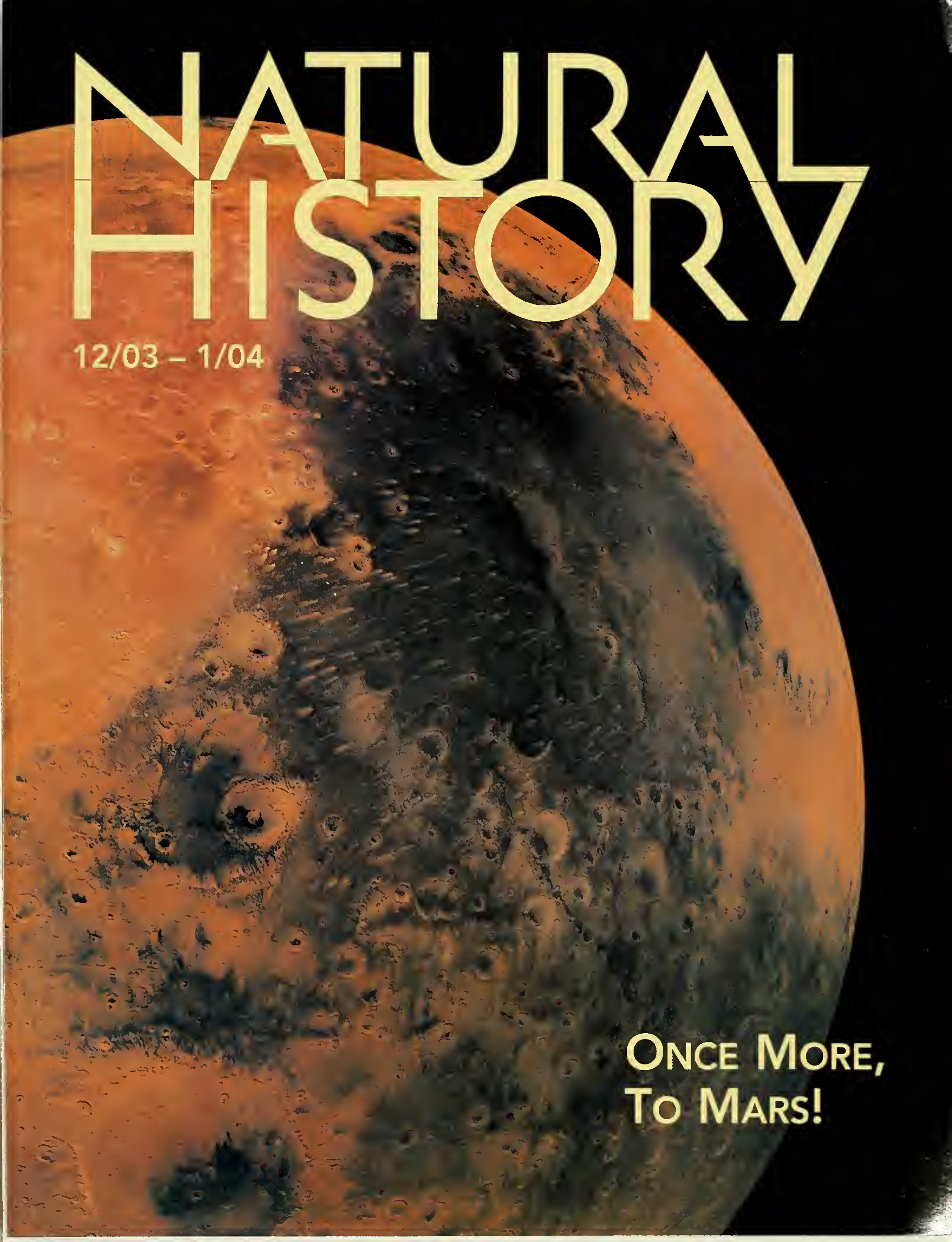
NATURAL HISTORY

12/03 – 1/04



Once More, To Mars!

NATURAL HISTORY

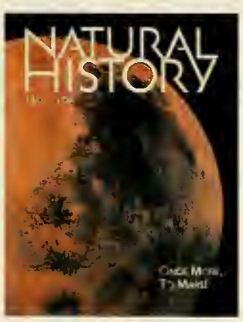
DECEMBER 2003/JANUARY 2004 VOLUME 112 NUMBER 10

FEATURES

COVER

Mars: Syrtis Major with wind streaks. Image made by a Viking orbiter.

STORY BEGINS ON PAGE 32



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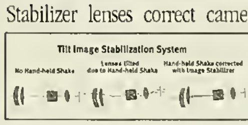

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Ah . . . Heaven!

Photograph by Art Wolfe

THE NATURAL MOMENT

◄ *See preceding pages*

Thirty-four years ago this January, a snow monkey much like the bathing beauties pictured here made the cover of *Life* magazine. Japanese macaques *(Macaca fuscata)*, as they are also known, have always been quick to soak up human culture. People are thought to have enticed monkeys into Japan's Yaen-Koen hot springs, near Nagano, about fifty years ago—apparently the monkeys' first dip in this natural hot tub after 500,000 years on Honshu Island. Other "people" skills, passed on to younger generations, include how to wash and salt potatoes with sea water, make snowballs, and trigger the automatic doors of supermarkets to shoplift food.

One ingenious troop of 150 snow monkeys got so good at stealing farmers' crops near Kyoto that the entire troop was banished to Texas in 1972. Over the years, the transplanted monkeys have proved their adaptability. Linda Fedigan, an anthropologist at the University of Calgary, in Alberta, says the Texas troop has learned how to eat prickly pear cactus and to warn each other about rattlesnakes and bobcats.

But some aspects of Japanese macaque culture, such as their matrilineal society, remain constant from place to place. Photographer Art Wolfe observed several mother-child pairs, including the one in the foreground here, ambling around the banks of the hot springs. They seemed relaxed and content simply to hang out together.

—*Erin Espelie*

UP FRONT

Once More, To Mars!

One of the defining episodes in the public embrace of the Internet was the 1997 Pathfinder mission to Mars. Sojourner, the six-wheeled rover deployed by the Pathfinder lander, was the little robot that could. After Pathfinder shed the air bags that had softened the landing, Sojourner crept down a ramp to the martian surface, shook out its solar panel, and opened up its electronic eyes. Then, on command from radio signals that took eleven minutes to make the transit, Sojourner motored up to big rocks, probed them with its onboard instruments, and, most important, sent pictures of its out-of-this-world surroundings back to Earth. Pathfinder became the target of what was, at the time, the biggest "hit blizzard" in Web history. Millions logged on. Television came of age with wars, assassinations, and political conventions; the Internet came of age with a visit to Mars.

This January NASA is doing its long-awaited encore: landing two new rover missions, Spirit and Opportunity, on opposite sides of the Red Planet. But Spirit and Opportunity are only part of the space armada scheduled to take part in this winter's unprecedented martian exploratory extravaganza. *Mars Express,* launched by the European Space Agency, will reach Mars on Christmas day (*Mars Express* carries its own lander, Beagle 2). Japan's *Nozomi* spacecraft will reach Mars in January. As they arrive, all four spacecraft will find *Mars Odyssey* and *Mars Global Surveyor* already orbiting the planet. And once again, you can log on to the Internet, as Robert Anderson describes in his "nature.net" column "Mars on My Mind" (page 61), and follow the action as it happens.

• • •

One of the many extraordinary things I learned from Michael H. Carr's splendid preview of the scientific purpose of the rover missions, "What Became of the Water on Mars?" (page 32), is the critical role of a hot, roiling iron core to the "health" of a planet. The core of Mars cooled billions of years ago, and so the planet is magnetically dead. With a map and a compass to find your way around, you could just as well throw away the compass.

But surely that's a trivial price to pay for a planet-size piece of real estate. In fact, though, as Carr explains, one result of the loss of martian magnetism was the slow attenuation of its atmosphere. On Earth, the atmosphere and the magnetosphere deflect the charged particles that stream in from the Sun at a million miles an hour: the solar wind. But on Mars, the thin atmosphere and the loss of magnetism leave the surface exposed to the full brunt of the solar wind. Living on the martian surface would be like living inside an oversize television picture tube—except that you would be part of the screen, and charged particles would be raining down on your head. Large molecules such as proteins and DNA don't do well under heavy ion bombardment. In short, without a good lead umbrella, living on Mars would be cancer city. If you think Mars might offer a second chance for a species that fouls its own nest on Earth, think again.

—PETER BROWN

CONTRIBUTORS

Trained in fine arts, nature photographer ART WOLFE ("The Natural Moment," page 4) published his first book, *Indian Baskets of the Northwest Coast,* just three years after earning a BFA from the University of Washington, in Seattle. In his twenty-five-year career he has worked on every continent and in hundreds of locations. Images from a recent photo safari in Africa can be previewed at his Web site www.artwolfe.com Wolfe's latest book, *Edge of the Earth, Corner of the Sky,* with essays by Art Davidson, focuses on landscape photography.

A native of Leeds, England, geologist MICHAEL H. CARR ("What Became of the Water on Mars?" page 32) has devoted a long career to the exploration of Earth's nearest neighbors. In 1962 he joined the United States Geological Survey. Since then, he has worked on the Apollo missions, on *Mariner 9,* and on the Viking and Pathfinder missions to Mars. Carr is a member of the team overseeing the operation of the two rovers, Spirit and Opportunity, scheduled to land on Mars this January. He is the author of *The Surface of Mars* (Yale University Press, 1984) and *Water on Mars* (Oxford University Press, 1996).

J. EMMETT DUFFY ("Underwater Urbanites," page 40), an associate professor of marine science at the Virginia Institute of Marine Science in Gloucester Point, Virginia (part of the College of William and Mary), has been a biophile since his undergraduate days in Mobile, Alabama, on the Gulf of Mexico. He has been investigating the social life of shrimps in the Caribbean for fifteen years and, more recently, the biodiversity and marine ecosystems of the Chesapeake Bay. Duffy is editing a book on crustacean behavioral ecology and social organization.

When NYREE J.C. ZEREGA ("The Breadfruit Trail," page 46) arrived at the New York Botanical Garden to do graduate work in systematics with assistant curator Timothy J. Motley, she wanted to study the origins and evolutionary relationships of a food plant. Motley introduced her to Diane Ragone of the National Tropical Botanical Garden in Hawai'i, who in turn introduced her to the garden's immense collection of breadfruit trees from regions around the Pacific Ocean. Zerega is currently a postdoctoral associate at the University of Minnesota, Twin Cities. Her article on human migrations and the origins of breadfruit in Oceania, coauthored with Ragone and Motley, will appear in 2004 in the *American Journal of Botany.*

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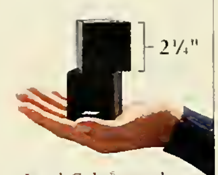

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Food Fight

As Marc J. Cohen writes in his review ["Crop Circles," 10/03], "few aspects of everyday life provoke such sharp disagreement as the emerging biotechnology of food." Barely mentioned by Mr. Cohen, the farmer is a major player in the battle over biotechnology.

In India, for example, farmers were critical in the struggle over whether to permit genetically modified (GM) cotton to be grown. The government tried to stop it, but a small company smuggled GM (Bt) cotton into the state of Gujarat, and for three years farmers grew it beside fields of traditional cotton. The secret was revealed in 2001 by a great bollworm infestation. Although the indigenous variety was devastated, the Bt cotton was unharmed. The government ordered the destruction of the illegal crop, but farmers had seen the overwhelming advantage of Bt cotton. The government soon approved its cultivation (S.A. Freed and R.S. Freed, "Green Revolution: Agricultural and Social Change in a North Indian Village," *Anthropological Papers of the American Museum of Natural History,* 85, 2002).

India is a democracy where 75 percent of the people live in rural areas. The farmers are voting with their plows.

Stanley A. Freed
American Museum of Natural History
New York, New York

MARC COHEN REPLIES: I was surprised that Stanley A. Freed felt that I had "barely mentioned" farmers in my review, since I identified boosting small-farmer productivity in developing countries as key to reducing world hunger, and as the main area in which biotechnology might help. Otherwise, I find his comments right on the mark. Indeed, Bt cotton has boosted the incomes of poor farmers else-

where in the developing world, including South Africa and China, while reducing pesticide use. The problem of how quickly the cotton pests will develop resistance to the Bt toxin remains a major issue in managing the technology. Research is also needed to determine the extent to which impoverished farm households are converting their income gains into better nutrition. In a case similar to the one Mr. Freed cites, soybean producers in Brazil engaged in civil disobedience on their farms, planting herbicide-tolerant seeds derived from biotechnology in defiance of a government ban. So there is no doubt that farmers in developing countries are major participants in the biotechnology debate.

Moonlighting

G. Jeffrey Taylor, in his article "Moonstruck" [9/03], refers to the Earth's tidal pull. But if the same side of the Moon always faces Earth, there should be no lunar tides. Shouldn't the force simply be Earth's gravitational pull? He also mentions mapping the Moon's magnetic field. But the lunar core is small and not liquid, so there should be no magnetic field. Could it be that what was mapped was the residual magnetization of portions of the lunar surface?

William J. Rihn
Laguna Beach, CA

G. JEFFREY TAYLOR REPLIES: Earth's gravitational pull creates a bulge on the side of the Moon nearer Earth and one on the opposite side. The Moon is commonly said to always present the same side toward Earth, but in fact it wobbles a bit. As the bulges move relative to the lunar surface, they create tidal forces in the rock. William J. Rihn is correct, it is not exactly "Earth's tidal pull." Nor does the Moon have a global magnetic field generated by an active core dynamo. There is a paleomagnetic field recorded in surface rocks (and also measured in lunar samples), which shows that the Moon once had such a global magnetic field. It existed before about 3 billion years ago and died out as the small core cooled.

Universal Clock

Neil deGrasse Tyson closes his column "In the Beginning" [9/03] with what seems to be a meaningless question: "What happened before the beginning?" Didn't time itself begin with the big bang?

David G. King
Southern Illinois University
Carbondale, Illinois

NEIL DEGRASSE TYSON REPLIES: The question, "What happened before the beginning?" may have no more meaning than the questions, "What lies north of the North Pole?" or "What time is it in Santa Claus's home?" Yes, we define time to begin at the big bang, but only as a convenience. Emerging theories provide for a multiple, perhaps infinite, number of universes, each with its own big bang, and, therefore, its own internal clock. What clock would we use to keep track of them all? If that question is meaningful, so too would be the question, "What happened before the beginning of our universe?"

The Best Defense?

I was surprised that one of the more infamous reasons for "pee" dumping by frogs wasn't mentioned in the "Endpaper" by Ryan C. Taylor ["Pees & Cues," 10/03]. If any urine makes contact with a creature's eyes, it will cause immediate burning and can cause the eyes to swell shut: a great defensive strategy if you're on a predator's menu.

Thomas Smilie
Lakeland, Florida

Ryan Taylor replies: In our study, Bryant Buchanan and I found that one benefit frogs may gain by dumping their bladder water is an increase in jumping performance. But that doesn't rule out other possible benefits. For example, when a frog dumps its bladder water, a snake may be temporarily distracted by chemical cues, allowing the frog to escape. But I am not aware of any studies demonstrating that the urine of frogs contains chemical irritants strong enough to cause eyes to swell shut. Snakes (probably one of the primary predators of squirrel treefrogs) have a scale covering the eye, which makes it particularly unlikely that frog urine would cause eye irritation. Mammalian predators such as raccoons readily prey on frogs with seemingly no ill effects.

When the Bough Doesn't Break

The lianas discussed by Adam Summers ["Extreme Forestry," 7/03–8/03] illustrate well the biomechanical problems faced by plants. Apart from the physical structure of a cell wall, the elasticity of tissues should be considered. For example, the aerial roots of parasitic strangler figs have flexible tissue, containing little lignin, that is woven into rigid wood fibers made up of cellulose microfibrils and a lot of lignin. The cells in the flexible tissue slip by each other with ease, a property that enables the roots to stretch like rubber rope, whereas the wood fibers resist a tearing force. Moreover, the sinuous shape of vines converts forces that might stretch the vine into shear forces, giving it spring-like elasticity.

Takashi Okuyama
Nagoya University
Nagoya, Japan

Adam Summers replies: Takashi Okuyama raises several good points. In particular, the overall structure of a plant plays an important role in its response to stress. Many vines look like a spring, and the coils absorb the energy of suddenly applied loads.

Amendment: A few commonly repeated historical errors were unfortunately propagated in Richard Ellis's article, "Terrible Lizards of the Sea" (9/03). The type skull of *Mosasaurus hoffmanni* was unearthed between 1770 and 1774 (not 1780), and the army surgeon who had it brought to the surface was Johann Leonhard (not C.K.) Hoffmann (1710–1782). French revolutionary troops confiscated the skull on November 8, 1794; Napoleon's army did not carry it to Paris.

Natural History*'s e-mail address is* nhmag@naturalhistorymag.com

By Stéphan Reebs

Save the Earth

Probably the first thing concerned citizens think of when the word "endangered" pops up is an animal: the California condor, the giant panda, the bowhead whale, the leatherback sea turtle. But right under our feet may be something equally endangered: the soils of America. Of the 13,129 soil "series," or species, that occur in the United States, 4,540 are classified as "rare" (having a total area of less than 2,500 acres) or "rare-unique" (present in only one state, and having a total area of less than 25,000 acres). According to Ronald Amundson, a soil scientist at the University of California, Berkeley, and his colleagues, if more than 50 percent of a rare or rare-unique soil has been lost to such incursions as housing, highways, or agribusiness, the soil should be considered endangered.

Some soils are getting scarcer in the United States.

The earth scientists caution that the diversity of soils on Earth today is the product of an unrepeatable combination of unique fauna and flora (many of them now extinct), as well as cyclic glaciations beginning about 1.6 million years ago. The resulting soil types—characterized by such features as depth, mineral composition, organic content, and texture—are therefore as unique as living species. Unusual soil types, moreover, are often the substrate for rare plants. Alter the soil, and the ecosystem changes.

By correlating a map of soil distribution with a satellite map showing land use, Amundson's team found 508 U.S. soils that are now endangered. California leads the list with 104, the most of any state. The rare soils of the country's agricultural heartland are in greatest jeopardy: more than 80 percent of Indiana's and Iowa's rare soils, for instance, are endangered. ("Soil diversity and land use in the United States," *Ecosystems* 6:470–82, October 2003)

Small Is Powerful

Sometimes small is ineffectual. But not when it comes to photosynthesis. The single-celled cyanobacterium *Prochlorococcus*—0.00002 inch in diameter—is the smallest known organism capable of photosynthesis. Yet numbers can make up for size: the bacterium is the dominant force in the production of organic material in the oceans.

You might think any organism that has to make all its own building materials from carbon dioxide, dissolved mineral salts, and light would need elaborate cellular machinery and a great many genes. If so, you'd be wrong. Alexis Dufresne, a biologist at the Biological Station of Roscoff in France, and an international team of investigators have sequenced the entire genome of the little powerhouse: one lone chromosome. In it they counted just 1,884 genes for making proteins and forty more genes for making transfer RNA. (By comparison, an *Arabidopsis* plant—the "lab rat" of plant-genetics research—has some 25,000 protein-coding genes.) Many genes responsible for nitrogen assimilation, movement, cell repair, and response to stress in other cyanobacteria are absent in *Prochlorococcus*. That leads Dufresne and his coworkers to think they've found the smallest genome that can sustain life through photosynthesis alone. ("Genome sequence of the cyanobacterium *Prochlorococcus marinus SS120*, a nearly minimal oxyphototrophic genome," *Proceedings of the National Academy of Sciences* 100:10020–25, August 19, 2003)

Oceans are home to the smallest known photosynthetic organism.

Many Moons

Astronomers have long known that Mercury and Venus have no moons, Earth has but one, and Mars two. The count for the other planets in the solar system, however, is far from fixed. New moons are constantly being discovered, and the pace has picked up dramatically in recent years.

In the first nine months of 2003 alone, the tally of discoveries totaled twenty-one new satellites for Jupiter, one for Saturn, three for Uranus, and one for Neptune (also announced in 2003, but discovered earlier, were two more for Uranus and one more for Neptune). That brings the known totals to sixty-one for Jupiter, thirty-one for Saturn, twenty-seven for Uranus, and thirteen for Neptune.

Why have so many moons eluded detection until now? Simply put, they're small and far away. Some measure little more than half a mile across, and the newest discovery, a Neptunian moon, is almost 3 billion miles from Earth. But state-of-the-art cameras, together with sophisticated computer programs that can quickly calculate the orbits of moving specks of light, are lifting the veil on the stealthy satellites.

Besides being small, the new moons have irregular shapes and highly elliptical orbits. Astronomers think they started life as wandering asteroids—chunks of rock—and eventually got caught in the planets' gravitational fields. (Up-to-date tabulations at www.ifa.hawaii.edu/sheppard/satellites/, maintained by David C. Jewitt and Scott S. Sheppard, both astronomers at the University of Hawai'i, in Honolulu)

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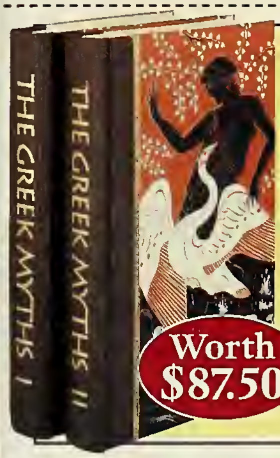

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Fair Is Fair

Capuchin monkeys know when they're getting a raw deal.

For more than two years Sarah F. Brosnan and Frans B.M. de Waal have been bartering with brown capuchin monkeys. Sometimes the animals get a fair deal, sometimes not. It's all part of a study the two primatologists are conducting at the Yerkes National Primate Research Center in Atlanta, on the evolutionary origins of the sense of fairness. Brosnan and de Waal propose that an aversion to inequity, regarded as a cornerstone of human cooperation, may have evolved in our primate ancestors.

In a recent experiment with pairs of captive capuchins, Brosnan handed a familiar token (a small rock) to one of the monkeys, then turned her own hand palm up. If the capuchin returned the token to Brosnan's hand within a minute, it got a reward. The same basic procedure was repeated nonstop with both monkeys, alternating between them, for twenty-five cycles.

