramas. A book signing follows.

D FINNIN AND J. BECKETT/AMNH

The Osborn Caribou diorama in the Hall of North American Mammals

WORKSHOP

Make It, Wear It: Felting

Sunday, 2/19, 1:00–4:00 p.m.

Make a felt scarf or hat with artist Tiiti Fortelny in this hands-on workshop.

FAMILY AND CHILDREN'S PROGRAMS

Charles Darwin and the Tree of Life

Saturday, 2/4, 12:00 noon and 2:30 p.m.

Reading, performance, and puppetry with MacArthur Fellow and author/illustrator Peter Sis. A book signing follows.

The Naturalist's Diary

Sunday, 2/5, 11:00 a.m.–12:00 noon

Starry Nights

Live Jazz

Rose Center for Earth and Space

6:00 and 7:30 p.m.

Visit www.amnh.org for lineup.

Friday, February 3

The 7:30 set will be broadcast live on WBGO Jazz 88.3 FM

Starry Nights is made possible, in part, by Constellation NewEnergy and Fidelity Investments.

Create an old-fashioned nature diary with educator Patricia Miranda.

Wild, Wild World: Raptors
Saturday, 2/11
12:00 noon–1:00 p.m. and 2:00–3:00 p.m.
Get a close-up look at owls, hawks, and falcons.

Dr. Nebula's Laboratory: Voyage through the Stars
Sunday, 2/19, 9:30–10:30 a.m.
Follow the course taken by Darwin aboard the *Beagle* and learn about ancient methods of navigating by the stars.

Return to Flight
Saturday, 2/4, 11:00 a.m.–12:30 p.m. (Ages 4 and 5, each child with one adult), or 1:30–3:00 p.m. (Ages 6 and 7, each child with one adult)
Students will prepare the Space Shuttle for take-off and learn what it takes to put a mission together.

Space Explorers: Romance of the Ancient Greeks
Tuesday, 2/14, 4:30–5:30 p.m. (Ages 8 and up)
Hands-on activities are followed by in-depth investigations in the Hayden Planetarium.

AMNH WINTER ADVENTURES
Monday–Friday, 2/20–2/24, 9:00 a.m.–4:00 p.m.

Ocean Adventures
Children will discover fantastic ocean creatures with fun-filled activities from fish "tales" to squid dissections. (For 4th and 5th graders)


NASA

Astronaut Michael Gernhardt

Destination Space: Astrophysics
Students will learn about the universe through hands-on activities and explorations in space science. (For 2nd and 3rd graders)

HAYDEN PLANETARIUM PROGRAMS
TUESDAYS IN THE DOME
Virtual Universe
SETI: Search for Extraterrestrial Intelligence
Tuesday, 2/7 6:30–7:30 p.m.

This Just In...
February's Hot Topics
Tuesday, 2/21, 6:30–7:30 p.m.

Celestial Highlights
Spring around the Corner
Tuesday, 2/28, 6:30–7:30 p.m.

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

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

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

Made possible through the generous support of Swiss Re.

Passport to the Universe
Narrated by Tom Hanks

LARGE-FORMAT FILMS
LeFrak IMAX Theater
Galápagos explores the unique fauna of the islands and the surrounding sea.

IMAX films at the Museum are made possible by Con Edison.

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.

AMNH eNotes delivers the latest information on Museum programs and events to you monthly via email. Visit www.amnh.org to sign up today!

Stunt Double

By Denton S. Ebel

Science museums are not always the sedate repositories you stroll through on your tour of their galleries. Exciting research goes on behind the scenes, out of sight of visitors. Sometimes even long-held samples from the collections take a star turn in the drama of scientific advance. Recently one of the meteorites in the collection I curate at New York's American Museum of Natural History (AMNH) got to play more than a bit part in the exploration of Mars.

In mid-January 2005, I got a call from Stephen Gorevan, chairman of Honeybee Robotics, a Manhattan-based company that designed and built a key instrument aboard the Mars rovers, Opportunity and Spirit. Opportunity, Steve told me, had been driving across the surface of Mars when it discovered an iron meteorite near its own heat shield.

A meteorite on Mars was an exciting find. What could Opportunity's earthbound handlers learn about it? Steve warmed to his topic. On the rover's extendable arm is Honeybee's rock abrasion tool, or RAT. It's a sophisticated grinding machine that sweeps the ubiquitous red Martian dust off rocks, grinds away the surface coating to get to the fresh rock underneath, and then brushes away the cuttings. Other instruments on the arm measure the rock composition before and after "ratting."