The reward setup had four variations: (1) The reward was a piece of cucumber ("boring" food) for both monkeys in the pair—equal treatment for equal "work." (2) The "subject" got cucumber and its partner got a yummy grape, even though both monkeys did the same work. (3) The partner was absent, but a grape was placed in the partner's area as the subject watched. Then the subject not only had to work but also got cucumber in return. (4) The partner was given a grape without having done any work; the subject did the work but got the cuke—outrageously unequal treatment.

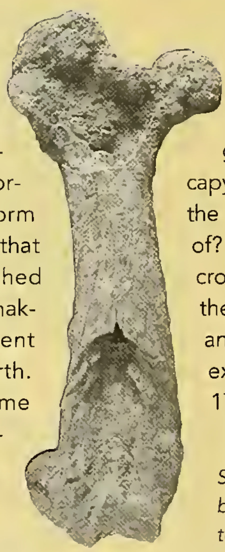
When treated unfairly, the five subjects often refused to return the rock token or tossed the cuke across the room. Occasionally a monkey settled for inequality, although sometimes it became more outraged as the unequal treatment persisted. ("Monkeys reject unequal pay," *Nature* 425:297–99, September 18, 2003)

The Mouse That Roared

Anybody unlucky enough to have rodentophobia should probably not contemplate hopping a time machine back to Miocene-era Venezuela. It seems that not all rodents in those days were cute little balls of fur like your daughter's guinea pig. Indeed, fossils of *Phoberomys pattersoni*—an 8-million-year-old close relative of the guinea pig recently discovered in a paleontological treasure trove known as the Urumaco Formation—show that this animal had plenty of long teeth and weighed almost as much as a Holstein cow.

To determine the animal's weight, Marcelo R. Sánchez-Villagra, a paleontologist at the University of Tübingen in Germany, and his colleagues measured the cross section of its leg bones, unlikely to have been broader than necessary to support the rest of the body. Factoring in *Phoberomys*'s likely form of locomotion, they calculated that the critter must have weighed something like 1,500 pounds, making it by far the largest rodent ever to have roamed the Earth. South America is still the home of overblown rodents, in fact, including the largest one extant: the sheep-size capybara.

On the basis of fossil plants surrounding the remains, as well as the shape of the animal's teeth, Sánchez-Villagra's team suggests that *Phoberomys* fed on rough grasses in or near water, as capybaras still do. So what would the über-rodents have been afraid of? Possibly the forty-foot-long crocodiles that abounded in the same place and time. ("The anatomy of the world's largest extinct rodent," *Science* 301: 1708–10, September 19, 2003)



Leg-bone cross section is a good indicator of an animal's weight.

Stéphan Reebs is a professor of biology at the University of Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

Gravity in Reverse

The tale of Albert Einstein's "greatest blunder"

By Neil deGrasse Tyson

Sung to the tune of "The Times They Are A-Changin'":

Come gather 'round, math phobes,
Wherever you roam
And admit that the cosmos
Around you has grown
And accept it that soon
You won't know what's worth knowin'
Until Einstein to you
Becomes clearer.
So you'd better start listenin'
Or you'll drift cold and lone
For the cosmos is weird, gettin' weirder.

—The Editors (with apologies to Bob Dylan)

Cosmology has always been weird. Worlds resting on the backs of turtles, matter and energy coming into existence out of much less than thin air. And now, just when you'd gotten familiar, if not really comfortable, with the idea of a big bang, along comes something new to worry about. A mysterious and universal pressure pervades all of space and acts against the cosmic gravity that has tried to drag the universe back together ever since the big bang. On top of that, "negative gravity" has forced the expansion of the universe to accelerate exponentially, and cosmic gravity is losing the tug-of-war.

For these and similarly mind-warping ideas in twentieth-century physics, just blame Albert Einstein.

Einstein hardly ever set foot in the laboratory; he didn't test phenomena or use elaborate equipment. He was a theorist who perfected the "thought experiment," in which you engage nature through your imagination, inventing a situation or a model and then working out the consequences of some physical principle.

If—as was the case for Einstein—a physicist's model is intended to represent the entire universe, then manipulating the model should be tantamount to manipulating the universe itself. Observers and experimentalists can then go out and look for the phenomena predicted by that model. If the model is flawed, or if the theorists make a mistake in their calculations, the observers will detect a mismatch between the model's predictions and the way things happen in the real universe. That's the first cue to try again, either by adjusting the old model or by creating a new one.

"Negative gravity" has forced the expansion of the universe to accelerate exponentially.

One of the most powerful and far-reaching theoretical models ever devised is Einstein's theory of general relativity, published in 1916 as "The Foundation of the General Theory of Relativity" and refined in 1917 in "Cosmological Considerations in the General Theory of Relativity." Together, the papers outline the relevant mathematical details of how everything in the universe moves under the influence of gravity. Every few years, laboratory scientists devise ever more precise experiments to test the theory, only to extend the envelope of its accuracy.

Most scientific models are only half baked, and have some wiggle room for the adjustment of parameters to fit the known universe. In the heliocentric universe conceived by the sixteenth-century astronomer Nicolaus Copernicus, for example, planets orbited the Sun in perfect circles. The orbit-the-Sun part was correct, but the perfect-circle part turned out to be a bit off. Making the orbits elliptical made the Copernican system more accurate.

Yet, in the case of Einstein's relativity, the founding principles of the entire theory require that everything take place exactly as predicted. Einstein had, in effect, built a house of cards, with only two or three simple postulates holding up the entire structure. (Indeed, on learning of a 1931 book titled *100 Authors Against Einstein,* he responded, "Why one hundred? If I am incorrect, one would have been enough.")

That unassailable structure—the fact that the theory is fully baked—is the source of one of the most fascinating blunders in the history of science. Einstein's 1917 refinement of his equations of gravity included a new term—denoted by the Greek letter lambda—in which his model universe neither expands nor contracts. Because lambda served to oppose gravity within Einstein's model, it could keep the universe in balance, resisting gravity's natural tendency to pull the whole cosmos into one giant mass. Einstein's universe was indeed balanced, but, as the Russian physi-

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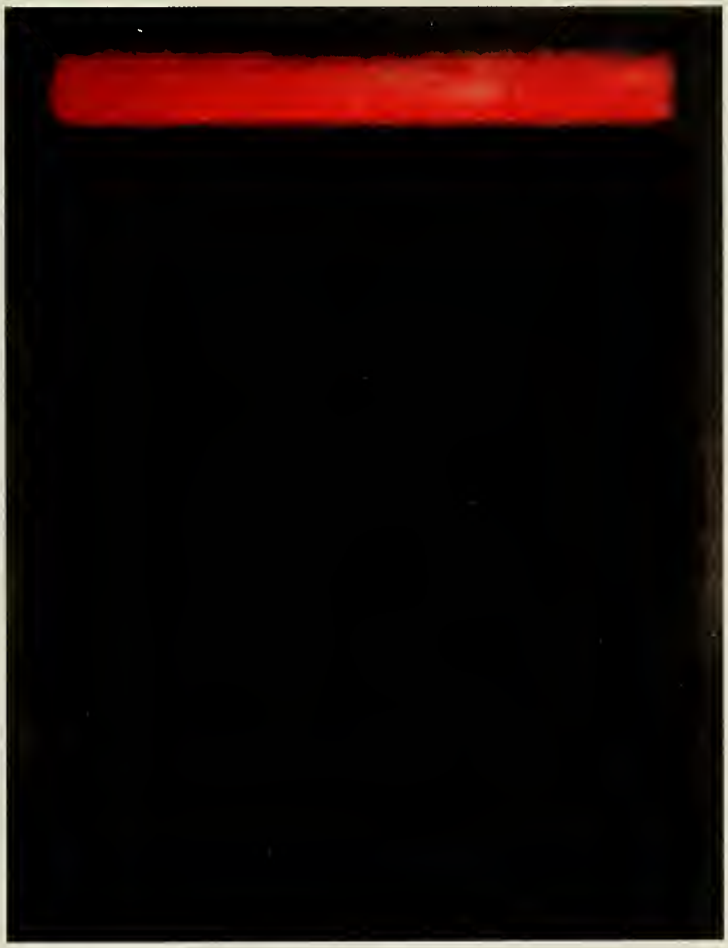
cist Alexsandr Friedmann showed mathematically in 1922, it was in a precarious state—like a ball at the top of a hill, ready to roll down in one direction or another at the slightest provocation. Moreover, giving something a name does not make it real, and Einstein knew of no counterpart in the physical universe to the lambda in his equations.

Einstein's general theory of relativity—called GR by verbally lazy cognoscenti—radically departed from all previous thinking about the attraction of gravity. Instead of settling for Sir Isaac Newton's view of gravity as "action at a distance" (a conclusion that discomfited Newton himself), GR regards gravity as the response of a mass to the local curvature of space and time caused by some other mass. In other words, concentrations of mass cause distortions—dimples, really—in the fabric of space and time. Those distortions guide the moving masses along straight-line geodesics, which look like the curved trajectories that physicists call orbits. John Archibald Wheeler, a physicist at Princeton University, put it best when he summed up Einstein's concept this way: "Matter tells space how to curve; space tells matter how to move."

In effect, GR accounts for two opposite phenomena: good ol' gravity, such as the attraction between the Earth and a ball thrown into the air or between the Sun and the Earth; and a mysterious, repulsive pressure associated with the vacuum of space-time itself. Acting against gravity, lambda preserved what Einstein and every other physicist of his day had strongly believed in: the status quo of a static universe. Static it was, but stable it was not. And to invoke an unstable condition as the natural state of a physical system violates scientific credo: you cannot assert that the entire universe is a special case that happens to be precariously balanced for eternity. Nothing ever seen, heard, or measured has acted that way in the history of science. Yet, in spite of being deeply uneasy with lambda, Einstein included it in his equations.

Twelve years later, in 1929, the U.S. astronomer Edwin P. Hubble discovered that the universe is not static after all: convincing evidence showed that the more distant a galaxy, the faster that galaxy is receding from the Earth. In other words, the universe is growing. Embarrassed by lambda, and exasperated by having thus blown the chance to predict the expanding universe himself, Einstein discarded lambda, calling its introduction his life's "greatest blunder."



Mark Rothko, *No. 5 (Red, Black, and Brown-Black)*, 1963

That wasn't the end of the story, though. Off and on over the decades, theoreticians would exhume lambda—more commonly known as the "cosmological constant"—from the graveyard of discredited theories. Then, sixty-nine years later, in 1998, science exhumed lambda one last time, because now there was evidence to justify it. Early that year two teams of astrophysicists—one led by Saul Perlmutter of Lawrence Berkeley National Laboratory in Berkeley, California; the other by Brian Schmidt of Mount Stromlo and Siding Springs Observatories in Canberra, Australia—made the same remarkable announcement. Dozens of the most distant supernovas ever observed, they said, appeared noticeably dimmer than expected—a disturbing finding, given the well-documented behavior of this species of exploding star. Reconciliation required that either those distant supernovas acted quite differently from their nearer brethren, or else they were as much as 15 percent farther away than the prevailing cosmological models had placed them.

Not only was the cosmos expanding, but a repulsive pressure within the vacuum of space was also causing the expansion to accelerate. Something had to be driving the universe outward at an ever-increasing pace. The only thing that "naturally" accounted for the acceleration was lambda, the cosmological constant. When physicists dusted it off and put it back in Einstein's original equations for general relativity, the state of the universe matched the state of Einstein's equations.

To an astrophysicist, the supernovas used in Perlmutter's and Schmidt's studies are worth their weight in fusionable nuclei. Each star explodes the same way, igniting a similar amount of fuel, releasing a similarly titanic amount of energy in a similar period of time, and therefore achieving a similar peak luminosity. Hence these exploding stars serve as a kind of yardstick, or "standard candle," for calculating cosmic distances to the galaxies in which they explode, out to the farthest reaches of the universe.

Standard candles simplify calculations immensely: since the supernovas all have the same wattage, the dim ones are far away and the bright ones are nearby. By measuring their brightness (a simple task), you can tell exactly how far away they are from you. If the luminosities of the supernovas were not all the same, brightness alone would not be enough to tell you which of them are far from Earth and which of them are near. A dim one could be a high-wattage bulb far away or a low-wattage bulb close up.

Fine. But there's a second way to measure the distance to galaxies: their speed of recession from our Milky Way, a recession that's part and parcel of the overall cosmic expansion. As Hubble was the first to show, the expansion of the universe makes distant objects race away from us faster than the nearby ones do. By measuring a galaxy's speed of recession (another straightforward task), you can deduce its distance from Earth.

If those two well-tested methods give different distances for the same object, something must be wrong. Either the supernovas are bad standard candles, or our model for the rate of cosmic expansion as measured by galaxy speeds is wrong.

Well, something *was* wrong in 1998. It turned out that the supernovas are splendid standard candles, surviving the careful scrutiny of many skeptical investigators. Astrophysicists were left with a universe that is expanding faster than they had ever thought it was. Distant galaxies turned out to be even farther away than their recession speed had seemed to indicate. And there was no easy way to explain the extra expansion without invoking lambda, the cosmological constant.

Here, then, was the first direct evidence that a repulsive pressure permeated the universe, opposing gravity. That's what resurrected the cosmological constant overnight. And now cosmologists could estimate its numerical value, because they could calculate the effect it was having: the difference between what they had expected the expansion to be and what it actually was.

That value for lambda suddenly signified a physical reality, which now needed a name. "Dark energy" carried the day, suitably capturing our ignorance of its cause. The most accurate measurements done to date have shown dark energy to be the most prominent thing in town.

Direct evidence indicates that a repulsive pressure known as dark energy permeates the universe, opposing gravity.

The shape of our four-dimensional universe comes from the relation between the amount of matter and energy that inhabits the cosmos and the rate at which the cosmos is expanding. A convenient mathematical measure of that shape is usually written as the uppercase Greek letter omega (Ω). If you take the matter-energy density of the universe, and divide it by the matter-energy density required to just barely halt the expansion (known as the "critical" density), you get omega.

Because both mass and energy cause space-time to warp, or curve, omega effectively gives the shape of

the cosmos. If omega is less than one, the actual mass-energy falls below the critical value, and the universe expands forever in every direction for all of time. In that case, the shape of the universe is analogous to the shape of a saddle, in which initially parallel lines diverge. If omega is equal to one, the universe expands forever, but only barely so; in that case the shape is flat, preserving all the geometric rules we all learned in high school about parallel lines. If omega exceeds one, parallel lines converge, and the universe curves back on itself, ultimately recollapsing into the fireball whence it came.

At no time since Hubble discovered the expanding universe has any team of observers ever reliably measured omega to be anywhere close to one. Adding up all the mass and energy they could measure, dark matter included, the biggest values from the best observations topped out at about 0.3. Since that's less than one, as far as observers were concerned, the universe was "open" for the business of expansion, riding a one-way saddle into the future.

Meanwhile, beginning in 1979, Alan H. Guth, a physicist at MIT, and others advanced an adjustment to big bang theory that cleared up some nagging problems. In brief, Guth explained why things look about the same everywhere in the universe. A fundamental by-product of this update to the big bang was that it drove omega toward one. Not toward one-half. Not toward two. Certainly not toward a million. Toward one.

Scarcely a theorist in the world had a problem with that requirement, because it helped get the big bang to account for the global properties of the known universe. There was, however, another little problem: the update predicted three times as much mass and energy as observers could find. Undeterred, the theorists said the observers just weren't looking hard enough.

At the end of the tallies, visible matter alone could account for very little of the critical density. How about the mysterious dark matter? Nobody knows what dark matter is, but observers knew there is five times as much dark matter as visible matter. They added that in as well. Alas, still way too little mass-energy. The observers were at a loss. "Guys," they protested, "there's nothing else out there." And the theorists answered, "Just keep looking."

Both camps were sure the other camp was wrong—until the discovery of dark energy. That single component raised the mass-energy density of the universe to the critical level. Yes, if you do the math, the universe holds three times as much dark energy as anything else.

A skeptical lot, the community of astrophysicists decided they would feel better about the result if there were some way to corroborate it. The Wilkinson Microwave Anisotropy Probe (WMAP) was just what the doctors ordered and needed. This NASA satellite, launched in 2001, was the latest and best effort to measure and map the cosmic microwave background, the big bang's blueprint for the amount and distribution of matter and energy in the universe. Astrophysicists can now say with confidence that omega is indeed equal to one: the matter-energy density of the universe we know and love is equal to the critical density. The tabulation? The cosmos holds 73 percent dark energy, 23 percent dark matter, and a measly 4 percent ordinary matter, the stuff you and I are made of.

For the first time ever, the theorists and observers kissed and made up. Both, in their own way, were correct. Omega is one, just as the theorists demanded of the universe, even though you can't get there by adding up all the matter—dark or otherwise—as they had naively presumed. There's no more matter running around the cosmos today than had ever been estimated by the observers. Nobody had foreseen the dominating presence of cosmic dark energy, nor

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So what is this stuff? As with dark matter, nobody knows. The closest anybody has come to a reasonable guess is to presume that dark energy is a quantum effect—whereby the vacuum of space, instead of being empty, actually seethes with particles and their antimatter counterparts. They pop in and out of existence in pairs, and don't last long enough to be measured. Their transient existence is captured in their moniker: virtual particles.

But the remarkable legacy of quantum mechanics—the physics of the small—demands that we give these particles serious attention. Each pair of virtual particles exerts a little bit of outward pressure as it ever so briefly elbows its way into space. Unfortunately, when you estimate the amount of repulsive "vacuum pressure" that arises from the abbreviated lives of virtual particles, the result is more than 10^{120} times bigger than the value of the cosmological constant derived from the supernova measurements and WMAP. That may be the most embarrassing calculation ever made, the biggest mismatch between theory and observation in the history of science.

I'd say astrophysicists remain clueless—but it's not abject cluelessness. Dark energy is not adrift, with nary a theory to call home. It inhabits one of the safest homes we can imagine: Einstein's equations of general relativity. It's lambda. Whatever dark energy turns out to be, we already know how to measure it and how to calculate its effects on the cosmos.

Without a doubt, Einstein's greatest blunder was having declared that lambda was his greatest blunder.

A remarkable feature of lambda and the accelerating universe is that the repulsive force arises from within the vacuum, not from anything material. As the vacuum grows, lambda's influence on the cosmic state of affairs grows with it. All the while, the density of matter and energy diminishes without limit. With greater repulsive pressure comes more vacuum, driving its exponential growth—the endless acceleration of the cosmic expansion.

As a consequence, anything not gravitationally bound to the neighborhood of the Milky Way will move away from us at ever-increasing speed, embedded within the expanding fabric of space-time. Galaxies now visible will disappear beyond an unreachable horizon. In a trillion or so years, anyone alive in our own galaxy may know nothing of other galaxies. Our—or our alien Milky Way brethren's—observable universe will merely comprise a system of nearby stars. Beyond the starry night will lie an endless void, without form: "darkness upon the face of the deep."

Are we missing some basic pieces of the earlier universe? What part of the cosmic saga has been erased?

Dark energy, a fundamental property of the cosmos, will, in the end, undermine the ability of later generations to comprehend their universe. Unless contemporary astrophysicists across the galaxy keep remarkable records, or bury an awesome time capsule, future astrophysicists will know nothing of external galaxies—the principal form of organization for matter in our cosmos. Dark energy will deny them access to entire chapters from the book of the universe.

Here, then, is my recurring nightmare: Are we, too, missing some basic pieces of the universe that once was? What part of our cosmic saga has been erased? What remains absent from our theories and equations that ought to be there, leaving us groping for answers we may never find?

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City.

Good Whale Hunting

Two tantalizing Russian reports take the author on a quest to the Antarctic, in search of two previously unrecognized kinds of killer whale.

By Robert L. Pitman

They always remind me of witch's hats—a little bit of Halloween in the winter wonderland. Looking across a flat plain of frozen Antarctic sea ice, I watch as a herd of killer whales swims along a lead—a long, narrow crack in the six-foot-thick ice. The fins of the males are black isosceles triangles, five feet tall, and they look like a band of trick-or-treaters coming our way. I am on board the U.S. Coast Guard icebreaker *Polar Star* as it back-and-rams the frozen ocean to open up a fourteen-mile-long channel into McMurdo Station, fifty feet at a whack. The National Science Foundation has offered me a bunk on board the vessel while I study the killer whales that inhabit the pack ice of the southern Ross Sea.

New killer whale on the block? Unlike the killer whale familiar to aquarium visitors, the kind pictured above, in the southern Ross Sea, lives in the Antarctic pack ice. To find their way from one breathing hole to the next, the whales "spyhop," lifting their heads above the surface to get a better view before picking their way through the dangerous and shifting channels of pack ice.

In the early 1980s, whalers from the former Soviet Union, presumably in the mood for some new product testing, slaughtered more than 900 Antarctic killer whales in one season. Workmen on the flensing deck of the factory ships, where the blubber and meat is stripped off the animals, quickly realized that two quite different kinds of killer whale were being hauled up the slipway for processing. The differences were so striking that two groups of Soviet investigators independently described new species of killer whale from the Soviet catch data—though it is not clear from their accounts whether they were describing the same, or different, new species.

In any event, one group's description was too vague, and a holotype, or museum reference specimen, was not designated, so the description has to be scientifically ignored. The other description, however, by Alfred Berzin and Vladimir Vladimirov, both cetacean biologists at the Pacific Research Institute of Fisheries and Oceanography in Vladivostok, Russia, provided some fairly solid evidence that there might be two species of killer whale in Antarctica. (Unfortunately, although Berzin and Vladimirov designated a holotype specimen, it has subsequently been discarded.) One species, of course, is the familiar denizen of SeaWorld, a large black-and-white form that lives throughout the world's oceans but does not penetrate into the Antarctic ice. It travels in herds of between ten and twenty animals and feeds almost exclusively on marine mammals, particularly Antarctic minke whales *(Balaenoptera bonaerensis)*. This form is likely just a summer visitor to Antarctica.

Berzin and Vladimirov reported that the second form, which they provided a name for—*Orcinus glacialis*—in their belief that the species was new to science, lives mainly in the pack ice, where it may be a year-round resident. It occurs, they said, in herds that sometimes number in the hundreds of individuals. The animal is between three and five feet shorter than *O. orca*, with markings that are yellowish in color instead of white, and feeds almost exclusively on fish. The yellow coloration is presumed to be from an infestation of diatoms. Caused by microscopic phytoplankton that occur in polar waters and on the underside of ice, the coloration is a characteristic of all forms of pack-ice killer whales, but not of *O. orca*. The pack-ice animal also has much smaller teeth than *O. orca*, which may be related to its diet of fish. Although the Russian description of *O. glacialis* is in many ways convincing, most cetacean biologists have not accepted the validity of a second species, much less a third one (the species described so vaguely by the second group of Soviet investigators). Yet the evidence is tantalizing enough that I have come to the Antarctic Ocean to see for myself.

As the *Polar Star* sits motionless at the head of the channel we have just created, killer whales that were swimming along the edge of the pack ice are now moving toward us through the broken ice that has filled in behind the ship. As they enter the dense pack ice, their heads start sprouting up through the shattered ice like giant black-and-white tulips. They are "spyhopping": hovering above the surface for a second or two, where they seem to be eyeing our vessel and the ice in between us and them, and then easing straight back down into the water.

It dawns on us that the entire herd of thirty or so animals are leap-frogging through the pack ice and moving toward the stern of our ship, seemingly interested in the pool of open water that our prop wash has created. Sometimes individuals pop up several times in the same spot, apparently looking ahead for the next open water before they proceed. Their heads jut high out of the water, maybe six feet or so, and they crane their necks to scan the surface in search of the next breathing hole. Getting stuck under the ice would spell certain death for these air-breathers, and they need to carefully plan their moves.

As they close in around us, we notice another intriguing behavior: just before the whales break the surface, the sea boils vigorously and a perfect circle of clear water opens up above them. Most of the broken ice behind the ship is tightly packed, and the shards are hard and often sharp. The adult whales are forcefully exhaling just before surfacing, opening up a breathing space several feet across so they won't cut or scrape their sensitive skin on the ice debris. Whale calves also surface in the ring of open water, right next to their mothers.

Later that evening a different group of twenty killer whales appears to be socializing in a large open pool in our channel. We count as many as twelve individuals that seem to be practicing synchronized swimming: they charge around at high speeds and make sharp turns, all the while keeping in tight shoulder-to-shoulder formation. One animal is swimming upside-down at the surface when an adult female strikes it midbody from below, propelling it sideways and ten feet out of the water. It looks like tons of fun.

Pack-ice killer whales of the Ross Sea, probably the form to which Russian biologists gave the new species name Orcinus glacialis, are also partly distinguishable by a "cape"—a dark coloring on the whale's back that is distinct from the lighter shading below, typified by the animal shown here. The cape is not present in O. orca.

A few days later we find another herd of killer whales beyond the pack ice. Captain Dave MacKenzie gives me the okay to go over the side in a launch, along with fifteen or so curious Coasties. Most of the crew truly enjoy being outside—if only because it is the only time they are allowed to smoke while on board the *Polar Star*. Probably none of them has ever been right up close to a whale in the wild before, and they aren't quite sure what to expect. Some of the killer whales are almost as long as our twenty-five-foot launch, and there is concern on the faces of the younger crew members, some only recently out of high school. Someone asks me if I am going to be killing any whales today, and I realize I should have given them a little talk before our initial outing.

The launch is rather boxy looking, but somehow it churns ahead at forty knots. We quickly catch up to the herd. These whales are the kind I came here to find: they are smaller than the usual form; and they have a distinctive "cape," or darker coloring on the back, in contrast to the lighter shading below, and yellowish instead of white patches. We are lucky to find them in open water. It is a fairly large group, maybe fifty-five individuals, including several adult males and some very young calves. They are scattered over a mile or so, in subgroups of between one and ten animals. My hope is to photograph as many individuals as I can from close range, to confirm that they are the pack-ice types. I also plan to collect some biopsy samples, which will enable us to compare these animals genetically with killer whale populations elsewhere in the world, to determine just how distinct they are. If the whales are cooperative, we'll get our photos and samples; if they're evasive, all we'll get is wet.

To collect the biopsy samples, I have brought two crossbows along: a small crossbow if the whales allow us close access, and a compound crossbow in case I have to call long distance, a hundred feet or more. The darts I shoot are regular aluminum-shaft arrows, but they have a float attached to the business end and a small cutting head threaded onto the tip. The cutting head extracts a plug of tissue about the size of a pencil eraser.

Normally when I shoot, the dart bounces harmlessly off the back of the animal and lands floating on the surface, where we motor over and pick it up. When I describe the biopsy operation to the launch crew, some seem uncomfortable with the idea at first, but that only lasts until they see the dart bounce off a whale like a soda straw off a truck tire. The darting itself usually has little noticeable effect on the whales and they are often more annoyed at the launch buzzing around among them, so we try to take care of business quickly and then leave them alone.

A lot is riding on this sortie—months of planning are coming to a head. The weather is sloppy, and subfreezing spray douses us whenever we head upwind (apparently a favorite direction for killer whales!). Clearly the weather is not going to give us much of a break. I just hope the whales will cooperate. Although I have talked to the helmsman in advance about how to approach the whales, I still have to shout instructions back from my lookout in the bow, over the din of the engine and the pounding of our launch against the waves. Our operation is akin to calf-roping from a jet ski, and our young driver begins a little apprehensively. But goading from the other crew members onboard carries the day, and soon she's charging into the fray.

The whales are moving along, all in the same direction and at a fairly fast clip; they seem to have an appointment somewhere. That makes it relatively easy for us because what we plan to do is come up directly behind them, traveling only slightly faster than they are, and then swing out sixty feet or so to the side. That maneuver will get us broadside to the whales and give us nice targets for the camera and crossbow, with minimal disturbance to the herd.

O. orca, the most familiar killer whale, is the largest member of the dolphin family. When the animal visits Antarctic waters, it probably does so only as a summer migrant, feeding in open water seaward of the ice pack. The whale is usually jet-black, with a white underbelly.

As we move to within 300 feet of our target subgroup, some of the whales slightly alter the way they swim, but clearly in response to our presence. Their surfacing rhythm changes, and some animals veer away from the group a bit as they dive. Some of the females rein in their calves. But ultimately the whales have no major reactions to us, and our prospects look good. I pick out a pair of adult males for the driver to sidle up to.

I fire a dart that seems to loft for an eternity. But it finds its mark, then bounces off the back of the nearest whale. As frequently happens when two whales travel close together, the companion whale responds to the darting the instant the target whale is hit. This companion gives a quick flick of the tail—just a little reminder that whales and dolphins perfected high-speed, wireless communication millions of years before human beings even began doodling on cave walls.

I wave wildly at the driver for us to go back and pick up the dart—she hasn't seen me shoot and is still throttling hard forward, trying to keep up with the whales. We finally do a hard turn to starboard and circle back to where my Day-Glo orange dart is bobbing in the middle of a slick left by the diving whale. As we ease in for the pick-up, I can see a tiny nub of blubber protruding from the end of the tip. We have the sample. The first one is always the most important.

We catch up with the herd again, trying to take more photographs and samples. And as we do, our boat crew looks on in stunned awe as four-ton killer whales lunge alongside, within ten feet of our launch. For sheer size and predatory power, the killer whale is probably the closest thing to a living *Tyrannosaurus rex* on Earth today. But there is also a remarkable beauty about the beasts: they fairly gallop, like sleek thoroughbreds, through the velvety cold Antarctic water, their black and white bodies a glistening collage of wet inner tube and white porcelain.

We spend almost two hours with the whales, half of it as my shipmates hold me by the ankles while I dangle over the side retrieving darts. (In my haste I forgot to bring a net, but fortunately the Coast Guard has a knack for pulling people out of the water.) Still, we have a fine outing: nine tissue samples and three rolls of exposed film.

As in nearly all biological investigations, simple questions rarely have sim-

ple answers, and the taxonomic status of Antarctic killer whales—How many species are there?—is no exception. All killer whales have a white pigmented area behind the eye called an eye patch. Around McMurdo, in the southern Ross Sea, I found that the killer whales in the pack ice have small, slanted eyepatches, and they apparently feed mainly on Antarctic toothfish *(Dissostichus mawsoni)*, a fish that grows to more than six feet long and more than 250 pounds.

The following year, however, near the Antarctic Peninsula on the other side of the continent, I found that the killer whales patrolling the pack ice are quite different: they have large eye patches that aren't slanted, and they prey mainly on the several species of seals that feed and live among the ice floes.

The seal hunters also forage in a distinctive way: they travel in scattered groups, spyhopping through the loose pack ice, looking for seals. And when they locate a seal on a floe, they have plenty of tricks for taking it off the ice. If the ice is thin, less than a foot or so, they can smash through from below. Sometimes, if a seal is on a small but thick chunk of ice, a large male whale will tilt one end of the floe up with its head, tumbling the hapless seal into the clutches of the rest of the waiting herd. At other times, a group of whales will swim off to 150 feet or so from a target seal, then turn and charge it. At the last second the whales turn sharply, sending a large wave over the floe that washes the seal off the ice and onto the menu. According to one report posted on the Internet, a killer whale lunged completely out of the water, stranding itself on an ice floe as it grabbed a seal. Immediately thereafter, two other herd members clapped their mouths onto either side of its tail and pulled it back into the water. I think people who train killer whales may be giving themselves too much credit.

After three seasons in Antarctica, I am convinced that in addition to the familiar killer whale from around the world, at least one and probably two additional species of killer whale lurk in the icy waters around the cold continent. What I have seen are three quite different-looking forms, which have different, but at times overlapping, ranges and habitats. The three forms also prefer different prey and travel together in herds of different size (the latter behavior suggests their social structure is probably different, too). And though there are no discernible physical barriers to prevent intermingling or interbreeding, I have never seen mixed herds or any individual that looks like an intermediate form, or hybrid. The failure to find any social mixing or apparent hybrids is highly significant in itself.

Pack-ice killer whales living along the Antarctic Peninsula may constitute a second new species. Characterized by large "eye patches," whitish oval markings above and behind the eyes, these orcas prey mainly on seals. The three most prominent spyhopping orcas in the photograph have encircled a Weddell seal on an ice floe; a leopard seal is at left, on an adjacent floe.

Like the earlier reports of the Soviets, these conclusions will be met with healthy skepticism by other marine-mammal scientists. To meet this challenge I have already begun some collaborative studies on the genetics, vocalizations, and morphology of Antarctic killer whales that will bring additional evidence to bear on these issues. The preliminary analysis of the tissue samples I have collected, for instance, already suggests that the three forms may not interbreed, but the results are still preliminary and verification will take a while. There are no simple answers.

But there is a sense of urgency to learn more about the Antarctic pack-ice killer whales, an urgency that goes far beyond academic concerns. Fishing boats from New Zealand and elsewhere have recently begun to experiment with commercial fishing for Antarctic toothfish in the southern Ross Sea. That raises a host of questions for pack-ice killer whales. How dependent are they on toothfish? How abundant is the toothfish? How many whales do the toothfish support, and where else do those whales occur? Will the new fishery, as our work suggests so far, endanger the food source of an entirely new and independent species?

Biologists have a long way to go before they can resolve such questions. Yet the answers could become critically important to the survival of the whales, particularly if they are forced to compete with an industrial-scale fishery. Until now, their obscurity in the Antarctic pack ice has served them well. But it may be time for pack-ice killer whales to come in out of the cold.

Robert L. Pitman is a marine ecologist with the National Marine Fisheries Service in La Jolla, California. He spends six to eight months a year at sea studying whales and dolphins. His most recent contribution to Natural History *was "Alive and Whale," in the September 2002 issue.*

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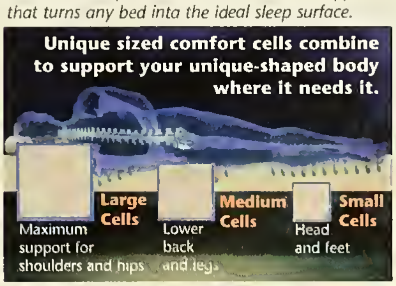

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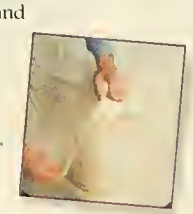

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Uphill Flight

A partridge's ability to climb overhanging slopes might explain how dinosaurs took to the skies.

By Adam Summers ~ Illustration by Roberto Osti

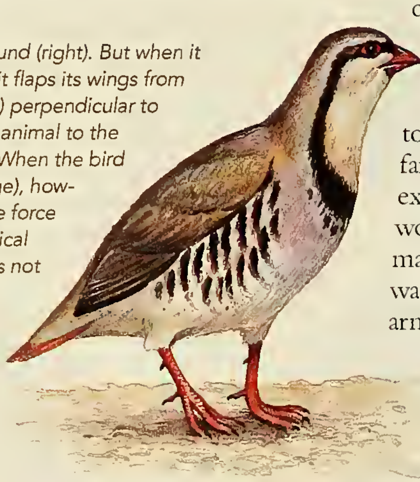
The debate over the origin of birds has raged through the paleontological community for more than a century. Fitting species into evolutionary family trees is painstaking and often contentious work, but truly amazing discoveries of feathered fossils in Liaoning Province in northeastern China have enabled paleontologists to identify the group of dinosaurs that gave rise to Tweety and brethren. The fossils, unearthed in the past decade, even give a peek at the origin of feathers. But paleontologists still debate one point: How did bipedal but terrestrial archosaurs (the "old lizards," which include dinosaurs, birds, and crocodilians) learn to flap their arms and fly? Not surprisingly (given the title of this column), biomechanics has come to the rescue. One of the most compelling hypotheses for the evolution of avian flight has recently been well fortified by observing the habits of some of today's poorest fliers.

Two main camps have dominated the debate about the origin of flight. According to the "trees-down" camp, arboreal dinosaurs first evolved the ability to glide off their perch in a tree, much the way colugos—the so-called "flying lemurs"—and some frogs, lizards, snakes, and squirrels do today. Later, the gliders evolved the ability to flap from tree to tree.

Proponents of the trees-down scenario maintain that wings and feathers would have been useful for gliding, even if they preceded such adaptations as the shoulder girdle, the huge pectoral muscles, and the peculiar wrist and hand structures that make possible the powered, flapping flight of birds. Yet, as detractors of the hypothesis point out, none of the extant gliding animals perform even rudimentary flapping. They are all strictly gliders, and there is no reason to suppose they will ever be otherwise. Even worse, the dinosaurs most closely related to birds, the unfeathered dromaeosaurs, which include such terrors as *Deinonychus* and the better known *Velociraptor,* were clearly terrestrial. So even though a change from gliding to flapping might be an easy idea to swallow, neither the several independently evolved gliders nor the fossil record lend it any support.

Partisans from the second camp, in contrast, favor a "ground-up" hypothesis. In their view, terrestrial, bipedal dinosaurs flapped their "arms" first and later evolved into fliers. But the ground-up hypothesis has faced an even tougher challenge than the trees-down view. Although the fossil record clearly demonstrates that pre-avian dinosaurs were fond of terra firma, explanations that require the transition from bald, sprinting dinosaur to feathered, flapping bird seem a bit far-fetched. Feathers might have, for example, evolved as insulation, which would further imply that dromaeosaurs were endothermic, or warm-blooded. Or maybe feathered arms were useful as a net to catch flying insects, or as a horizontal stabilizer—like a tightrope-walker's pole—for swiftly running, predatory bipeds.

One biologist has come



Chukar partridge does not use its wings when on level ground (right). But when it climbs a steep slope (lower illustration on opposite page), it flaps its wings from roughly its head to its tail, generating a force (purple arrow) perpendicular to the plane in which the wings move. That force "holds" the animal to the ground, giving extra traction to the bird's feet as it climbs. When the bird climbs a vertical surface (upper illustration on opposite page), however, its wings beat in a more back-to-front fashion, and the force they generate has both a horizontal (blue arrow) and a vertical (red arrow) component. Although the vertical component is not necessary for climbing a tree trunk—the bird generates enough force for that with its legs alone—the component shows that the bird (or, equally, perhaps, a protobird or a feathered dinosaur) can redirect the wing-flapping force merely by altering the plane in which the wings are flapped. Such an ability would have been crucial to the origins of flight, as wings were co-opted to provide thrust instead of traction (top).

up with a ground-up proposal that, on the face of it, might seem even more off the wall. Kenneth P. Dial studies the biomechanics of flight at the University of Montana in Missoula. He suggested recently that flight arose from arm movements intended to push a bird (or a feathered dinosaur) into the ground rather than lift it up. The genesis of that odd idea was his observation that, when running up a slope, a chukar partridge *(Alectoris chukar)* flaps its wings quite differently than a bird does when it tries to get off the ground.

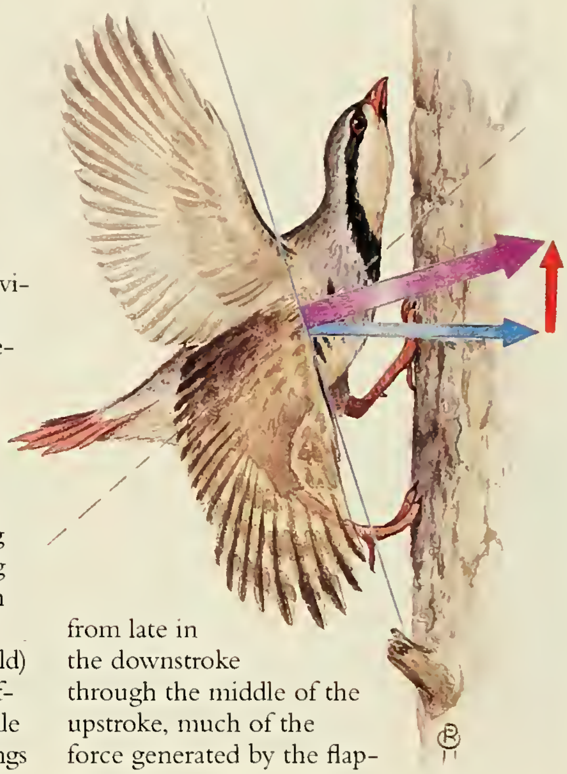
Partridges, chickens, and quail are known as galliform birds (the name comes from the Latin word *gallus,* meaning "rooster," and the Galliformes are all chickenlike). Typically, they have broad, stubby wings; easily fatigued flight muscles; and chicks that are ready to run, though not to fly, when they hatch. When a predator such as a fox or a weasel threatens a young chukar partridge, the bird escapes by fleeing up a steep slope. As it runs uphill, the chukar flaps its wings madly. The behavior has long been regarded as a failed attempt at flying, pointless because the young chukar's flight feathers (called remiges) are not yet fully developed.

Dial first established that though the remiges are not long enough to enable takeoff, they do improve traction enough for the young chukars to climb. After trimming or removing the remiges of chukars of various ages, Dial discovered that without the help of feathers, the birds could not run up slopes steeper than sixty degrees. Fully feathered animals, however, could scamper and flap their way up vertical and even slightly overhanging slopes.

Dial then turned his attention to the birds' legs. To measure their contribution to the climb, he constructed two kinds of ramp, smooth and textured, which gave quite different traction to scrabbling claws. No matter how well feathered they were, adult birds and young birds alike couldn't scale smooth ramps steeper than fifty degrees.

The data could be explained in two ways. It might initially seem obvious that the flight feathers, though short on the younger birds, nonetheless provide enough vertical lift to make the chicks light on their feet, boosting them up the steeper slopes. Alternatively, the flapping wings could be generating force in the direction of the ramp, increasing the hind-limb traction of the fleeing chicks. This hypothesis also fits with another observation: the stroke of every chukar's (whether young or old) wing beat while running is quite different than that of its wing beat while flying. Rather than flapping the wings from back to belly, as other birds do, the partridges flap from head to tail.

To test the two hypotheses, Dial and his student Matthew W. Bundle attached a small accelerometer to the back of a bird (the instrument measures the acceleration of the bird's center of mass at any point in time) and filmed the animal running up a ramp. They confirmed that



from late in the downstroke through the middle of the upstroke, much of the force generated by the flapping wings helps a chukar's feet get traction.

This research implies a plausible model for the selective advantage of both the flapping motion and a poorly feathered wing. Lightly feathered dromaeosaurs might have relied on wings for help in climbing steep slopes and even entering trees, just as extant galliform birds do. The peculiar flapping style that helps ground the bird could then easily be co-opted into the wing stroke now present in flighted birds. The chukars vary the angle of their wings depending on the slope of the substrate they're climbing, and the angle becomes increasingly similar to that of a flying bird as a chukar climbs slopes of ninety degrees or steeper.

It's not conclusive evidence for the evolution of flight—and since behavior doesn't fossilize, one can never be certain. For the first time, however, the ground-up proponents have a model that's not so much "off the wall" as up it.