But the RAT had never been tested on an iron meteorite. So Steve's question was simple. Would the grinding bit survive?

Iron meteorites are much, much harder than basalt, the predominant kind of rock the rovers had been encountering. In fact, until the invention of steel, meteoritic iron was the hardest malleable material available to toolmakers. The grinding bit on the RAT is made of diamond fragments embedded in hard resin. The diamond, of course, is harder than an iron meteorite, but Opportunity's RAT had already done twenty-two grinds. Although the bit still seemed in good condition, no one wanted to wear it out with one shot on a meteorite.

Above: Test grinding of the Santa Rosa meteorite left a nearly circular hole 46 millimeters across and less than a millimeter deep. Below: Artist's conception of the Mars rover Opportunity, sampling an iron meteorite on the Martian surface.

Steve continued: Could Honeybee's lab test a duplicate RAT on a meteorite from the collection at AMNH? Without hesitation, I said, Yes!

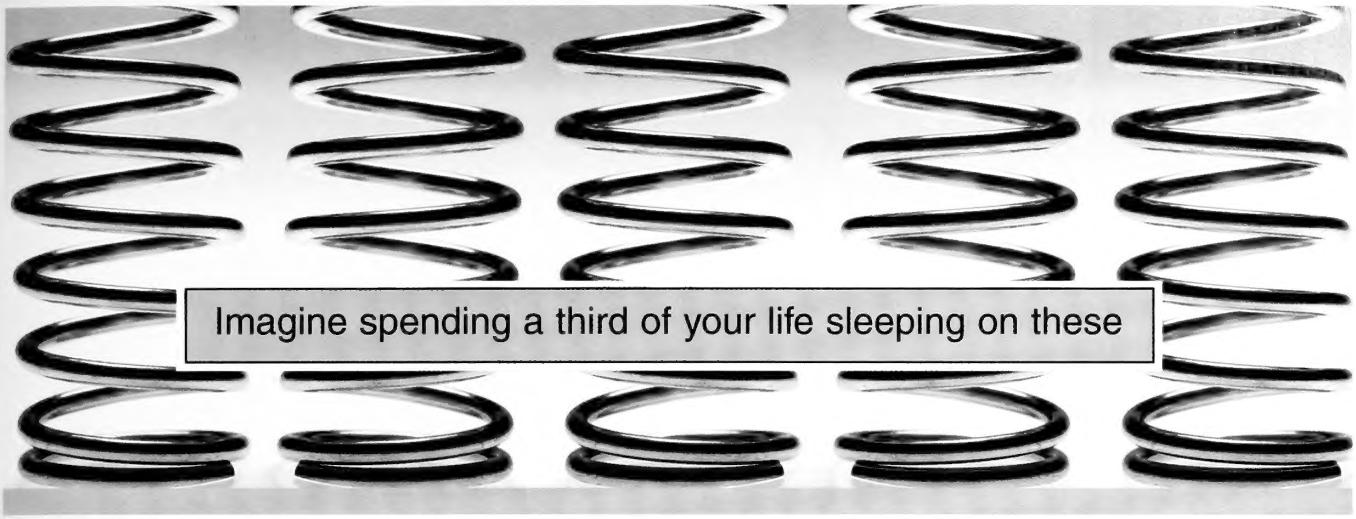
Our collections exist to advance knowledge of the natural world. Helping to study the first meteorite ever found on another planet certainly fit that mission. Our sample was needed to help Steven Squyres, the principal investigator for the rovers, make a scientific decision critical to one of the most productive NASA missions ever. Here was an opportunity (no pun intended) to complement and support extraterrestrial field research with a laboratory experiment, made possible by AMNH's collection.

We needed a large piece of meteorite with a flattish surface, because the head of the RAT had to rest against its target. I ultimately chose one of our samples of the Santa Rosa meteorite, discovered in Colombia in 1810.

Two Honeybee engineers, Philip Chu and Alastair Kusack, tested a RAT on both cut and natural faces of the Santa Rosa sample, in a chamber that reproduced Martian air composition, pressure, and temperature. Their results showed that grinding Santa Rosa wore down the bit on the RAT extremely fast. My advice was: "Don't risk it. We're there to study Mars, not iron meteorites."

And that's what Squyres decided. Opportunity carried out some more investigations of the surface of the meteorite, then moved on. Santa Rosa is safely back at AMNH, along with a vial of particles recovered from the grinding. It bears only a shallow scar: a reminder that it served our mission with strength and stubborn resolve.

Denton S. Ebel is a curator in the department of earth and planetary sciences at the American Museum of Natural History in New York City.



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