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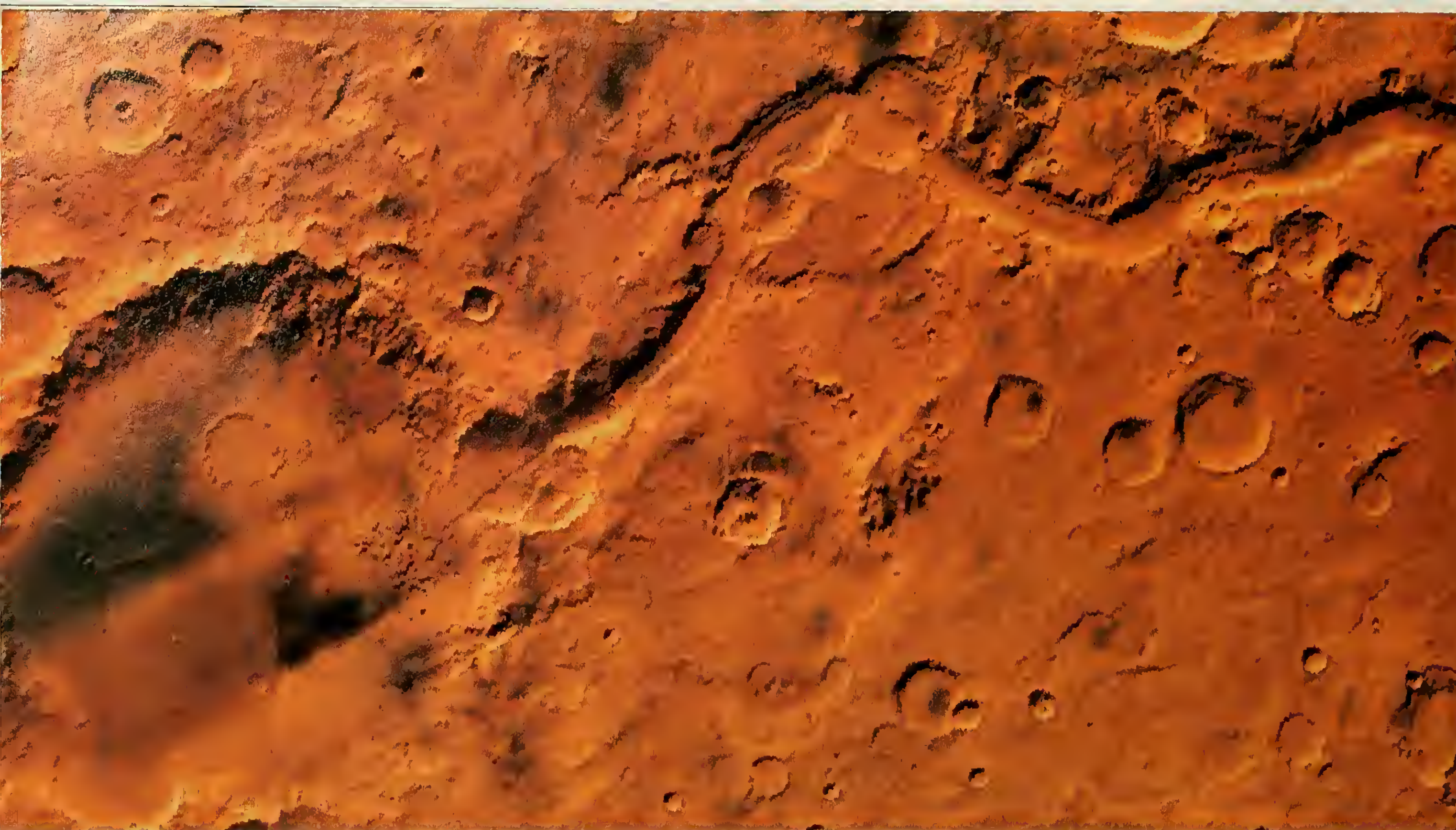
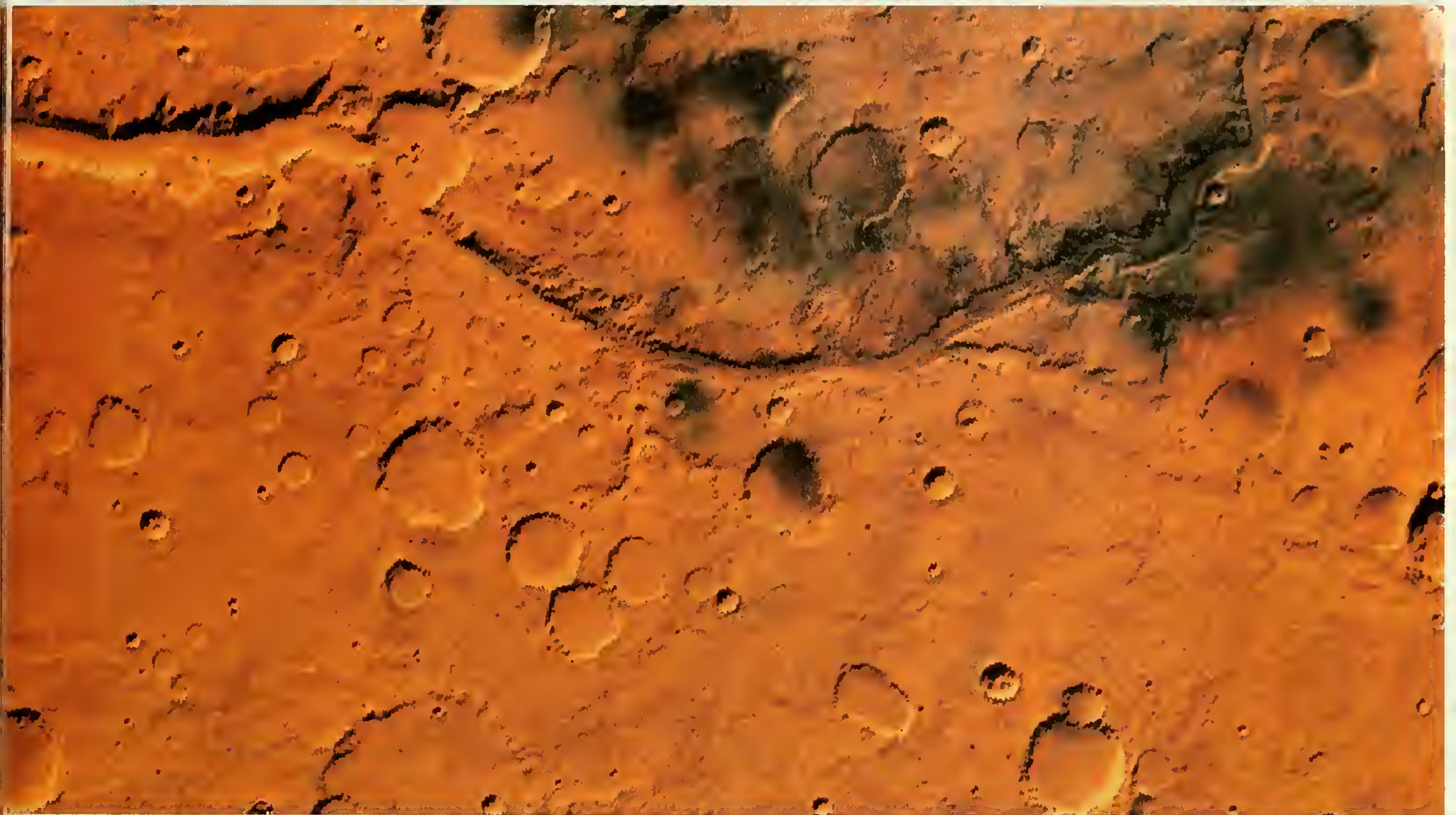


Gusev crater (left), the landing site for the NASA rover Spirit, may be an ancient lake bed. Feeding into the crater from the southeast is Ma'adim Vallis, a dry valley that appears to have been cut by a 540-mile-long river. (Ma'adim is Hebrew for "Mars.") The Gusev crater, some 100 miles across, probably dates to at least 3.8 billion years ago, when the large-scale bombardment of the inner solar system by meteorites ceased. The crater floor, however, is quite smooth, probably because of the deposition of sediments by the river, which could have continued until much later. Eventually rivers would have ceased to flow, probably because the planet turned colder (if, indeed, it was ever warm) and the remaining liquid water either froze or evaporated into space. The photomosaic shown here was made by a Viking orbiter; "north" is toward the left.

What Became of the Water on Mars?

This January, a cluster of spacecraft will converge on the Red Planet, probing for clues to the mysterious but unmistakable role of water in its past.

By Michael H. Carr



As this issue of *Natural History* went to press, at least six spacecraft were already orbiting—or speeding toward a rendezvous with—the planet Mars. In the vanguard of this wave of martian exploration are two NASA orbiters, the *Mars Global Surveyor,* in orbit since 1997, and the *Mars Odyssey,* in orbit since 2001, which have by now collectively observed the planet for eight years. The two have already returned an enormous amount of data about Mars: its topography, which reflects a surprisingly complex geological history, incorporating thick stacks of layered sediments and seemingly recently waterworn gullies; its ancient magnetic field, now vanished because its core has cooled, but still traceable in the magnetization of ancient rocks; its surface chemistry and its primarily basaltic mineralogy; and its fine-scale surface structures, sculpted by wind and ice. The data from the two orbiters have also been crucial for planning the other missions now approaching Mars, particularly in helping planetary geologists pick exploration sites that are both scientifically interesting and relatively free of hazards to landing.

First among the approaching missions is another orbiter, *Nozomi,* launched by Japan's Institute of Space and Aeronautical Science in 1998. It is due to arrive in January. *Nozomi* will examine the interaction of the planet's upper atmosphere with the so-called solar wind, made up of highly energetic particles from the Sun. Since Mars has no magnetic field, it is constantly bombarded by the solar wind. The particles carry enough energy to break molecules in the upper atmosphere into their atomic constituents. Some of the lighter resultant elements get carried away in the solar wind, and so the planet is gradually losing its atmosphere. Knowing how fast that is happening today will enable scientists to estimate how thick the atmosphere was in the past, and so—because of the greenhouse effect of an atmosphere—how warm the planet may once have been.

This past June the European Space Agency launched the *Mars Express,* made up of an orbiter, the eponymous *Mars Express,* and a lander known as the Beagle 2. *Mars Express* will go into orbit this Christmas Day, minutes after Beagle 2 is scheduled to land on Isidis Planitia [*see map on page 35*]. The lander is to measure surface and atmospheric properties, and will probe as deep as five feet into the martian soil. Its onboard instruments will seek bulk organic matter, as well as the isotopic signature of the biologically important element carbon. Most elements occur in nature as a mix of isotopes of slightly differing atomic weights. On Earth, some biological processes preferentially utilize certain isotopes of some elements, so that the carbon isotopes that occur in organic molecules, for instance, have different weights than the ones that occur in inorganic compounds. Measuring the isotopic ra-

Teardrop-shaped islands in the region known as Ares Vallis suggest the awesome force of martian floods. The large crater at the lower right is about three miles across. The islands were left standing as the floodwaters, deflected by craters, eroded away and scoured the surrounding terrain. This region is near the 1997 landing site of the Pathfinder rover. Water would have flowed from the lower right corner of the image in a torrent probably lasting a few days—if earthly floods are any guide. The image was made by the Mars Odyssey.

tios on Mars will provide clues about possible biological activity.

The orbiter *Mars Express* has numerous instruments for analyzing the surface and atmosphere, including a high-resolution stereo camera and instruments for measuring surface composition that complement the ones on *Mars Global Surveyor. Mars Express* also has a radar device for detecting water more than a mile below the surface.

Finally, this past summer NASA launched two Mars rovers, which will join the two U.S. spacecraft already examining the planet. Spirit, the first rover, is scheduled to land on the surface on January 4, 2004; Opportunity, the second, will land on January 25. The two rovers will land on opposite sides of the planet and investigate the geology of regions where liquid water might once have been present. The targets of their searches will be water-bearing minerals and sediments laid down by water.

The two rover missions, along with the other four, constitute by far the greatest assemblage of spacecraft people have ever sent to Mars. Their presence will dramatically pick up the tempo of the research begun by the Viking missions and, more recently, by the 1997 Pathfinder rover. Those missions failed to find any evidence of life on the martian surface. Yet of all the extraterrestrial bodies in the solar system, Mars is still the most likely place where conditions might have been hospitable for life. If Spirit and Opportunity successfully carry out their missions, planetary scientists will have a much better idea of whether some form of life evolved on Mars in the past, and of where we might best go to look for it, or for its remains.

The modern roots of people's fascination with Mars extend at least as deep as the late eighteenth century. By that time observations had already revealed that Mars has some remarkably Earth-like qualities: polar caps, seasons, clouds, a day that lasts roughly twenty-four hours, and even, it seemed, oceans. On the basis of those observations, the contemporary English astronomer William Herschel speculated that life existed on Mars.

It wasn't until the late nineteenth century, however, that the public became caught up in what quickly grew to be a frenzied discussion about the ways of martians. The dynamo behind the popular hysteria was a nineteenth-century American named Percival Lowell. Lowell, a scion of a prominent Boston family, was a devotee of Asian culture and an accomplished amateur astronomer. The main "evidence" Lowell offered for his speculations about life was an elaborate network of "canals" that had been observed and mapped by the Italian astronomer Giovanni Schiaparelli. Lowell suggested that intelligent martians had built the "canals" to transport water from the polar caps to the equatorial deserts. Other observers failed to see the waterworks, but the possibility of civilizations populated by martian little green men led to a torrent of writings about martian invasions, the potential colonization of Mars, and the threat of interplanetary wars.

In spite of Lowell's claim to the contrary, little can be seen of Mars's surface features through a telescope; the planet is just too small and too far away. The sightings of the canals proved to be imaginary, the result of too much striving to make out features at the limits of telescopic resolution. Scientific interpretation of the martian surface did not realistically begin before observations could be made from spacecraft. And for those hoping to confirm Lowell's ideas, the first such images, obtained in the 1960s by NASA's *Mariner 4*, were deeply disappointing. The small areas photographed showed no canals, no oceans, no oases.

But water on Mars still seemed a real possibility. The *Mariner 9* spacecraft revealed a complex surface geology: volcanoes, canyons, dry valleys, lava plains, and, most intriguingly, flood channels. The discovery of the flood channels led to tantalizing visions of running water—and it went almost without saying that where water flows, there could be life. The data were returned to Earth in 1972, just as NASA was preparing the Viking missions. The discoveries were timely because the main emphasis of those missions was to search for life. Once again, however, the outcome was disappointing: Viking did not even find organic molecules suggestive of the presence of life on the planet's surface—much less life itself.

After the Viking program, the pace of Mars exploration slowed. The focus shifted from the direct and rapid detection of life to acquiring a better understanding of the planet. That still meant looking for water, or at least for where it might have been. In the meantime, public attention drifted elsewhere, until two events renewed wider interest in Mars.

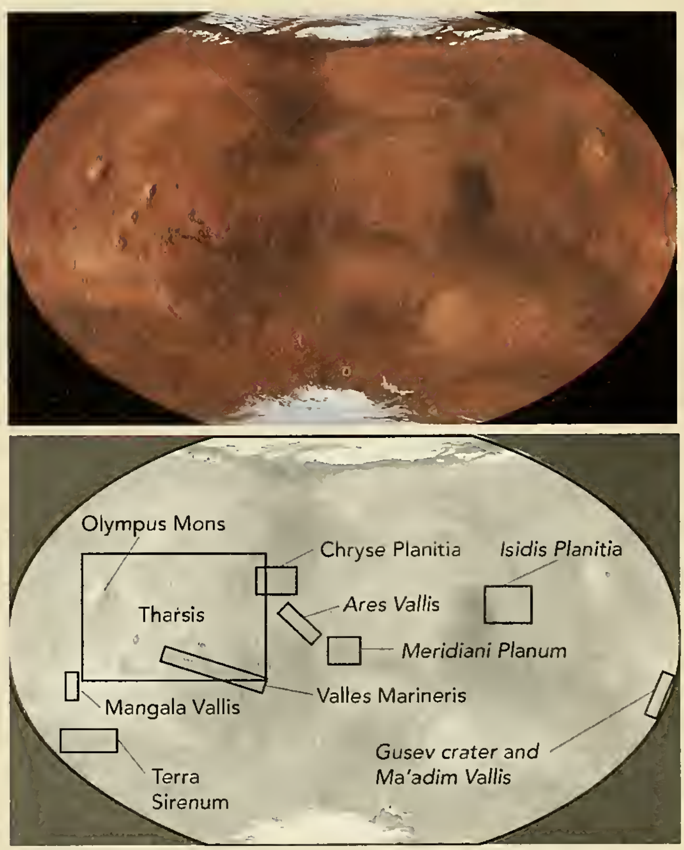
The first event was the announcement in 1996 that a meteorite from Mars contained evidence—possibly fossilized bacteria—suggestive of ancient life. The second event was the extraordinary success of NASA's Pathfinder rover in 1997. The martian meteorite that caused such a fuss in 1996 is generally no longer considered to contain any fossils, and nonbiological explanations of the observed mineral formations now seem more appropriate. Yet the search for water—and life—on Mars has hardly been abandoned. The new convergence of spacecraft is proof enough of that, all of them trying to help answer essentially the same questions that fired the imaginations of Herschel and Lowell: Has liquid water ever been abundant on the martian surface? And if so, has it enabled the planet to support life?

The geology of Mars is a spectacle to behold. The planet's southern hemisphere bears the scarring of heavy bombardment by meteorites; the craters, much like the ones that pockmark the highlands of our Moon, clearly date to the era, sometime before 3.8 billion years ago, when all the bodies of the inner solar system were subject to heavy meteorite bombardment [*see "Moonstruck," by G. Jeffrey Taylor, September 2003*].

The northern martian hemisphere, however, is sparsely cratered, indicating that the old cratered surface there has been buried by younger materials. What are these materials? They could be volcanic, but Timothy J. Parker and his coworkers at NASA's Jet Propulsion Laboratory in Pasadena, California, have speculated that they are sediments in what were once ocean basins. Their elevations are some three miles lower than those of the cratered southern uplands. Perhaps, then, the old, cratered surface is partly buried by marine sediments. But what exactly caused the northern depression is unknown.

Straddling the boundary between the northern plains and the southern highlands is Tharsis, a broad dome more than 3,600 miles across and more than six miles high at its center. The dome is comprised mostly of layers of volcanic rock, which can be seen in the walls of canyons on the dome's eastern flank. On the Tharsis dome are several huge volcanoes, the largest being the 370-mile-wide, fourteen-mile-high Olympus Mons.

But Olympus Mons is not the most spectacular surface feature of the planet. That distinction prob-



Mars can be roughly divided into a low, northern terrain—possibly the basin of an ancient ocean—and a highland, southern terrain, which is deeply cratered. The image was made by the Mars Global Surveyor.

ably belongs to the Valles Marineris, a system of interconnected canyons extending 2,000 miles eastward from the summit of the Tharsis dome to a low region called the Chryse Planitia, which adjoins the northern plains. The canyons in the Valles Marineris are typically 120 miles across and between 3.7 and 6.2 miles deep. Their origin is unknown, but faults that radiate outward from Tharsis can clearly be seen in the canyon walls, suggesting that stresses caused by the Tharsis bulge may have fractured the crust and formed great rift valleys. Once the rift valleys formed, landslides and water erosion probably enlarged the rifts to create the canyons that we see today.

The canyons themselves are not entirely the product of erosion (as is, for instance, the Earth's Grand Canyon). But they still preserve evidence of a wetter Mars. Layered deposits, which may be the remnants of sediments suspended in long-dry lakes, cover some of the floors of the canyons. Near the east end of the system of canyons are some areas of collapsed ground, out of which rise several huge, seemingly waterworn flood channels. Other flood channels emerge from the east end of the canyons as well, possibly as a result of the sudden release of water from lakes within the canyons.

In the effort to explore Mars for water, one of the most perplexing and important issues to address is its climate. Today the planet is inhospitable to any life resembling the life on Earth. The atmosphere, mostly carbon dioxide, is thin: its surface pressure is less than 1 percent that of the Earth's atmosphere.

Such a thin blanket of air provides almost no greenhouse warming, so surface temperatures average −67 degrees Fahrenheit at the equator, and less than −103 degrees Fahrenheit at high latitudes. It is so cold that carbon dioxide condenses out of the atmosphere each winter to form thin but extensive polar caps. Their retreat each summer exposes water-ice caps more than a mile and a half thick. Geologists have known about that abundant ice since 1976, but liquid water must be quite rare.

The scarcity of liquid water on Mars today is not easy to square with the abundant evidence that large volumes of water flowed on the planet in the past. In addition to the channels left by large floods, dry valleys that appear to have been cut by slow-moving water also meander across much of the old cratered terrain in the southern highlands. Dry river valleys also occur occasionally on younger surfaces, particularly on volcanoes. Their presence and their distribution on the surface strongly suggest that warm climatic conditions prevailed at times in the past, particularly early in

Deeply eroded gullies in a crater wall, hundreds of feet high, are visible in the upper half of this image from the Terra Sirenum region. The gullies were probably eroded by water, derived either from springs on the crater wall or from the melting of snow that had accumulated within the crater. In this region, many of the rocks are strongly magnetized, indicating that when they formed, early in the history of Mars, the planet had a strong magnetic field. The image was made by the Mars Global Surveyor.

martian history, when most of the valleys were formed. Perhaps early Mars had a thick atmosphere that was subsequently eroded by large impacts and by the solar wind, or was destroyed by chemical reactions with the surface.

But not everything on Mars conforms with that picture of a warmer, wetter planet in the past. Under warm, wet conditions, rocks weather to produce salts, such as carbonates, and hydrated minerals, such as clays. Those minerals have not been detected by the orbiters. Moreover, computer simulations suggest that the greenhouse effects of a carbon dioxide atmosphere could not have created a wet climate: no matter how thick it was, it could not have trapped enough solar energy to stabilize liquid water.

Yet geomorphologists insist that the evidence on the surface for running water is unequivocal. The salts and clays, they argue, must be hidden from view, and some factor must be missing from the computer simulations. Climatologists are equally adamant that warm conditions were unlikely, particularly in the planet's early history. At that time the Sun's energy output was likely to have been lower. But if Mars was never warm and wet, the prospects that some form of life once flourished there become very dim.

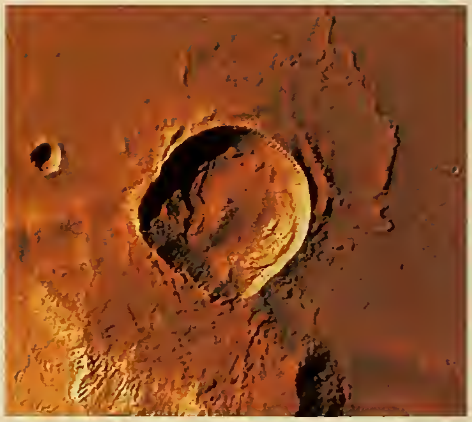
The need to study the history of water on Mars has heavily influenced NASA's choice of landing sites. But mission scientists had to balance that objective with a large number of engineering criteria: a site's altitude must be at least 0.8 miles below the martian "sea level," so that there is enough air for the parachutes to work. The site must be low in latitude as well, so that solar panels can get the most intense sunlight possible. And it must not be too windy, too rocky, too dusty, too rough, or too cold at night.

Two landing sites were eventually chosen. The first, for Spirit, is on the floor of an ancient, ninety-five-mile-wide impact crater called Gusev [*see image on page 32 and 33*]. A broad, 540-mile-long channel known as Ma'adim Vallis cuts through the southern rim of Gusev and extends deep into the southern highlands. Within the crater a group of hills stands at the mouth of the channel, which could be the remnants of a former delta. If the channel was cut by water, the water must have pooled within Gusev before exiting slowly to the north, and much of the material displaced by water erosion would thus have settled out where the water pooled.

Windblown sediments, ash from a large volcano some 150 miles to the north, and lava eruptions within the Gusev crater itself may also have helped fill the crater. Layered deposits have been partly eroded by the wind in some places, exposing an etched surface. Elsewhere, dunes are common. Sediments deposited by the water may also have been brought to the surface by the meteorite impacts that gave rise to the many craters visible today. If Spirit can find such materials, they would help show whether a lake once existed within the Gusev crater, and under what conditions the sediments were deposited. The size of the particles, their shape, their composition, variations from layer to layer, and the presence or absence of a cement will all provide clues to answer such questions as: What were the climatic conditions when Ma'adim Vallis was cut? What is the composition of the highland rocks? Was the early martian climate ever really warm and wet?

The second landing site, for Opportunity, is in Meridiani Planum, which lies on the side of the planet, opposite the Gusev crater [*see map on page 35*]. The Meridiani site represents a different line of attack in the search for water—a mineralogical rather than a geomorphological approach. Gray hematite, an iron-bearing mineral that normally, but not exclusively, forms in a wet environment, was detected there by the orbiting *Mars Global Surveyor.*

The hematite lies in the uppermost layer of a geologically complicated region. That top layer is part of a series of layered deposits partly overlying the ancient cratered surface, which has been cut by river valleys. The hematite layer appears to be thin, and the underlying layers poke through it to the surface in many places. The rover Opportunity should be able to sample both the hematite-bearing layer and the layers below. It may also be able to collect samples of the ancient cratered surface, because meteorite impacts may have excavated such material and thrown it into the site.



"Splosh" crater, about five miles across, indicates that a meteorite collided with water- or ice-rich ground. Some sixty miles to the west of the crater is a large flood channel (not shown) called Mangala Vallis (Mangala is Sanskrit for "Mars"). Impact craters such as the one shown are common all over Mars. The image was made by a Viking orbiter.

How the hematite was deposited presents an intriguing puzzle. It is unlikely that the layers of sediment formed in a lake, because no basin is present. Instead, they were probably deposited from the air, perhaps as volcanic ash. The hematite could have formed from iron-rich materials in the original layers of sediment, or it could have been deposited from iron-rich water percolating through the sediments. The rover Opportunity will seek to determine how the layers were laid down, and look for evidence of water from hot springs, which could arise out of local volcanic warming. On Earth, such springs, as in Yellowstone, commonly support hardy organisms. Perhaps they did on Mars, too.

Operating the rovers on Mars will be a demanding task for those of us who control them from Earth. Every day will begin with an assessment of the data from the preceding day. We'll interpret new images or spectra and determine the new position of the rover as quickly as possible. Then, within two hours of receiving the new data, all the project scientists will meet to discuss the data and what to do next: Shall we do more analyses on the rock we examined yesterday? Shall we get a more detailed look at the cliff a hundred yards away? Shall we move to a new location, and if so, where?

After settling on the broad plan, the various scientific groups—chemists, geologists, mineralogists, and the like—will disperse to draw up a wish list of observations. Two hours later we'll reconvene, reconcile our differences, and make a plan roughly consistent with the resources available: time, power, data bits for transmission, and so forth.

A long and tedious process translates the plan into specific commands that are finally sent to the spacecraft. The rover will carry out the program, and the next day the process will start all over again.

The availability of solar power limits each rover's lifetime to just a few months. The goal is for each to travel at least 600 yards, but the actual distance will depend on the site, the ease of travel on it, and the scientific interest of the terrain around the landing site. At this stage we can only hope we have chosen the sites wisely. But if we have, and if our good fortune continues, in just a few more months some of our questions about Mars's ancient past will be answered, and we will have a better understanding of the role of water in the evolution of the planet. □

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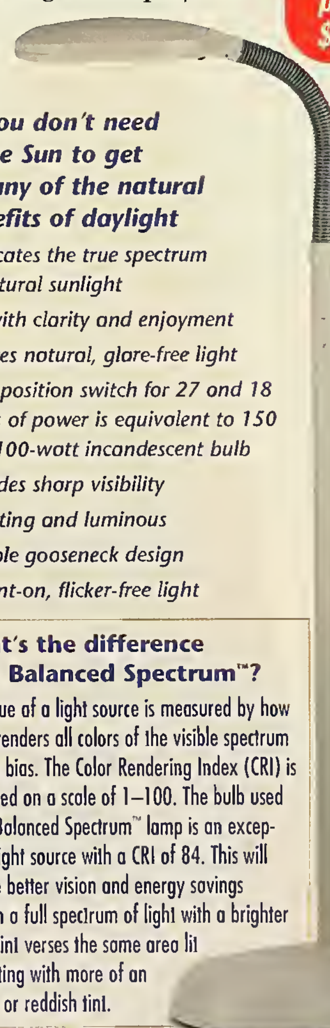

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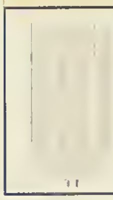

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Underwater Urbanites

Sponge-dwelling snapping shrimps are the only known marine animals to live in colonies that resemble the societies of bees and wasps.

By J. Emmett Duffy

Diving the pellucid waters of the Caribbean Sea off the coast of central Belize, down past jewel-like transparent plankton, I see the ridge of the Belize Barrier Reef materializing out of the turquoise depths. Even before the reef becomes visible, I sense its proximity from the muffled crackling that issues from the submarine landscape. In places the crackling is so vigorous it sounds like frying bacon. The noise is the clamor of countless little "snapping shrimps" (also known as "pistol shrimps"), so named for the report each one produces by swiftly closing its disproportionately large and powerful fighting claw. The chorus of snapping and crackling is the sound of homeland defense.

Although rarely seen, snapping shrimps are one of the great success stories of the Earth's tropical seas. Hundreds of species—all members of the family Alpheidae—and millions of individuals pack into the reef's innumerable nooks and crannies, even lodging in the delicate arms of feather stars [*see photograph on page 43*]. Where snapping shrimps truly flourish, though, is within the internal canals of the living sponges that pepper the reefs. Sponges often exceed even corals in both abundance and species diversity. And throughout the Caribbean, sponge canals—akin to the interior of a Swiss cheese—are teeming with snapping shrimps of the genus *Synalpheus.*

More than a hundred species of synalpheids have been described worldwide, ranging from the size of a rice grain to the size of a baby carrot. Some forty of the species are native to the Caribbean; most of them are ecological specialists that inhabit the passageways of one or, at most, a few sponge species. Their apparently unrequited dependency makes the shrimps parasites: they scrape their sustenance from the linings of their host sponges' canals with a small, specialized claw. (In fact, as the synalpheids live out their lives within a given host, their stomachs become packed with the delicate spicules that form the sponge's skeleton.) Because the inner architecture of their hosts provides not only safe shelter but also a permanent food supply—and because the shrimps are undeterred by the sponges' formidable defensive chemistry, which foils most other predators and invaders—synalpheid populations have expanded to fill nearly every cubic centimeter of the sponge canals.

The queen of a colony of Synalpheus regalis *snapping shrimps is pictured here inside a living tropical sponge. The green spheres are the queen's eggs.*

Having successfully escaped the reef's ubiquitous predators by occupying its living fortresses, sponge-dwelling snapping shrimps face a challenge familiar to crowded urbanites everywhere: stiff competition for space. Several years ago, in an effort to understand why many reef animals adopt symbiotic lifestyles, I conducted a census of Caribbean sponge inhabitants. And I was puzzled, as several workers had been before me, by the paucity of female shrimps. I well remember the night back in 1988 in Panama when, bent over a microscope, I suddenly realized that the shrimp aggregations I was studying were not merely deficient in females. They comprised exactly one breeding female per sponge, even though the aggregations were made up of as many as sixty individuals. That was my first tantaliz-

Elephant ear sponge (Agelas clathrodes), which occurs throughout the world's tropical oceans, is often inhabited by social species of Synalpheus snapping shrimps. As many as 350 individual shrimps, but usually only one "queen," live in such a sponge, much the way social insects live in a hive.

ing clue that a few species of shrimps are social creatures, living in organized colonies—one colony to a sponge. This way of life—organized, cooperative defense of the community's turf—had previously been unknown among marine animals. Snapping shrimps, it turns out, are living the lives of social insects; they are the ants, bees, termites, and wasps of the deep.

Until quite recently, the retiring lifestyle and puzzling taxonomy of *Synalpheus* made the fascinating biology of snapping shrimps largely inscrutable, despite their abundance. Even my recognition that they live remarkable social lives came about entirely by accident. In retrospect, one can see why evolution might favor such close social relationships. By working together, a group of diminutive shrimps transcends the limitations of size and, with the aid of the single massive fighting claw sported by each individual, musters a formidable resistance against would-be intruders.

A colony of synalpheid snapping shrimps is essentially a two-parent family with a whole lot of grown male children hanging around.

In our next several years of fieldwork my colleagues and I showed that at least five *Synalpheus* species live in tightly packed colonies. Most colonies have just one breeding female each, though in a few colonies we identified more than one. All other members are most likely either males or sexually undifferentiated juveniles. But in *S. regalis*—a species found so far only on the Belize Barrier Reef—the analogy with the social insects is particularly close. A colony always includes just one breeding female and (judging by genetic evidence) one dominant breeding male, even though it can have as many as 350 members. That genetic structure makes most of the members of the colony into full siblings: offspring of a single breeding pair that reigns as "queen" and "king" for most of the colony's life.

Such collections of kinfolk arise because the social species of synalpheid shrimps exhibit "direct development": their eggs hatch directly into crawlers rather than into the planktonic swimmers that typically hatch from the eggs of their close crustacean relatives. Born into a suitable sponge, juvenile synalpheids needn't travel far to fulfill their needs. Both observational and genetic evidence indicates that the juveniles of direct-developing *Synalpheus* species typically remain for an extended time—perhaps for life—in the sponge of their birth. Periodically a few young adult snapping shrimps probably strike out in search of a new domicile, but in general, a colony of *S. regalis* is essentially a two-parent family with a whole lot of grown male children hanging around.

In the parlance of behavioral ecology, the genetic and social properties of *S. regalis* and its direct-developing, colonial cousins make the species "eusocial." The term means that most inhabitants of the colony, rather than engage in reproduction themselves, help raise and defend the offspring of a lucky few.

In spite of the seeming evolutionary advantages of a common defense, eusocial animals present one of the most enduring paradoxes in nature: If adaptive evolution proceeds via the differential survival and reproduction of individuals, how can a species arise in which most individuals never breed at all? Darwin himself was famously troubled by the dilemma; in *Origin of Species* he writes that the phenomenon of sterile workers among the social insects posed the "one special difficulty, which at first appeared to me insuperable, and actually fatal to my whole theory." The extreme case of the sterile worker, however, is just one example of a broader question: How does evolutionary theory account for the occurrence of altruism—behavior that does not benefit an individual creature but is beneficial to others of its species—in a Darwinian world?

Darwin correctly anticipated that the key to the paradox of eusociality is the close genetic relatedness between an insect colony's breeders and its sterile workers. But the full explanation did not emerge until the 1960s, when the late English evolutionary biologist William D. Hamilton first put forward his ingenious ideas. As Hamilton pointed out, among species in the order Hymenoptera, a complex mechanism of sex determination known as haplodiploidy gives rise to "supersisters": all the female offspring of a colony's queen share 75 percent of their genes, rather than the 50 percent shared by full sisters in most other animals. In other words, in colonies of social insects the sterile workers, which are almost exclusively female, are more closely related to their sisters than they would be to their own offspring (if they had any).

Hamilton suggested that the differential relatedness between sisters and offspring might explain the high frequency of eusociality among hymenopterans. In theory, a female social insect gets a larger genetic payoff from raising a sister than she does from raising a daughter. Hence a worker female is better able to transmit her own genes to future generations indirectly, by ensuring that the queen mother of the colony produces more "supersisters," than she can by breeding herself. The social structure of the colony thus emerges from the genetic self-interest of its constituent workers.

The close genetic relatedness among colony members in *S. regalis* is consistent with the usual pattern of eusociality based on kinship. But genetics is only part of the story. Many animals live in kin groups; few, however, have taken family life to the extremes that the eusocial animals have. Colonies of bees and snapping shrimps have hundreds of members, but the number of breeders in each colony hovers around one. As Hamilton recognized, the other, interlocking part of the story behind what is often called "animal altruism"—the foundation of advanced sociality—is ecology.

In the past couple of decades biologists have documented eusociality in a growing list of animal species besides the social insects. Those species include the naked mole rat, a burrow-dwelling mammal that lives in East Africa; certain aphids; a group of inconspicuous gall-forming insects called thrips [*see "Altruism in the Outback," by Bernard J. Crespi, November 2001*]; an Australian "ambrosia" beetle; and, now, sponge-dwelling snapping shrimps.

As the number of such examples grows, so does the opportunity to identify the evolutionary drivers of advanced social life. A good way to start is to look for commonalties among disparate eusocial animals. In 1991 the evolutionary biologist Richard D. Alexander of the University of Michigan in Ann Arbor and his colleagues compared naked mole rats and termites. Both of these eusocial species are genetically diploid—that is, their offspring carry two sets of chromosomes, one set from each parent. In that regard, they are just like most animals other than the hymenopterans.

Alexander and his coworkers then proposed that most cases of eusociality in diploid animals would arise when three conditions are satisfied: the animal undergoes a gradual metamorphosis sometime during its life cycle; the offspring receive extensive parental care; and the individual animals occupy, in the words of Alexander and his colleagues, "long-lasting, expansible niches (nests or microhabitats) safe from predation and rich with food that does not require exiting the safety of the niche to obtain it." Those three conditions, they contended, promote sustained interaction among close relatives. Furthermore, when the three conditions are satisfied, nonbreeders can increase their genetic contribution to future generations indirectly, either by helping close relatives to breed or by defending the communal nest.

Sponge-dwelling shrimps are also diploid, and so they provide an independent test of the hypothesis put forward by Alexander and his team. And sure enough, the eusocial species of *Synalpheus* are among the few crustaceans that undergo gradual metamor-

Feather star is an echinoderm that serves as home turf for Synalpheus *shrimps in the Indian and western Pacific Oceans. One shrimp, with an oversize left fighting claw, is visible at the two o'clock position.*

phosis (other examples are sow bugs and sand fleas), and among the even fewer in which offspring remain with their parents for a goodly amount of time. Moreover, the quoted passage is an almost perfect description of life within the long-lasting niche of a sponge's canals. The lives of snapping shrimps seem to offer dramatic support for the contention that those three conditions lead to eusociality.

But according to Alexander and his colleagues, there is a fourth condition that strongly drives eusociality: enemy pressure. Here, too, evidence from synalpheids supports their analysis. The occupied territory in an individual sponge is usually filled to capacity. But the canals of a living sponge are too narrow for most predators of the shrimps. What kind of enemy could the shrimps be defending against?

The answer appears to be other synalpheids. The host sponge provides such a scarce and valuable resource—combining abundant food, living space, and safety from predators—that settling and keeping it is a matter of life and death for the sponge dwellers. My associates and I have witnessed defenders among captive colonies in the laboratory fighting to the death to repel intruders—clear evidence of the high stakes of territorial defense [*see photograph above*].

Turf war between two male S. regalis snapping shrimps. Each brandishes his huge fighting claw (leaf-shaped structures in contact at center of photograph) at his opponent prior to physical battle.

In a Darwinian world, nonbreeding members of crowded colonies must be contributing to the colony, or their burden on resources would not be tolerated. Observing captive experimental colonies of *S. regalis,* my team has discovered that large nonbreeding males constitute the first line of defense against intruders. Such males often patrol boldly and restlessly throughout the sponge, and they are more likely than other colonists to be found near its periphery. Like the honeybee workers that sacrifice their own lives to protect the hive, they are the colony's sterile defenders.

Other eusocial animal groups defend themselves with stingers, mandibles, and sharp teeth. Synalpheid shrimps and some of their closest relatives also possess a formidable defensive tool: the major chela, a marvel of bioengineering that is also known as the fighting claw or snapping claw. (The smaller, minor chela is used in feeding.) In both sexes of *Synalpheus* the major chela is the most visually conspicuous feature, though it is proportionally larger in males. One of the two "fingers" of the oversize limb bears a plunger that fits snugly into a socket in the other finger. As the plunger is slammed into the socket, a focused and remarkably strong jet of water is forced out, producing the species' characteristic warning: a bubble that collapses with a loud snap.

Physical confrontations between two competing shrimps generally start with contact by the first pair of antennae, and often escalate to a state of readiness in which the snapping claw is cocked open in a threat display. If a fight breaks out, the claw becomes a weapon, grappling with the opponent's claw or pinching it in a sensitive region, sometimes inflicting serious damage. The major chela is used in other ways as well. Eva Tóth, a postdoctoral investigator in my laboratory, is studying a striking phenomenon we call "mass snapping," which probably serves as a warning to intruders: members of *Synalpheus* colonies snap their claws in unison for a few seconds, producing a startling sound clearly distinguishable from the chaotic background noise of the reef environment.

By shouldering the burden of colony defense, the large *S. regalis* males make it safe for the vulnerable queen to feed and reproduce abundantly, and for the sexually undifferentiated juveniles to feed and grow. Field comparisons among species of *Synalpheus* shrimps suggest that the division of labor translates into greater efficiency and greater competitive success. Eusocial species are much better able to keep other shrimps from entering their host sponge than are their non-eusocial relatives.

The division of labor between reproduction and defense is most clearly manifest in *S. filidigitus,* another, smaller eusocial species that lives on the

Belize Barrier Reef, the largest coral reef in the Northern Hemisphere, is prime territory for living sponges and the colonies of snapping shrimps that reside within the sponges.

Belize Barrier Reef and is the closest relative of *S. regalis.* Queens in *S. filidigitus* colonies frequently lose the snapping claw in adulthood, and so must depend entirely on the other adults of the colony for protection. *S. filidigitus* thus presents a striking parallel with the advanced eusocial insects, whose queens typically become nearly helpless egg-laying machines.

Yet Darwin's conundrum remains: Why does only a single female breed? How can the evolution of sterility be explained?

Of several available hypotheses, the most straightforward is dominance: in several wasp species, as well as in social vertebrates such as wolves, meerkats, and certain birds, the breeder aggressively prevents subordinates from reproducing. In *S. regalis,* however, the queens in the captive colonies we observed showed no evidence of such aggression or behavioral dominance. And since the fighting claw is typically missing in *S. filidigitus* queens, the primary breeder in that species could not dominate her competitors through aggressiveness.

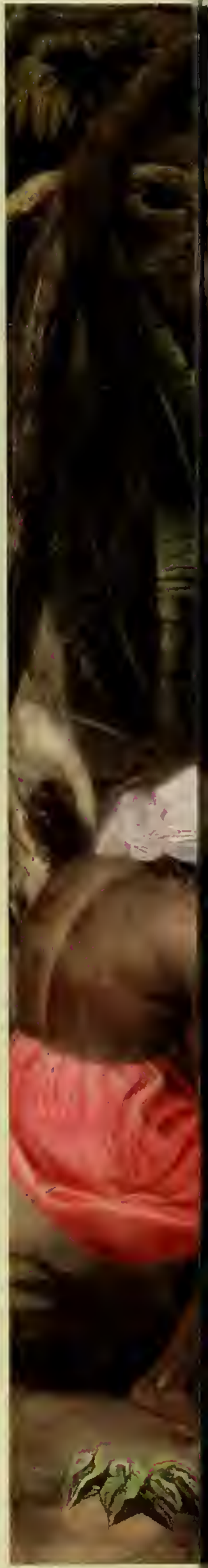
A more likely possibility—supported, for instance, by the case of the Damaraland mole rat of southern Africa—is that sterility results from the avoidance of inbreeding, and is often behavioral rather than physiological. Eusocial shrimp colonies, after all, are made up entirely of close relatives. A nonbreeding shrimp has two options: either bide its time and potentially inherit the nest in the future as a breeder, or risk its life defending the colony as a whole, thus indirectly advancing its own genetic fitness by helping close relatives. But the specialized life history and ecology of sponge-dwelling shrimps foster long-term occupation of specific nest sites by multigenerational family groups. Breeding opportunities turn over slowly, and dynastic lineages persist, headed by one or a few breeders of each sex. So the best strategy for a nonbreeding adult is to aid its siblings and parents by keeping intruders at bay.

How, then, to explain the spotty distribution of eusociality among the numerous species of *Synalpheus*? After all, many of the species have direct development and specialize in one or just a few hosts. All the species, moreover, bear the snapping claw. Perhaps the severity of competition, or the low turnover rate in the housing market, tips a delicate balance toward eusociality in certain species. Whatever the details of the explanation, it seems clear that the enigmatic ecology of sponge-dwelling shrimps must hold the key to understanding how these humble creatures have achieved the highest form of social life in the sea. □

The Breadfruit Trail

The wild ancestors of a staple food illuminate human migrations in the Pacific islands.

By Nyree J.C. Zerega



Many years ago a god named Ku came to Hawai'i and married a mortal woman. Together they had a large family, but Ku never told her he was a god. One year, a terrible famine came to the islands, and Ku's family became weak with hunger. When Ku could no longer bear his family's suffering, he confided to his wife: "If I go on a long journey, I can get food for our children and everyone on the island, but I will never be able to return." At first his wife would not hear of such a thing, but after watching her children slowly starve, she finally relented. The couple walked together into their garden, where Ku kissed his wife good-bye and disappeared into the earth. In her grief Ku's wife waited at the spot where he had disappeared, watering it for several days with her tears. Soon a sprout pushed up from the spot and rapidly grew into a tree. Within just a few days Ku's body had transformed into a large tree trunk, his arms into branches, his blood into a white latex flowing through the tree, and his head into a fruit that provided Ku's family with the food he had promised. The tree, and the food, was the breadfruit.

This legend is just one of many that are told to account for the origins of breadfruit *(Artocarpus altilis)*. It is little wonder that the plant is the stuff of legend, for it has been cultivated as a staple starch crop in the Pacific islands for thousands of years. Biologists, however, are still looking for a more down-to-earth explanation of the plant's origins. The puzzle begins with the fact that many breadfruit trees are seedless and sterile. Sometime in the past, cultivators must have transformed a fertile plant into one that needs human intervention to reproduce itself. But what was the ancestral tree? Breadfruit is scattered across thousands of islands in the Pacific, but no close wild relatives grow throughout much of this range. Thus there is no prime local candidate for botanists to name as breadfruit's ancestor. And if the transformation did not occur throughout the Pacific, it probably occurred in just one place, and the sterile trees must have been spread by human means. But where did these people come from?

Seafaring people reached Australia and New Guinea at least 40,000 years ago and, relaunching from those lands, settled the Solomon Islands by 30,000 years ago. But the broader peopling of Oceania—the middle and southern Pacific islands—did not get underway until about 4,000 years ago. Most scholars attribute the resurgence in settlement to a people they call the Lapita, after an archaeological site in New Caledonia. The main evidence for the patterns of their migrations comes from tracing a characteristic style of pottery, in which geometric and, occasionally, representational designs were stamped into the clay. Linguistic and genetic data generally support the archaeological conclusions.

The Lapita, thought to have come from somewhere in island Southeast Asia, first traveled to the northern coast of New Guinea. They continued their migrations eastward through Melanesia and into the far reaches of eastern Polynesia, making their way to Easter Island by about 1,700 years ago [*see map on pages 48 and 49*]. Micronesia is much more culturally and linguistically heterogeneous than Polynesia, and its island

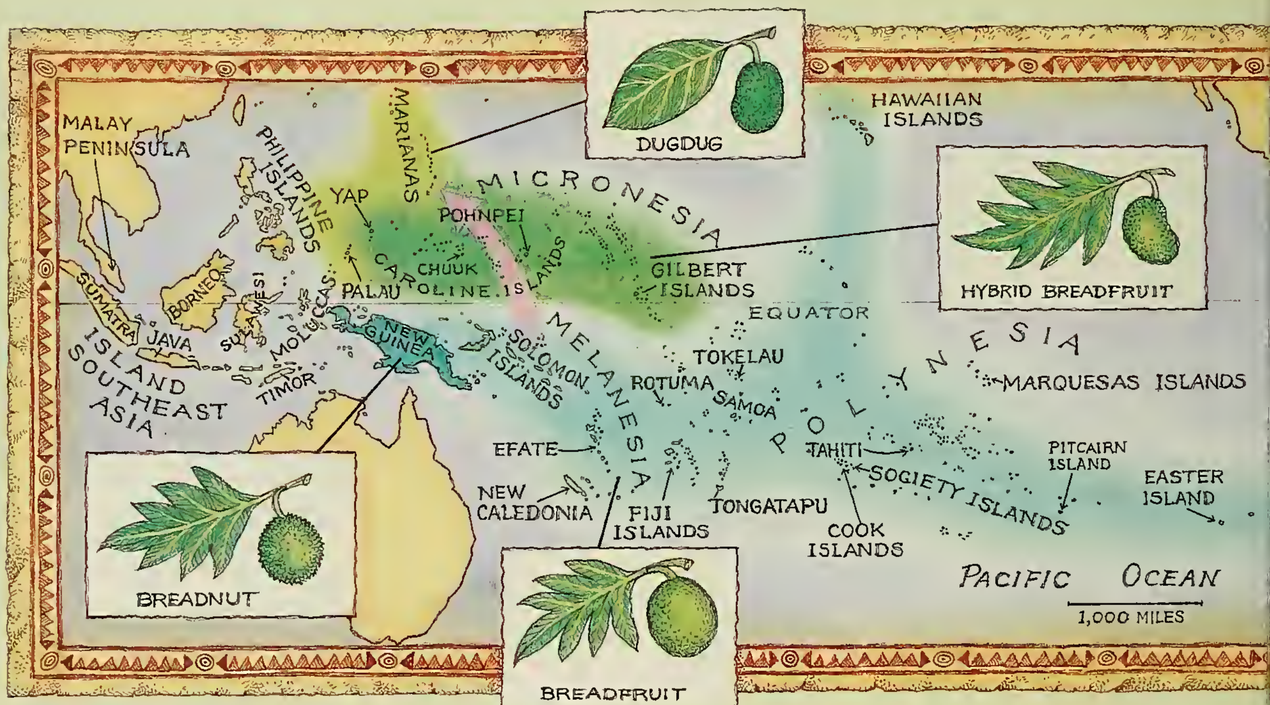
Thomas Gosse, Transplanting of the Bread-Fruit-Trees from Otaheite [Tahiti], *1796. Gosse's hand-colored mezzotint depicts Lieutenant William Bligh, standing at right in uniform, overseeing the collection of young breadfruit trees for transport to the Caribbean. Although the voyage, on* HMS Bounty, *ended in the famed mutiny in 1789, Bligh carried out his mission on a later voyage. Analysis of breadfruit DNA is enabling biologists to trace its wild origins, and the spread of related cultivars by Pacific islanders.*

groups were probably settled by migrants who came at various times from island Southeast Asia, Melanesia, New Guinea, and elsewhere. The last of the principal Oceanic islands to be settled were the Hawaiian Islands, about 1,700 years ago, and New Zealand, about 1,200 years ago—in both cases by Polynesians.

Prehistoric seafarers casting off from their home islands to settle elsewhere would have been sure to take along breadfruit trees, which provide an abundance of fruit. The first breadfruit trees, like their unknown progenitor, may have been capable of reproducing by means of seeds. At some point, however, the voyagers must have begun to transport and transplant root cuttings, which can be nicked with a sharp blade to produce shoots. In that way the trees were propagated vegetatively throughout Oceania.

If migrating people were responsible for the propagation of breadfruit, finding its wild progenitor might contribute to far more than the botanical problem of finding the origins of the plant. By tracing the paths of ancient breadfruit, light might be shed on the routes taken by the ancient mariners who transported it. Unfortunately, reconstructing the plant's botanical history has long proved difficult. During the millennia breadfruit has been cultivated, the trees changed with time and place. Mutations occurred, and cultivators on various islands selected for trees that grew best under local particularly conditions or whose fruits were particularly appealing in size, taste, and texture. My hope was that DNA evidence obtained through the new tools of molecular biology would finally resolve the puzzle of the species' origins.

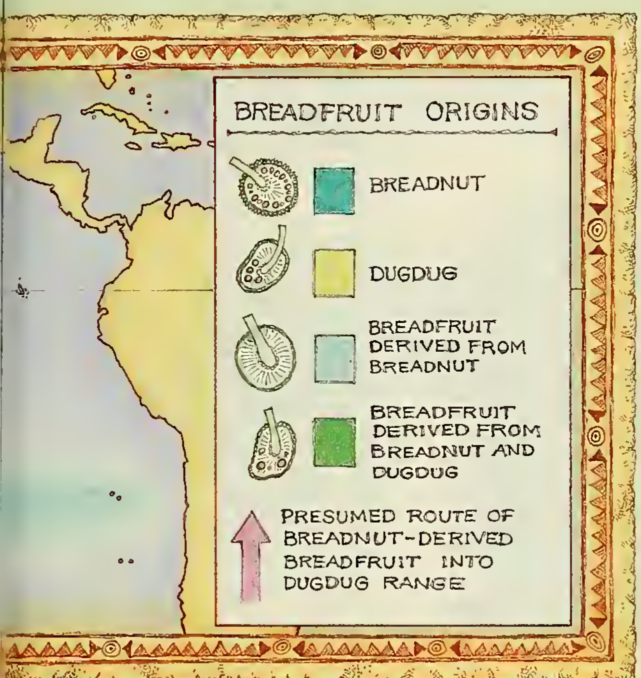
Scholars have put forward at least two testable hypotheses about the origins of breadfruit. The first was advanced in 1940, when Eduardo Quisumbing, a Filipino botanist, suggested breadfruit may be "derived, by selection, from some species perhaps even approximating the 'camansi.'" He was referring to the breadnut, *A. camansi,* native to New Guinea and possibly the Philippines and the Moluccas. It produces edible, chestnutlike seeds. A second, much more complex hypothesis was proposed in 1960 by Francis Raymond Fosberg, an accomplished American botanist of the Pacific flora.



Origins of breadfruit and its precursors, proposed by the author on the basis of her genetic analyses and the archaeological record, are traced through the islands of the Pacific. A seafaring people known as the Lapita quickly spread through Melanesia and Polynesia, bringing the breadnut plant with them as they fanned outward from New Guinea. The Lapita often carried cuttings on their long ocean voyages, and so, over time, the breadnut, propagated by seeds, was transformed into the breadfruit, a plant that is often sterile. At some stage, they or other early voyagers brought breadfruit into the range of the dugdug plant (purple arrow), and so the two closely related species were able to hybridize. Many breadfruit cultivars in Micronesia bear the genetic stamp of that union.

Fosberg implicated two other species in addition to the breadnut. One is the Philippine endemic commonly known as antipolo *(A. blancoi)*, which is used primarily for lumber. The other, often called dugdug *(A. mariannensis)*, is endemic to certain uplifted limestone islands in Micronesia, namely Palau and the Marianas. The islanders consume both its seeds and the surrounding flesh.

Fosberg suggested that antipolo first hybridized with breadnut, giving rise to sterile breadfruit. But he also noted that Micronesian breadfruit has its own unique characteristics. For example, some specimens have leaves like those of the dugdug but seedless fruit like that of breadfruit; others have deeply cut leaves like the breadfruit's, but those leaves have brownish and reddish hairs on the leaf veins, like the dugdug's. To account for those features, Fosberg suggested that in Micronesia the sterile breadfruit trees had somehow hybridized with dugdug.



To begin my own study into the origins of breadfruit, I wanted to test both these hypotheses about its wild progenitors. That led immediately to my first question: Are breadnut, dugdug, and antipolo the species most closely related to breadfruit, and if not, what is? Second, is there evidence that any of those species contributed to breadfruit's gene pool?

I determined the DNA sequences for two regions of the genome in nearly forty species in the breadfruit genus, *Artocarpus*. The genus belongs to the mulberry family (Moraceae) and encompasses many useful and curious species. On the basis of the DNA sequences, I constructed a family tree for *Artocarpus*, which showed that breadfruit is closely related to breadnut and dugdug but not to antipolo.

In DNA sequencing, the base pairs, or molecular building blocks, in a species' chromosomes are identified one by one. But a single genome can include billions of base pairs. Although the speed at which this kind of data can be generated is rapidly increasing, many biologists must content themselves with sequencing only small regions of an organism's genome. Unless those regions happen to be highly variable, they may not shed much light on the genetic relatedness among closely related species. The regions I had sequenced were just too similar to reveal how breadfruit, breadnut, and dugdug fit together on the tree of life. I needed more data.

I turned to a method of DNA fingerprinting called amplified fragment length polymorphisms (AFLP). In effect, the technique takes many snapshots of an organism's entire genome, increasing the chances that informative regions will be found. The first step in the process is to extract DNA and treat it with enzymes that slice it into many small fragments. Examining all of these fragments is not feasible, so the next step is to "amplify" (make many copies of) only a subset of the fragments. Among the amplified fragments, some will be unique to the single individual source of the DNA, whereas others will be shared with other members of the same species. Of the latter, some will prove to be unique to the species as a whole, and others will be shared with members of various other species. By sorting through the amplified fragments, the investigator can determined which of them are "fingerprints" of particular individuals, species, or even more distant genetic relations.

I realized I would have to analyze tissue from several individual specimens of breadfruit, dugdug, and breadnut. Would that force me to island-hop around the Pacific, collecting samples of trees from tropical forests and white-sand beaches? As arduous (and appealing) as that might be, there was a quicker (and cheaper) way.

Kahanu Garden, part of the National Tropical Botanical Garden, is situated on the Hawaiian island of Maui, near the Pi'ilanihale Heiau, a structure of lava rock thought to be the largest ancient Polynesian place of worship. Approximately ten acres of the garden is devoted to the largest known collection of breadfruit cultivars in the world: more than 200 trees have been collected from seventeen Pacific island groups and beyond. Although the collection was originally established in the 1970s, the bulk of it was assembled in the 1980s by Diane Ragone, the director of the National Tropical Garden's Breadfruit Institute. At this one location I obtained samples of breadfruit from Java and the Philippine Islands, in island Southeast Asia, and from various islands in Melanesia, Micronesia, and Polynesia. Only a handful of dugdug and breadnut trees grow at Kahanu, however, so I traveled, along with Timothy J. Motley of the New York Botanical Garden, to New Guinea and the Marianas. In both places knowledgeable local botanists helped me collect more samples.

When I examined the DNA from all the trees, I found many genetic fingerprints that were common to breadfruit, breadnut, and dugdug. That confirmed just how closely related the three species are. But I was also able to identify some dugdug fingerprints absent in all breadnut trees, and some breadnut fingerprints absent in all dugdug trees. Looking at the distribution revealed an intriguing pattern. Both breadnut and dugdug fingerprints were present in virtually all Micronesian breadfruit cultivars. But most of the breadfruit cultivars in Melanesia and Polynesia included only the fingerprints of breadnut, not of dugdug.

To some extent, then, both Quisumbing and Fosberg were correct. Overwhelmingly, in Melanesia and Polynesia, breadfruit cultivars were derived through selection from breadnut, just as Quisumbing surmised. But Fosberg was right to think there was something different about the Micronesian breadfruit trees. In Micronesia, breadnut or breadnut-derived breadfruit appears to have hybridized with dugdug, probably not in a single event but in a process known as introgression, in which a series of interspecies crosses are followed by repeated backcrosses. The result was a unique diversity of cultivars.

How do these findings tie in with the migrations of people across the Pacific? Here's a possible explanation. As the Lapita people voyaged eastward from New Guinea, they likely carried along whatever they needed of the wild breadnut, so that they could establish breadnut as a crop. But breadnut seeds remain viable for just a few weeks; seafarers who anticipated a long ocean voyage, such as the ones that led colonizers to regions east of the Solomon Islands, would have known to bring along root cuttings. (In fact, the Lapita vegetatively propagated several of their important crops, including yams and taro.) By propagating and spreading their breadnut trees via cuttings, generation upon generation of islanders transformed it into the breadfruit, a species that did not reliably produce viable or edible seeds but that could be consumed as a starch crop.

Human settlement of Micronesia was not so straightforward as it was in Melanesia and Polynesia, and several migration routes may have been established. One route scholars have suggested began in the eastern Solomon Islands or in the islands to their southeast, and followed a northward course to the Caroline Islands. Lapita or other people taking that route could have introduced the breadnut-derived breadfruit into Micronesia. Migrations and trade routes within Micronesia could then have brought the introduced breadfruit into the range of the native dugdug, where the two species could have cross-pollinated.

Breadfruit tree, shown here in an engraving made about 1800, grows to a height of sixty-five feet.

The earliest breadnut-derived breadfruit occurs in Melanesia, where breadfruit cultivars that produce seeds are still commonly found. I speculate that such fertile plants may be what hybridized with dugdug. Nothing like them persists in Micronesia, however, though the hybrid breadfruit trees themselves sometimes do produce seeds. The ancestral cultivars may have disappeared from the region because of a difference in environmental conditions or because people who lived there—perhaps owing to the availability of the edible dugdug seeds—preferentially selected seedless cultivars.

Finally, the route from Melanesia into Micronesia might well have been a two-way street. I discovered dugdug fingerprints in a small number of

Tahitian breadfruit is shown here as it was published in the journals of Captain James Cook, during Cook's first Pacific voyage, 1768–1771.

cultivars I sampled from the Solomon Islands and farther east, in Efate, the Fiji Islands, Samoa, and the Society Islands. The evidence suggests that hybrid breadfruit cultivars, developed in Micronesia, could later have joined the breadnut-derived breadfruit in Melanesia and Polynesia.

Much more remains to be learned about the finer details of how people selected and spread breadfruit trees. Because of the genetic scrambling that has taken place, and can still occur, between fertile plants, and because of the continual movement of humans, the picture is complex. Bringing it into sharper focus will keep us breadfruit botanists plying the Pacific for years to come. □

THIS LAND

Giving Cranes a Lift

A Mississippi refuge preserves a bird and its habitat.

By Robert H. Mohlenbrock

Mississippi sandhill cranes, an endangered subspecies

With their stately stature, wingspreads as broad as eight feet, loud calls, and elaborate courtship dances, cranes are among the most impressive birds in the world. Two species are native to North America, the whooping crane *(Grus americana)* and the sandhill crane *(G. canadensis).* Whooping cranes, whose population fell to just sixteen birds in 1941, now number about 300, thanks to a much publicized conservation effort. Nevertheless, they still teeter on the edge of extinction. Sandhill cranes, which number more than half a million, would seem to be in much better shape. Yet there are six subspecies of sandhill crane, and not all are thriving. The rarest, the Mississippi sandhill crane *(G. canadensis pulla),* is the focus of another concerted conservation effort, now under way at the Mississippi Sandhill Crane Wildlife Refuge northeast of Biloxi, Mississippi.

Because this subspecies is listed as endangered, only a limited area of the refuge is open to the public. The best opportunities to view the cranes come in January and February, when the refuge offers tours to blinds overlooking areas where the birds feed. The visitor can always see native shrubs and trees along the entrance road, or follow the Dees Nature Trail that leads through a savanna and along an open water marsh. In addition, Scott Hereford, the lead biologist at the refuge, and his colleagues have created an informative video about the history of the cranes and their environment, which plays at the Visitor Center. The following account is based on information provided by Hereford and the refuge staff.

At one time Mississippi sandhill cranes probably frequented marshes and savannas all the way from southern Louisiana to the Florida panhandle. A savanna is a grassland scattered with trees, a combination that often suggests a manicured parkland. But the savannas along the coast of the Gulf of Mexico were hardly parks; rather, they owed their existence to acidic, poorly drained soils and frequent natural fires, which suppressed shrubs and most trees except for longleaf pines. Because the grasses attracted game animals and were suitable for cattle grazing, Native Americans and early settlers kept the savannas intact by setting fires themselves.

Around the middle of the twentieth century, however, lumber companies systematically harvested longleaf pines from the savannas and planted slash pines to supply the paper industry. The companies suppressed fire and improved the drainage, to favor the growth of the slash pines. Other industries, joined by vacationers and retirees, swelled the surrounding towns and further impinged on the savanna habitat. By 1972, when they were designated a separate subspecies, Mississippi sandhill cranes had been reduced to a single, isolated, non-migrating population near Biloxi that numbered only about thirty birds, including just five or six nesting pairs. Fortunately they soon became beneficiaries of the Federal Endangered Species Act of 1973.

It was a close call: Interstate Highway 10 was slated to pass through the only remaining habitat for the birds. Construction was held up while a federal court case was heard, the first under the 1973 law. As part of the settlement, the Department of Transportation purchased 1,960 acres adjacent to one of the interchanges and along the connecting road to protect some lands from development. Although the

highway was built, this acreage became part of the refuge when it was established in 1975.

The refuge, which covers some thirty square miles, is the object of a long-term restoration project. Through prescribed burning, fire is once again suppressing the growth of invasive shrubs. In areas too wet for fire to be effective, unwanted shrubs and trees are cleared by hand or by machine. Several ponds have also been created for the cranes to roost near, replacing some of the many marshes that were drained years ago.

Mississippi sandhill cranes make their nests on the ground, primarily in the savannas, on the borders of narrow swamps, and on the edges of small ponds. The cranes, which usually mate for life, become sexually mature at about age three, but they often do not become parents until two or three years later. Both parents share in building the nests, incubating the eggs, and caring for the chicks. During the nesting season, in spring and early summer, the female usually lays just two eggs, which hatch in thirty days. The chicks can swim the same day they hatch. Two days later the chicks can accompany their parents into the savanna, and by the time the young birds, called colts, are between seventy-five and ninety days old, they have learned to fly. Unlike many birds, the young cranes remain with their parents until the next nesting season.

Parent birds rarely succeed in rearing both of their chicks. Consequently, since 1965, some of the "extra" eggs have been taken to out-of-state wildlife centers to be hatched in captivity. Some of these birds and their offspring are maintained in captive flocks; others are released. Precautions are taken to make sure that the ones to be released remain wary of people. Some are reared in pens by captive foster parents. Others are hand-reared, but human contact is minimized through the use of one-way glass and full-body bird disguises. Tame young birds are kept in adjacent pens, so that the hand-reared birds will be familiar with other members of their species.

The juvenile captive birds bound for release are shipped to Mississippi after about a month, and they quickly learn to fit in with the refuge population. Now about a hundred Mississippi sandhill cranes live in the refuge or on adjacent land, including about twenty-five breeding pairs—though without the captive-breeding program, the population still could not sustain itself.

Yellow pitcher plants in bloom

HABITATS

Savanna Principal grasses that grow beneath the longleaf pine are Beyrich threeawn, bushy bluestem, cutover muhly, little bluestem, and toothache grass. Colorful spring wildflowers include candyroot, several meadow beauties, Osceola's plume, pale grasspink, rose pogonia orchid, southern colicroot, tuberous grasspink, yellow colicroot, and yellow milkwort. Showing off in autumn are blazing star, bristleleaf chaffhead, goldcrest, redroot, two kinds of native sunflower, woolly sunbonnets, and several species of yellow-eyed grasses.

For visitor information, contact:
Mississippi Sandhill Crane
National Wildlife Refuge
7200 Crane Lane
Gautier, MS 39553
228-497-6322
http://mississippisandhillcrane.fws.gov

Wet depressions in the savannas are home to various sedges and rushes and a few small trees of poison sumac. Because the soil is acidic and infertile, some plants are carnivorous, supplementing their diets by trapping small insects. Among them are a bladderwort, a butterwort, two kinds of pitcher plant, and three kinds of sundew.

Open marsh Sandweed grows extensively beneath bald cypress, pond cypress, swamp bay, swamp tupelo, and other trees. Nonwoody plants in or near the water include arrow arum, bulltongue arrowhead, foxtail club moss, golden club, Jamaica swamp saw grass, pipewort, royal fern, tall pinebarren milkwort, and several kinds of sedges and rushes.

Shrub border Among the native shrubs along the entrance road are black titi, five kinds of holly (dahoon, gallberry, large gallberry, myrtle-leaved holly, and yaupon), leatherwood, two kinds of wax myrtle, two kinds of wild blueberry, and a wild huckleberry.

Robert H. Mohlenbrock is professor emeritus of plant biology at Southern Illinois University in Carbondale.

Gifted in Science

For the young readers in your life

By Diana Lutz

For Small People

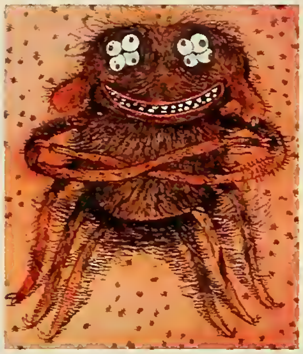
***Fireflies at Midnight,** by Marilyn Singer; illustrated by Ken Robbins (Atheneum Books for Young Readers, April 2003; $16.95)*

Fireflies at Midnight describes the everyday lives of common animals on a summer's day. The day begins with a robin's wake-up call and ends with a mole's droning lullaby. On each two-page spread a short poem faces a photograph of an animal that has been

manipulated to look like a painting. Parents will enjoy reading the verses, which expertly mimic an animal's song or the rhythm of its motion, from the frog's "baron I'm the baron" to the firefly's "Come/(flash)/Choose me (flash flash)."

***An Interview with Harry the Tarantula,** by Leigh Ann Tyson; illustrated by Henrik Drescher (National Geographic, September 2003; $15.95)*

Radio host Katy Did interviews Harry Spyder about his recent traumatic encounter with a human. As is the annoying habit of interviewers everywhere, she delves into Harry's love life (he must transfer his web sack of sperm to a female, but he's afraid of female spiders because they eat males). Two scientists served as expert consultants for this simple but pleasing narrative, which ends with "Tarantula



Facts." The real draw, though, is Henrik Drescher, whose off-the-wall illustrations make the tarantula a lovable (though admittedly "harry") old crank.

***The Queen's Progress: An Elizabethan Alphabet,** by Celeste Davidson Mannis; illustrated by Bagram Ibatoulline (Viking, May 2003; $16.99)*

Celeste Mannis unabashedly admits that *The Queen's Progress,* an ABC book, began life as a long historical novel. But when she finally threw out her thousand-page manuscript and

started over, she had seven years of research at her disposal. They weren't wasted. *The Queen's Progress* is not just an alphabet book; it's also a brief history of a "progress" (the royal version of a summer trip), a murder (or near-murder) mystery, and a seek-and-find book (the queen's three small rescuers appear in many of the illustrations). Because of its complex layering, the book will stand up to many readings. Bagram Ibatoulline's illustrations are done in the style of Elizabethan state portraits; the courtiers' elaborately decorated clothing is rendered more realistically than their faces.

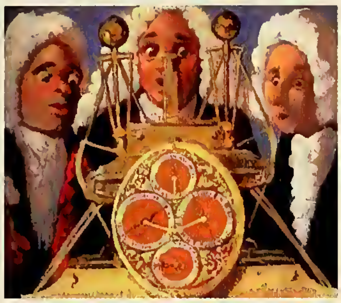
For Medium-Size People

***The Man Who Made Time Travel,** by Kathryn Lasky; illustrated by Kevin Hawkes (Farrar, Straus & Giroux, April 2003; $17.00)*

John Harrison, an uneducated but persevering clock maker, devoted a lifetime to inventing a mechanism that would keep accurate time at sea. He thus solved "the longitude problem," making it possible for sailors to avoid shipwreck by determining their east-west position when they were out of sight of land. Since the 1995 publication of *Longitude,* Dava Sobel's best-selling book on the topic for adults, the story of Harrison and his clock has slowly worked its way to more and more elementary reading levels.

Here Harrison appears once again (somewhat improbably) in a superb picture book by an award-winning author and an equally accomplished artist. The continually varying integration of text and art in *The Man Who Made Time Travel* is a book-lover's delight, and its luminous and whimsical paintings portray even wizened government officials and the mechanical innards of clocks in a warm and friendly glow. This is another Kathryn Lasky and Kevin Hawkes collaboration; their first, *The Librarian Who Measured the Earth* (1994), was selected by the *School Library Journal* as a "best book" of the year, and this one deserves similar accolades.

Parents of older children might want to consider *The Longitude Prize,* a book for young adults by Joan Dash, pub-



lished in 2000 (Farrar, Straus & Giroux). It supplies more of the historical context for the longitude problem, and explains how historians know what is known about Harrison. The book is embellished with witty line drawings and cleverly decorated initial capitals, both by Dušan Petričić.

How to Hold a Crocodile: Plus Hundreds of Other Practical Tips, Fascinating Facts and Wicked Wisdom, *by The Diagram Group (Firefly Books, September 2003; $19.95)*

Children of a certain age spend enormous amounts of time trying to figure out what adults are up to by reading *Ripley's Believe It or Not!, The Big Book of Big Secrets, Life's Imponderables,* and other outlandish guides to adult life, apparently under the illusion that they are getting the inside scoop. *How to Hold a Crocodile,* a similar compendium of popular lore, is full of oddball practical tips (how to paint a room, how to cheat at growing a big squash); dubious historical information (how to be a butler, how to make a quill pen); outdated social etiquette (how to choose the appropriate glass, how to get an audience with the

pope); and tricks of various kinds (how to magnetize a walnut, how to climb through a playing card). All this esoterica is punctuated by full-size game boards for obscure games and instructions for playing them.

The editors remark that they were not able to test all of the ideas since "none of [us] was prepared to volunteer for mummification." Accordingly, they don't promise that all the ideas really work. They doubt, for instance, that Aristotle ever managed to measure a flea's leaps by dipping its legs in wax. I can vouch, however, for the method of cleaning a burned pot (fill with cold water, add one tablespoon of vinegar, and boil for five minutes). I tested it several times in the course of writing these reviews.

Horseshoe Crabs and Shorebirds: The Story of a Food Web, *by Victoria Crenson; illustrated by Annie Cannon (Marshall Cavendish Corp., October 2003; $16.95)*

The horseshoe crab is the most child-friendly of animals: slow enough to be caught, about the right size and weight to be carried, fierce-looking but harmless, spectacularly alien, and (if dead) the possessor of a truly magnificent reek. But this gentle book coaxes children to think beyond the beast itself. Every spring, the crabs' mass beaching and egg laying become a great egg feast for starving shorebirds on the wing northward, from Patagonia and Tierra del Fuego. The names of the feeding migrators—red knots and ruddy turnstones—trip off the tongue in lyrical sentences crafted for their sound as well as their

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meaning. Annie Cannon's watercolors—the laughing gulls surrounding the text in sinuous S-shaped curves, for instance—similarly combine accuracy with poetry. Victoria Crenson confines to an author's note the gloomy observation that fewer and fewer crabs are returning to spawn, thus freeing children to revel in the joy of the horseshoe crabs' spectacular spring celebration.

For Nearly Grown People

Close to Shore: The Terrifying Shark Attacks of 1916, *by Michael Capuzzo (Crown Publishing Group, April 2003; $16.95)*

An adaptation of Michael Capuzzo's 2001 adult nonfiction best seller, *Close to Shore* tells the true story of the rogue shark that killed three men and a boy along the Atlantic coast early in the twentieth century. It also breaks most of the rules of nature writing. The shark is not a magnificent apex predator, but a kind of ichthyologic serial killer. Transgressing the ideal of objectivity, Capuzzo imagines the state of mind of the swimmers and, even more daringly, that of the shark. He even writes in an ornate style similar to that of contemporary newspaper accounts.

But though he's dancing on a high wire, Capuzzo never falls off. He did the hard work needed to re-create not just the events but also the texture of the time. He read medical and scientific journals, novels, plays, and love poems from the era, in addition to hundreds of newspaper accounts of the events and several hundred books about sharks. More important, he has the storyteller's gift. *Close to Shore* starts slowly, but it becomes a driving and nearly unstoppable freight train of a tale.

The Case of the Monkeys That Fell from the Trees: And Other Mysteries in Tropical Nature, *by Susan E. Quinlan (Boyds Mills Press, March 2003; $15.95)*

Twelve ecological mysteries are set in tropical forests. In each case a scientist notices something odd, follows the clues, tests a hypothesis through experiment, and eventually uncovers a surprising hidden connection or an unsuspected association. One scientist, for instance, wonders why female ithomiine butterflies are following swarms of army ants. After several false leads, he discovers that butterflies are using the ants to locate birds. Why? The bird droppings are a good source of the nitrogen that the butterflies need to produce eggs.

Much ecology writing for children is dull, second-hand, and sermonizing. Susan Quinlan, a biologist herself, reads the primary literature and talks to the scientists whose work she describes. She is among a handful of

children's writers who manage to capture the passion, beauty, and joy of the scientific pursuit. Quinlan's books are also characterized by her unusual respect for a young audience. She is careful to be clear, but at the same time she assumes children can follow the scientists' arguments, that they will be interested, not bored, and that they will value nature as much as she clearly does. Above all, she does not lecture or seek to place on small shoulders the burden of solving the crushing environmental problems our generation has created.

An American Plague: The True and Terrifying Story of the Yellow Fever Epidemic of 1793, *by Jim Murphy (Clarion Books, June 2003; $17.00)*

Children's books about the history of medicine tend to be guilty of old-fashioned scientific triumphalism. But the usual yellow-fever stories, the ones about Walter Reed and about the Panama Canal, are only a small part of the last chapter of *An American Plague*. Written from a disabused modern perspective, *American Plague* points out that reservoirs of yellow fever remain intact in monkeys (thus making its elimination unlikely); that there is still no cure for the disease once it is contracted; and that stocks of the vaccine are limited.

But Jim Murphy's powerful account is primarily a social history. No one knew at the time how yellow fever was transmitted or how it might be controlled, and those uncertainties exposed the fault lines of eighteenth-century Philadelphia society. Murphy discusses the role of black societies in nursing the sick; the famous case of Dr. Rush, who believed so blindly in his own cure (bleeding) that he almost killed himself with it; the improbable heroism of "a grogshop man" named Israel Israel; and even the impact of yellow fever on foreign policy: George Washington had trouble making decisions because his papers had been left behind in "boarded-up houses" when he fled the stricken town.

Those planning gifts for almost-grown-up readers should also consider The Longitude Prize, *noted in the review of* The Man Who Made Time Travel, *above.*

For Grown People with Childlike Curiosity

The Tree of Life: Charles Darwin, by Peter Sís (Farrar, Straus & Giroux, October 2003; $18.00)

Starry Messenger, Peter Sís's earlier book about Galileo, had a bold and simple story to tell, and a clear structure: the Inquisition quenched the stars in Galileo's eyes but could not put out the ones in his mind. *The Tree of Life,* Sís's story of Darwin, is more muffled and difficult—as was the man himself. After a youth spent under his father's thumb, Darwin escaped on the HMS *Beagle,* but on returning to England he fell into procrastination and ill health. He was only stirred to publish his famous theory years later, when another naturalist was about to beat him to the punch.

Both Sís's books are layered mysteries, with clue upon clue buried in delicate marginal illustrations and spiraling quotations that slow the skimmer and coax the hasty reader into thought. In *Starry Messenger* the

mysteries were solvable with the clues at hand. But in *The Tree of Life* the clues are too subtle and too learned. Unless you already know the intellectual history of the nineteenth century, you will lose yourself in the details, like Darwin on the sand path he made at Down House, "thinking, thinking, thinking."

Even the theory of evolution, presented on the book's only foldout, is somehow smothered by the fact that it is expressed in quotations from the heavily coded language of *Origin of Species*. And compared with *Starry Messenger*'s bright defiance, *The Tree of Life* has a much more melancholy tone. Galileo under house arrest was freer than Darwin was, in the prison of his own mind. As the pages grow grayer, Darwin turns to investigating the formation of vegetable mold, and becomes increasingly isolated behind his cloak and beard. Sís's Darwin is not for children, I think, but it would make a wonderful gift for the right adult.

Diana Lutz keeps an eye on children's literature for her daughter Emily. She is also the editor of Muse, *a science magazine for children.*

For the Coffee Table

By Laurence A. Marschall

The holiday season is supposed to offer some time for quiet reflection. Gift givers, well aware of the absence of such occasions in their own lives, still imagine that the lives of their friends and family are not so constrained by reality. Here, then, is a highly selective listing for holiday shoppers of some of the finest coffee-table books published in 2003 on science and nature.

The Universe: 365 Days, *by Robert J. Nemiroff and Jerry T. Bonnell (Harry N. Abrams, Inc., June 2003; $29.95)*
Earth from Above: 366 Days, *photographs by Yann Arthus-Bertrand (Harry N. Abrams, Inc., December 2003; $29.95)*

With its uplifting views of space, along with brief commentaries by two veteran astronomers, *The Universe: 365 Days* conveys the immensity and richness of the cosmos. The book's picture-a-day format, with images ranging from amateur snapshots of streaking comets to views of distant galaxies made by the Hubble Space Telescope, provides a better wake-up than a strong cup of black coffee. You can augment each entry with a picture from the book's mother Web site, Astronomy Picture of the Day (http://antwrp.gsfc.nasa.gov/apod/astropix.html), which has been serving up this mind-enhancing fare daily since the mid-1990s.

For an equally stirring view in the opposite direction, try the companion volume, *Earth from Above: 366 Days.* A continuation of the French photographer Yann Arthus-Bertrand's ten-year-long photographic and environmental project (represented in two previous volumes), the book showcases 200 of his new photographs. The aerial images present both famil-

A Celebration of the World's Barrier Islands, *by Orrin H. Pilkey; batiks by Mary Edna Fraser (Columbia University Press, June 2003; $44.95)*

Some 2,200 barrier islands fringe the world's coastlines, but that number is constantly subject to revision. Nibbled at by storms and gobbled up by tsunamis, barrier islands are among the most rapidly changing geological features on Earth. Without frequent replenishment by sand and gravel they can disappear entirely, and new ones are constantly forming. Orrin Pilkey, a professor emeritus of geology at Duke University in Durham, North Carolina, provides an informative guide to the wheres and wherefores of barrier islands—from the vacation meccas off the east coast of North America, to the exotic carbonate archipelagos of Mozambique, to the ice-battered slivers of tundra that line the Arctic Ocean. Aerial and satellite photographs illustrate each geological peculiarity that the text brings into focus, but the most remarkable images in the book are the batiks created

by Mary Edna Fraser. Her overflights of shorelines in the open cockpit of her grandfather's 1946 Ercoupe airplane provided the inspiration for dyed fabrics that capture the delicate shapes and shadings of these evanescent landforms.

iar and exotic scenes, but all appear surprising from the vantage point of a hovering bird (most were shot from helicopters). It is sobering, in some cases, to see how much the hand of man has altered the face of nature.

My Family Album: Thirty Years of Primate Photography, *text and photographs by Frans de Waal (University of California Press, October 2003; $29.95)*

Frans de Waal, a perceptive primatologist and an eloquent writer, has made a career of studying the social

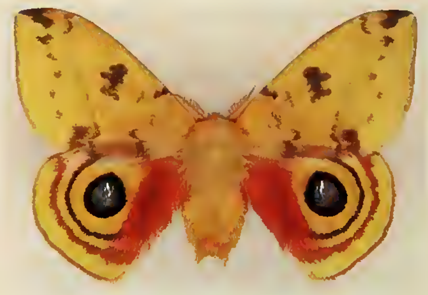
interactions of apes and monkeys in zoos around the world. In three decades of fieldwork he also made, by his own estimate, some 50,000 photographs. *My Family Album* is a sampling of his favorites: 128 elegantly composed black-and-white images that recall the classic pictorialism of the 1920s. His tight focus on faces, made possible because his subjects knew him so well, conveys a genuine sense of intimacy. Most striking of all the features, though, are the eyes. Apes and monkeys make eye contact with each other and with the camera, just as people sometimes do.

In brief paragraphs accompanying the photographs de Waal tells the story behind each look and gesture. He obviously has great love for the apes and monkeys he's known, and his pictures and anecdotes invite the reader to feel, rightly, that primates are members of our own extended family.

Night Visions: The Secret Designs of Moths, *by Joseph Scheer (Prestel, December 2003; $45.00)*

A few pages of technical notes by artist Joseph Scheer on the reproduction of his photographs, along with essays by lepidopterist Marc Epstein and media specialist Johanna Drucker, make up nearly all the text in this mammoth and colorful book. Not much else is needed to accompany its spectacular ultra-close-ups, which showcase the technical virtuosity attainable with digital printing and scanning (the latter at resolutions of 2,000 to 14,000 pixels per inch).

A luna moth, *Actias luna,* whose



wing coloration camouflages it against leaves and stems from a distance, becomes so large on these pages that it looks like a carpet of green grass, covered inexplicably with rich tufts of whitish hairlike scales and two decorative ferns (the moth's antennae). *Euclea delphinii,* a nondescript brown insect, turns out on close inspection to be as soft, plump, and fuzzy as a teddy bear. A copy of this brilliant book on your coffee table will cause as much of a stir as an unshielded porch light on a summer evening.

De Historia Stirpium Commentarii Insignes *(Notable commentaries on the history of plants), by Leonhart Fuchs (Basel, 1542: Octavo Editions, September 2003, CD-ROM ed.; $30.00)*

Few gift givers have the resources to purchase a sixteenth-century herbal for the book collector or gardener on their list. Octavo Editions has the solution. Here, on one compact disk, is a complete facsimile of the first edition of one by Leonhart Fuchs, plus notes and commentary by the botanical historian Karen Reeds. Considered a landmark in scientific illustration when it appeared, Fuchs's book is still

highly regarded for the fine detail of its woodcuts. Now, with the magic of modern digital imagery, it is possible to zoom in on every stem of hyacinth, every leaf of gentian. For book collectors with other interests, Octavo Editions (octavo.com) also offers a large variety of rare and highly sought-after titles—from an original Mercator world atlas to Josiah Dwight Whitney's 1868 *Yosemite Book* (the latter includes twenty-eight early albumen prints of one of America's most popular landmarks). All the facsimiles are available, of course, for thousands of dollars less than the paper or parchment originals.

Prehistoric Art: The Symbolic Journey of Humankind, *by Randall White (Harry N. Abrams, Inc., June 2003; $45.00)*

Before there was writing—in other words, for most of humanity's occupancy of this planet—there was art. Buxom figurines of the mother goddess, reindeer antlers incised with hunting scenes, and images of woolly mammoths scratched into the calcite walls of caves endure as records of the sensibilities of early *Homo sapiens.*

But such representations are still deeply mysterious: the mind-set of their creators is so distant, so alien to modern culture, that the temptation is to view them as merely beautiful, or as mere charms to ensure a successful hunt, or as mere expressions of primitive superstition. Randall White, a professor of anthropology at New York University, is a thoroughly literate modern, but he is also an ardent student of ice-age archaeology. His magisterial survey of prehistoric paintings and sculptures attempts to evoke the voices of their anonymous creators. The book's handsome color photographs convey beauty and drama, but without such an able interpreter as White, the artworks would not speak authentically for themselves.

Extraordinary Pigeons, *by Stephen Green-Armytage (Harry N. Abrams, Inc., October 2003; $24.95)*

City dwellers regard pigeons as flying rats, creatures whose insatiable appetite for crumbs is matched only by their marksmanship in public defecation. Yet the pigeon family, Columbidae, is one of the most adaptable avian populations on Earth. So ancient is their domestication that Darwin (who kept a well-stocked dovecote at his country estate) considered the selective breeding of pigeons a paradigm of the evolutionary process.

Stephen Green-Armytage's photographs of avian finery have the chic detachment of high-fashion portraiture: a Jacobin winks coyly from the folds of its hood, like a model wrapped in a feather boa; a white pigmy pouter poses erect and proud, with a puffed-up chest of olympian proportions. Even jaded urbanites will be charmed by the extravagance of these feathered queens.

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

nature.net

Mars on My Mind

By Robert Anderson

As Mars was making its much-publicized close approach to Earth recently, I often looked up at the southern sky at night and, in my imagination, tracked the Red Planet's movements. No telescope needed: I could see the disk in my mind's eye. I felt its presence. Now, with the imminent landings in January of the two NASA rovers, Spirit and Opportunity, I can imagine myself closer still to Mars—a virtual geologist traversing the rocky terrain of a hostile, alien planet.

Earthbound explorers like me haven't had a show like this since NASA posted the exploits of its 1997 Mars Pathfinder rover, causing, at the time, the biggest "hit blizzard" on a single Web site in Internet history. Once again space buffs can tag along via the space agency's Web site, Mars Exploration Rover Mission (mars.jpl.nasa.gov/mer/overview). Surf the menu bar below the title to acquaint yourself with what's available for your trip at this site. And preview the entire mission through its spectacular series of animations (under the "Multimedia" list, from the menu bar, click on "Video" and then on "Animation").

Before your departure, take a look at how the image of our most alluring celestial neighbor has changed with time. Go to Planet Mars in Popular Culture (humbabe.arc.nasa.gov/mgcm/fun/pop.html), a site put together by David Catling of NASA Ames Research Center, and scroll down through Mars-themed novels, radio shows, and movies. A sister site, Planet Mars Chronology (humbabe.arc.nasa.gov/mgcm/fun/mars_chro.html), offers a time line of the Red Planet's influence on science and culture. To find out how we project ourselves nowadays onto the barren surface of the planet, check out "Face on Mars" and "Cydonia Research," available by choosing the NSF "Archive" page of the e-journal *New Frontiers in Science* (www.newfrontiersinscience.com/index.shtml). Be sure to "Access high resolution animated content" by clicking on the hypertext. For those who daydream of actually setting foot on Mars, I recommend Explore Mars Now (www.exploremarsnow.org). The site's interactive habitat lets you walk around the first Mars "space base," and hints at the difficulties of survival there.

Perhaps the best overall introduction to the planet can be found at Windows to the Universe (www.windows.ucar.edu/). After entering the site, choose "Mars" from the extensive highlighted list. A good place to begin is "Tour Mars!" To dig deeper into the details of the Martian surface, try the clickable atlas (www.roving-mouse.com/planetary/Mars/Atlas/clickable-globe.html). And if there's a place on Mars you've got your heart set on seeing, go to the site of the *Mars Global Surveyor* (mars.jpl.nasa.gov/mgs). The satellite began orbiting and photographing the Red Planet in 1997, and so far has taken more than 120,000 pictures. Yet those photographs cover only about 3 percent of the planet. This past September NASA began taking requests from the public for areas to be imaged, and posting them monthly at the site (look for "Public Requested Image").

The image I found most moving, though (mars.jpl.nasa.gov/mgs/sci/earth/index.html), was not of Mars at all, but showed what the first people living there would see if they looked back at their home planet with a decent telescope.

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

Star Baby

T Tauri shows that a stellar nursery can be a rough-and-tumble place to live.

By Charles Liu

Winslow Homer, *Snap the Whip*, 1872

In 1852 the English astronomer John Russell Hind, exploring the constellation Taurus through his telescope, found a dim star that wasn't noted on his charts. The new star, named T Tauri, has since become something of a minor celebrity among astronomers. It owes its fame primarily to its status as a stellar ingenue: it's just a million or so years old, which, for a star about as massive as the Sun, is very young indeed. Nowadays all stars of similar age and mass are known as T Tauri stars; they're immensely important because they afford astronomers a chance to study, by inference, the early history of our own solar system and Sun, born more than four and a half billion years ago.

Astronomers have learned a lot about this stellar baby, the original T Tauri, in the past 150 years. Among the most significant discoveries has been that T Tauri was part of a multiple birth: astronomers identified a second star in the system in 1981 and a third star in 1997. Another study, made early in 2003, suggested that a close encounter between the second and third star, acting as a kind of gravitational slingshot, had hurled the third star out of the system. Now a research team led by Elise Furlan, an astronomer at Cornell University in Ithaca, New York, has discovered that, if the slingshot hypothesis is true, the T Tauri system probably includes a fourth object, too.

T Tauri is about two one-hundredths of a percent the age of our Sun. That's approximately the difference between a baby only a few days old and a middle-aged adult. Although people of both ages are alike in having head, limbs, and torso, their behavior and physical development bear hardly any resemblance at all. Much the same is true for a novice star like T Tauri and a middle-aged star like our Sun.

Like a human baby, a stellar baby is unpredictable. When Hind discovered T Tauri, it was shining at about magnitude ten—roughly one-fiftieth the brightness visible with the unaided eye. In the following forty years, though, the star gradually dimmed by 98 percent, then, inexplicably, it started brightening again. Today it's about as bright as it was when Hind first saw it. The star is still inconstant, however: modern measurements show that, even from one day to the next, T Tauri's brightness can change by as much as half its typical output. Although the causes of the variation remain unclear, the star's interaction with the gassy, dusty environment in which it was born certainly plays a big role.

An infant star, like a baby, also is hungry. T Tauri is so young that the nuclear fusion of hydrogen into helium, which makes mature stars shine, hasn't even begun. Without nuclear fusion, the star's luminosity depends on gravity: matter falling onto the stellar surface from the surrounding gas cloud glows as it accelerates; and the protostellar gas ball, as it collapses inward from its own weight, also becomes hot enough to glow. Plenty of power is generated as a consequence, enough to make T Tauri shine, but the energy isn't as steady and predictable as nuclear fusion. The thick clouds still swirling around the star further accentuate the swings in luminosity. As T Tauri consumes the matter around it, it grows in mass and in energy output, often spitting up swirling streams of energetic particles called T Tauri winds.

One big difference, though, between human and stellar childbirth is the frequency of twins and triplets. A woman's chances of bearing twins are typically about one in a hundred. But astronomers think that as many as two-thirds of all new stars are born as binaries or multiples. T Tauri was no exception. As I noted earlier, at least three components have been identified, known as North, South-A (the 1981 discovery), and South-B (1997).

Astronomers have long suspected that such systems, with several young stars in close orbit about one another, might occasionally fling one of their components out of the system in a gigantic gravitational game of crack-the-whip. High-precision radio astronomy observations made in early 2001 suggested that the stars in T Tauri were doing just that: South-B seemed to be exiting the system, after having swung around South-A in a curlicue path during the past two decades.

Furlan and her collaborators aimed the 200-inch Hale Telescope, at the Palomar observatory in California, at the system not to investigate the gravitational slingshot, but to study T Tauri's circumstellar environment. (The radio data had not yet been published when the Furlan team began their work.) Using an infrared camera fitted with adaptive optics designed to cancel out the distorting effects of Earth's atmosphere, the astronomers were able to plot the apparent positions of South-A and South-B to accuracies of better than ten milliarcseconds. That's about 1/400,000 of a degree of arc, or the apparent diameter of a penny at a distance of 200 miles. After the radio observations were published, and they compared that data with their own, however, Furlan's group realized that South-B isn't the star moving along the crack-the-whip trajectory after all. It is apparently still orbiting South-A. Nevertheless, the Furlan team doesn't suspect that the earlier data were faulty. On the contrary, they think those measurements actually detected a fourth body in the T Tauri system. That body, tentatively named South-C, is probably being ejected after a close encounter with South-B.

If that interpretation holds up, the gravitational "flinger"—T Tauri South-B—is too faint in radio waves to be detected with radio telescopes, whereas the "flingee"—T Tauri South-C—is too faint to be seen in infrared light. What does that say about South-C? One possibility is that South-C isn't a star at all, but rather a brown dwarf, though it could be an ordinary, low-mass young star.

So imagine, if you will: a bright young star, orbited by two other young stars, all swaddled in swirling clouds of gas and stellar winds, with another large body thrown in—and being thrown out—for good measure. That's quite a commotion for a star at the dawn of its life.

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 DECEMBER AND JANUARY

By Joe Rao

Mercury sets during twilight in December and is barely visible all month. It passes between the Sun and the Earth on the 26th.

In January, however, the planet puts on an excellent show. Mercury is low in the east-southeastern sky at dawn; look for it an hour before sunrise. Find ruddy Antares in the constellation Scorpius; Mercury is below and to the left of the star, and becomes increasingly distant from it as the month progresses. The little planet shines at magnitude −0.2 between the 17th and the 24th and brightens through the rest of the month. Unfortunately, the early morning is brightening as well, making the planet harder to see.

Venus grows progressively more conspicuous in December, a radiant evening "star" in the southwest visible soon after sunset. For observers at midnorthern latitudes, the planet begins the month less than 15 degrees above the horizon at sunset; by New Year's Eve, though, Venus has shifted to 23 degrees above the horizon at sundown. Binoculars help reveal background stars in the twilit sky as Venus glides past the top of the "teapot" of the constellation Sagittarius during the first third of the month. On Christmas night a slender crescent Moon and Venus make for an eye-catching celestial tableau.

In January, Venus, gleaming at magnitude −4, ascends dramatically higher, its sunset altitude increasing to 33 degrees by month's end. Seen through a telescope, Venus wanes from nearly full to more definitely gibbous. But the naked-eye view of the planet streaking across half of Capricornus and most of Aquarius as the month progresses is the really exciting spectacle. On the 24th Venus and the crescent Moon virtually replicate their Christmas-night encounter.

Mars, fading after its autumnal glory, is near its highest point in the sky at evening twilight and sets at about midnight. In December the planet, shining south of both Pisces (the fishes) and the square of Pegasus (the winged horse), progresses 15 degrees eastward relative to the two constellations. On the 1st Mars is 79 million miles from Earth and shines at magnitude −0.4; by New Year's Day the planet has receded 25 million miles more, and dimmed to magnitude 0.2.

Mars declines in brightness again, by another half a magnitude, during January, as the Earth's smaller orbit further separates the planets. On the evening of the 27th Mars hovers above a fat crescent Moon.

Jupiter rises in the east just after midnight as December begins, and at about 10:15 P.M. by month's end. It's shining brilliantly at magnitude −2.1 all month in the constellation Leo (the lion)—about 18 degrees east of Regu-

STATEMENT OF OWNERSHIP

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EXPLORER GUIDE

lus, Leo's brightest star, at midmonth. Regulus precedes Jupiter on their way up the sky by about ninety minutes, but the giant planet is well worth waiting for: even when Jupiter is low in the sky, its four bright moons present an ever-changing dance for the telescope.

In January giant Jupiter rises four minutes earlier with each passing night, and comes up just after 8 P.M. local time by month's end. The planet rises practically due east, and so climbs the sky rapidly as the evening passes—more than 20 degrees in less than two hours. By the end of January it reaches its highest point around 2:30 A.M.

In December Saturn makes its finest apparition in thirty years. It arrives at opposition to the Sun on New Year's Eve, rising as the Sun sets, reaching its highest point in the southern sky at midnight, and setting as the Sun rises. It is also closer to Earth on this night (748.3 million miles) than it has been since another, similar opposition in December 1973. Because of its unusual proximity, Saturn shines as bright as it can ever get: magnitude –0.5. Not until January 2034 will the planet repeat this year's spectacular show. Its rings are dramatically tipped more than 25 degrees to our line of sight: a certain delight for anyone lucky enough to receive a telescope as a holiday gift.

In January Saturn is already well up in the east at sundown and sets in the west-northwest an hour or two before sunrise. The Moon passes to the north of Saturn on the evening of the 6th.

The Moon waxes full on December 8 at 3:37 P.M. It wanes to last quarter on the 16th at 12:42 P.M. and becomes new on the 23rd at 4:43 A.M. It waxes to first quarter on the 30th at 5:03 A.M.

In January the Moon waxes full on the 7th at 10:40 A.M. It wanes to last quarter on the 14th at 11:46 P.M. and becomes new on the 21st at 4:05 P.M. It waxes to first quarter on the 29th at 1:03 A.M.

The Gemenid Meteor Shower should entice even those observers faced with mid-December cold. Now considered the richest of the annual meteor showers (surpassing even the celebrated Perseids of August), the show should peak on the night of December 13–14. You might see as many as 120 "shooting stars" an hour—but expect considerable interference from a waning gibbous Moon toward morning, when the meteor rates are highest.

The solstice takes place at 2:04 A.M. on December 22. Winter begins in the northern hemisphere; summer begins in the southern.

The Earth reaches perihelion, its closest approach to the Sun, at 1:00 P.M. on January 4. The Sun is 91,400,172 miles away.

Unless otherwise noted, all times are given in Eastern Standard Time.

Dr. Sacha Spector on Saving "the Other 99 Percent"

Sacha Spector is Invertebrate Conservation Program Manager with the Museum's Center for Biodiversity and Conservation (CBC). We caught up with Sacha in his invertebrate lab at the Museum, as he is busy gearing up for the CBC's March symposium, Expanding the Ark: The Emerging Science and Practice of Invertebrate Conservation.

SERGIO AYZAMA

Sacha Spector doing field research in Bolivia

Q: What exactly are invertebrates, and why should people care about them?

Invertebrates are united by what they *don't* have, namely backbones, rather than any shared features. If you think of the evolutionary "Tree of Life" of animals, vertebrates—mammals, birds, reptiles, etc.—make up only a single branch. All the other animal branches are invertebrates. So invertebrates really represent the vast majority of evolutionary history on Earth. While people mostly think of insects, invertebrates actually encompass a huge range of animals found on land and in water. Some of these we're quite familiar with, like squid, lobsters, corals, and jellyfish, but there's a whole universe of lesser-known invertebrates out there, like tardigrades or "water bears," chitons, and flatworms. As a group, invertebrates probably constitute 99 percent of all animal life on Earth, so we share this planet with millions of invertebrate species.

Invertebrates are essential elements of every ecosystem—they fill niches as herbivores, carnivores, parasites, and decomposers. They also serve as food for mammals, birds, fish, reptiles, amphibians, other invertebrates, and even carnivorous plants! Ecosystem services provided by invertebrates—such as pollination of crops, soil creation and aeration, decomposition, and seed dispersal—are estimated to be worth trillions of dollars to our economy each year. It is said that over one third of the human diet depends directly or indirectly on pollination by insects.

Q: Invertebrates seem to suffer from an image problem...some elicit fear, while others are seen as pests.

Usually, we fear things we don't understand. One of my favorite things is getting kids to look at insects with a microscope—one look at the metallic colors of a beetle or the reflections from a fly's eye and the "eeewww" usually turns into "cool!" As for pests, only a tiny percentage of invertebrates are injurious, and those we're most familiar with are generally non-native species introduced by humans, such as the gypsy moth, Japanese beetle, and some types of cockroaches. But every organism has its function in the web of life—

CBC's Spring 2004 Symposium

Expanding the Ark: The Emerging Science and Practice of Invertebrate Conservation

March 25 and 26, 2004, 9:00 a.m.–6:00 p.m.

Tickets: $100
$80 Museum Members, seniors
$25 students (with ID)
After Friday, February 6, 2004: $125
$100 Museum Members, seniors
$50 students (with ID)

For information or to purchase tickets, call 212-769-5200 or visit http://research.amnh.org/biodiversity/.

Mantis making a meal of a planthopper

even mosquitoes. Mosquito larvae are an important food source for fish and other aquatic creatures, and the adults feed a lot of birds and bats.

Q: What drew you to the study of invertebrates?

My interest in invertebrates hit me later in life. In fact, I went off to college wanting to become a professional trombonist. But I was also very concerned about the environment, and I've always loved the outdoors, so I eventually changed my major to biology. (Also, I quickly realized I would never make a great trombonist.) I did a few insect-related projects as an undergraduate, and the more I delved into biodiversity research, the more I realized that invertebrates were being left out of the majority of conservation efforts. My current research is related to addressing this issue. Because invertebrates as a whole are so numerous and diverse, and most groups are poorly understood, I'm working on designing approaches to choosing a few invertebrate groups about which we can quickly compile as much data as possible, and then use those groups as "information surrogates" for invertebrate conservation planning.

Q: Are invertebrates facing the same threats and endangerment as mammals, fish, and other species?

Absolutely. The three most endangered groups of organisms in the United States—freshwater mussels, crayfish, and stoneflies—are all invertebrates. Widespread threats such as habitat loss, introduced species, and pollution, are rapidly driving many invertebrate species to the edge of extinction. Part of their plight lies in their very diversity—how do you plan and manage communities of organisms when you aren't sure what (or how many) you're dealing with? This is one of the major questions that we will be looking at in the *Expanding the Ark* symposium.

Q: What can we do as individuals to help conserve invertebrates?

There are important things you can do every day. Pesticides, which often kill many other organisms besides the target pest, are a major threat to invertebrates, so one major thing everyone can do is to support farming without chemical pesticides by choosing organic foods. In the suburbs and rural areas, light pollution is a concern as it attracts insects away from their habitats, disrupts their egg laying, mating, and feeding, and also makes them more susceptible to predation. You can reduce or eliminate outdoor lights or, if necessary, install motion detectors or use yellow lights that don't attract insects. But probably the most important thing you can do is to learn about the invertebrates that live in your area. We save what we care about, so the first step is just getting out there and learning to love the fascinating and often beautiful creatures all around us.

MUSEUM EVENTS

EXHIBITIONS

A buff-breasted sandpiper engages in a courtship display

Seasons of Life and Land: Arctic National Wildlife Refuge
Through March 7, 2004
Over 40 large-format color photographs by conservationist Subhankar Banerjee focus on the interdependent relationship of land, water, wildlife, and humanity in Alaska's Arctic Refuge.

Petra: Lost City of Stone
Through July 6, 2004
This exhibition tells the story of a thriving metropolis at the crossroads of the ancient world's major trade routes.

In New York, Petra: Lost City of Stone *is made possible by* Banc of America Securities *and* Con Edison. *The American Museum of Natural History also gratefully acknowledges the generous support of Lionel I. Pincus and HRH Princess Firyal and of The Andrew W. Mellon Foundation. This exhibition is organized by the American Museum of Natural History, New York, and the Cincinnati Art Museum, under the patronage of Her Majesty Queen Rania Al-Abdullah of the Hashemite Kingdom of Jordan. Air transportation generously provided by Royal Jordanian.*

The Bedouin of Petra
Through July 6, 2004
Photojournalist Vivian Ronay's evocative color photographs document the Bedoul group of Bedouin tribes living near the archaeological site of Petra in Jordan.

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

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 31, 2004
The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory *is made possible through the generous support of Bernard and Anne Spitzer.*

Vietnam: Journeys of Body, Mind & Spirit
Through March 7, 2004
Gallery 77, first floor
This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.

LECTURES

The Saga of Life
Tuesday, 12/9, 7:00 p.m.
With Nobel laureate Christian de Duve.

Sylvia Earle on Sustainable Seas
Thursday, 12/18, 7:00 p.m.
With the National Geographic Society's Explorer-in-Residence Sylvia Earle.

Petra: Lost City of the Nabataean People
Tuesday, 1/13, 7:00 p.m.
A panel discussion of cross-cultural influences among the many cultures that passed through the ancient city of Petra.

FAMILY AND CHILDREN'S PROGRAMS

Architecture and Archaeology
Saturday, 12/13, or Sunday, 12/14
10:30–11:30 a.m. (Ages 4–6, each child with one adult)
1:30–3:00 p.m. (Ages 7–9)
Astounding Science for Families
Sunday, 12/14, 1:00–2:00 or 3:00–4:00 p.m.
Casting and Model-Making
Sunday, 1/18, 2:00–4:00 p.m.

GLOBAL WEEKENDS

Kwanzaa 2003
Saturday, 12/27, 12:00–6:00 p.m.
This soulful celebration includes activities and performances for the whole family.

Living in America: The Haitian Experience
Saturdays, 1/10, 17, and 31, and Sunday, 1/18, 1:00–5:00 p.m.
Celebrate the 200th anniversary of Haiti's independence with performances, films, and workshops.

Global Weekends are made possible, in part, by The Coca-Cola Company. The American Museum of Natural History wishes to thank the May and Samuel Rudin Family Foundation, Inc., the Tolan Family, and the family of Frederick H. Leonhardt for their support of these programs.

HAYDEN PLANETARIUM PROGRAMS

Lonely Planets
Monday, 12/1, 7:30 p.m.
With David Grinspoon,

NASA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

N49, debris from a stellar explosion in the Large Magellanic Cloud

Southwest Research Institute.

The Origin of Structure
Monday, 12/8, 7:30 p.m.
With Jeff Hester, Arizona State University.

Virtual Universe
Redefine your sense of "home" on this monthly tour through charted space.

The Grand Tour
Tuesday, 12/2, 6:30–7:30 p.m.

Our Nearest Stellar Neighbors
Tuesday, 1/6, 6:30–7:30 p.m.

This Just In...
The latest news from the universe.

January's Hot Topics
Tuesday, 1/20, 6:30–7:30 p.m.

Celestial Highlights
Find out what's up in next month's sky.

Winter Sky
Tuesday, 12/30, 6:30–7:30 p.m.

Greek Mythology
Tuesday, 1/27, 6:30–7:30 p.m.

COURSES

Matter and Energy
14 Thursdays, 1/29–5/13, 6:30–8:30 p.m.

Stars, Constellations, and Legends
Five Wednesdays, 1/14–2/11, 6:30–8:00 p.m.

Choosing a Telescope
Three Mondays, 1/26–2/9, 6:30–8:30 p.m.

Introduction to Astronomy
Six Mondays, 1/26–3/8, 6:30–8:30 p.m.

Stellar Death
Five Thursdays, 1/29–2/26, 6:30–8:30 p.m.

Scientific Revolution
Five Thursdays, 1/22–2/19, 6:30–8:30 p.m.

The Science of the Rose Center
Six Tuesdays, 1/13–2/17, 6:30–8:30 p.m.

Pictures to Papers
Four Tuesdays, 1/20–2/10, 6:30–8:30 p.m.

PLANETARIUM SHOWS

SonicVision
Friday and Saturday evenings
Presenting sponsor: Sun Microsystems, Inc.

The Search for Life: Are We Alone?
Narrated by Harrison Ford
Daily
Made possible through the generous support of Swiss Re.

Passport to the Universe
Narrated by Tom Hanks
Daily

Look Up!
Saturday and Sunday, 10:15 a.m.
(Ages 5 and under)

LARGE-FORMAT FILMS

Volcanoes of the Deep Sea
Explore Earth's most hostile environments and its strangest creatures on the deep sea floor.

India: Kingdom of the Tiger
A glorious tribute to this magnificent land and the mighty Bengal tiger.

INFORMATION

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

TICKETS AND REGISTRATION

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

All programs are subject to change.

Starry Nights
Live Jazz

Friday, 12/5, 5:30 and 7:00 p.m.
Rose Center for Earth and Space

David "Fathead" Newman Quartet

Tune in to the 5:30 set live on WBGO Jazz 88, hosted by Morning Jazz's *Gary Walker.*

Call 212-769-5100
or visit www.amnh.org
to find out who's playing in January.

Starry Nights *is made possible by Lead Sponsor Verizon and Associate Sponsors CenterCare Health Plan and WNBC-TV.*

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ENDPAPER

On Thin Ice

By Kirsten Weir

I grew up in rural Michigan, in a house surrounded by woodlands, with a sparkling, spring-fed lake for a backyard. In the autumn the lake reflected the patchwork of reds and oranges from the maple trees that ringed it. In the spring the still surface mirrored the pale green of new buds. The cool water always looked darkest then, dyed by the tannins leached from fallen leaves during the long winter. As warm weather came on, the water cleared.

The lake was our childhood playground, summer and winter; it embodied my sense of the seasons. Each hot day of summer vacation I played and swam in the water until my fingers were wrinkled prunes. When the bitter winter winds blew in, the surface froze to a perfect rink. My sisters and I had strict orders to stay off the ice until my father tested it and pronounced it safe, but from the moment he gave the go-ahead, we'd skate until our toes went numb.

We were (most of the time) obedient children. We never ventured onto the ice until permission was granted. Other creatures were not so patient. One winter a buck fell through the ice.

I don't know who first spotted the struggling deer, but I remember pressing my face against the living-room window that afternoon and watching him thrash about, trying to regain solid ground. He was a large, heavy animal, with an impressive rack of antlers, and each time he heaved himself onto the ice, another chunk of it would break beneath him, plunging him back into the frigid water.

It was clear that the deer was making no progress, so my father called in the "troops." A group of neighbors soon congregated along the shore to assess the situation and work out a plan. After some discussion, my father and a neighbor got out a few shovels and broke up the thin ice around the mouth of the stream that ran into the lake. Then they launched our rowboat, carrying a length of heavy rope. Fortunately the animal was close by, but as the rescuers made their way toward him, the buck made desperate lunges in the opposite direction, smashing through the thick sheet of ice as he went.

The two men fashioned a lasso and, after several attempts, managed to encircle the deer's head with the rope. They coaxed the terrified animal gradually

M.A. Hall, *Stag at Echo Rock*, c. 1850

toward the shore, and helped him climb the bank. The rescue operation took more than an hour.

When, freezing and exhausted, he finally felt land beneath his limbs, the buck collapsed. My mother covered him with blankets, and a neighbor phoned the local chapter of the Humane Society for help. When their man arrived, he told us there was nothing for it but to give the deer a quick and painless death.

No one in the rescue party was ready to consign the animal to such a fate. After all, he had put up a magnificent struggle. But it was my father who flatly refused to give in. "You hear that?" he shouted at the buck. "They're going to kill you." He kicked the animal firmly in the rump. "Get on, get out of here."

To our astonishment, the buck got up. Wobbly-kneed, as though he were punch-drunk, he stumbled toward the woods. After a few yards he picked up his pace. Then his gait returned to normal, and he vanished into the trees.

My father died a year ago this spring; a few months after that, my childhood home went up for sale. On a hot, bright July day, my sisters and I took the rowboat to the middle of the lake and sprinkled his ashes into the cool, blue water. We couldn't think of a better way to say goodbye.

Kirsten Weir is a science writer who lives in New York City. She has a degree in biology from Kalamazoo College in Kalamazoo, Michigan, and a master's degree in science journalism from New York University.

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