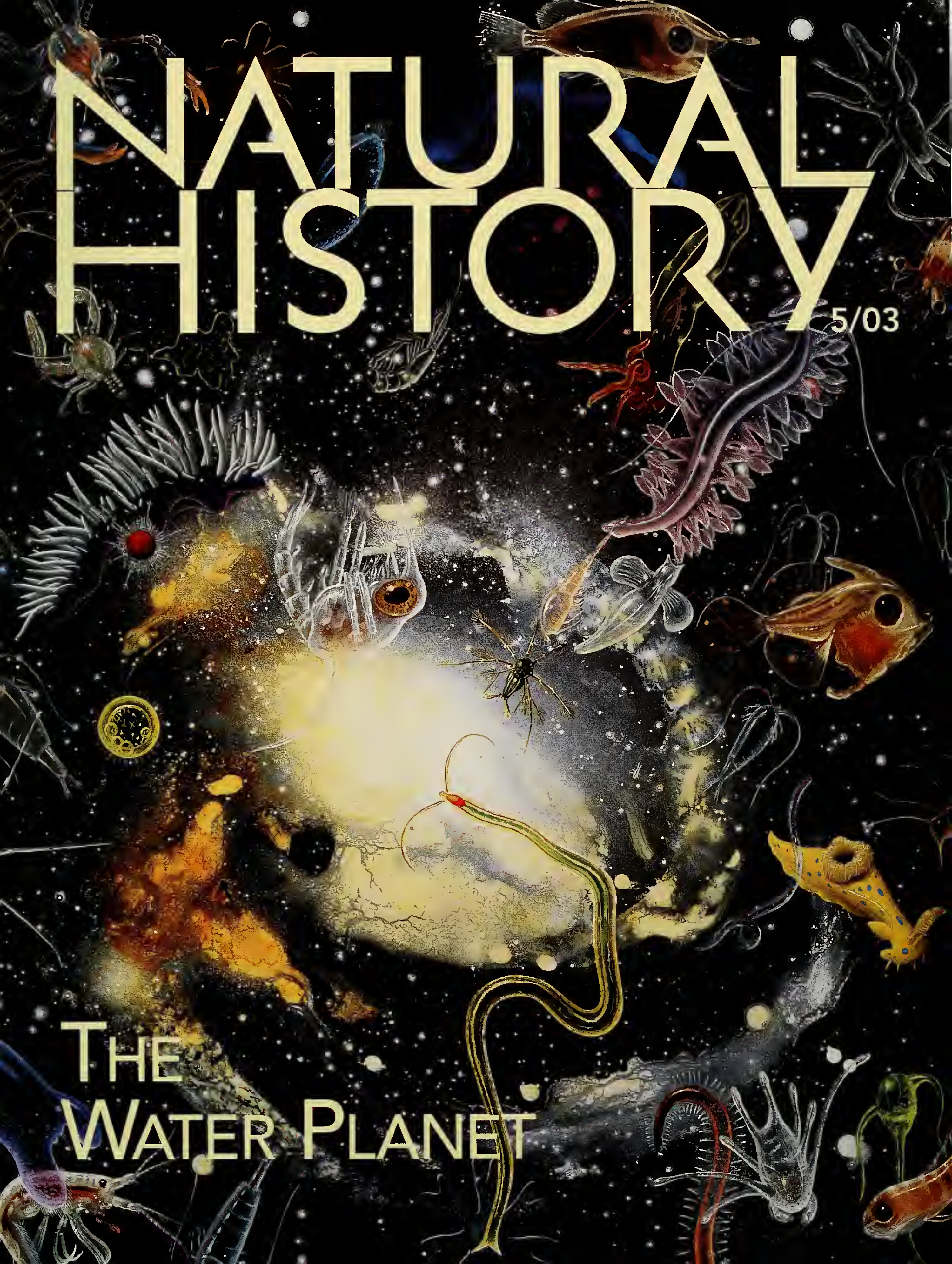
NATURAL HISTORY
5/03
THE WATER PLANET

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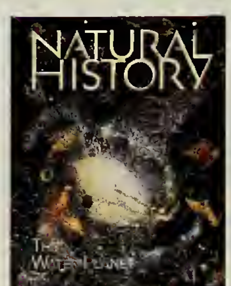
MAY 2003 VOLUME 112 NUMBER 4

FEATURES

THE WATER PLANET

COVER
Alexis Rockman, *Biosphere: Hydrographer's Canyon*, 1994

STORY BEGINS ON PAGE 40



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Model in
stainless steel.
Oysterlock bracelet.

THE NATURAL MOMENT

Bubble Feast

Photograph by Duncan Murrell

THE NATURAL MOMENT

◄ *See preceding pages*

To say that baleen whales feed by passively filtering krill is almost to insult the mammals' truly sophisticated behavior. Humpback whales *(Megaptera novaeangliae)* are known to hunt in remarkably cooperative and cohesive groups. Pictured here, in an Alaskan inlet, is a humpback mid-maneuver in a feeding mode known as bubble-netting. The giant's grooved throat, studded with sensory nodules and acorn barnacles, bulges with Pacific herring—an elusive and fast-moving species compared to krill—caught by coordinated efforts.

At a depth that depends on the number of feeding whales and the quantity, location, and kind of prey, one whale begins the hunt by blowing massive air bubbles. Another member of the pod (often six or seven whales in all) sounds a deep, resonant call that signals a move to drive the school of fish upward, trapping them at the surface in a roiling "net" of bubbles. As sonar studies have shown, each whale probably takes a particular position in the herding operation of every hunt.

For decades photographer Duncan Murrell has observed the humpback whales by paddling unobtrusively alongside the pods in his kayak. The whale in the photograph, Murrell says, "launched from the water," catching him slightly off-guard—a minor jolt for the photographer, who, that very same morning, had been sprayed with blowhole oil, slapped by a monstrous flipper, and momentarily beached on the body of a whale. —*Erin Espelie*

UP FRONT

Thinking Blue

One of the most astonishing discoveries a visitor can make during a first love affair with New York City is "the whale," a ninety-four-foot life-size model of a blue whale that has swum overhead since 1969 in the vast Hall of Ocean Life, at the American Museum of Natural History. For sixteen months, though, the whale has been swimming in the dark—getting a thorough cleaning and anatomical updating as the entire exhibition gets a facelift. This month, on May 17, the whale resurfaces into public space.

But even without such a motivating occasion as the return of the whale, you don't have to be a mariner to think about the Earth as the water planet. All you have to do is gaze at one of those glorious images of our planet that NASA has made from space. What biologists see, though, when they look at the blue of our planet is more like sap or film than simple liquid, a soupy goo so thick with suspended, replicating cells that it constitutes a kind of living plenum, a continuous fullness of life.

Edward F. DeLong brings the story of microscopic sea life up to date in his article, "A Plenitude of Ocean Life" (page 40). DeLong recounts how the so-called Archaea, whose identity as one of the three great branches of life went unrecognized until a few decades ago, are now known to comprise between 20 and 30 percent of all oceanic microbial cells. Previously unknown genera of bacteria-size "picoplanktonic life," DeLong reports, reach densities greater than 100,000 cells per milliliter of seawater. One such genus, *Prochlorococcus,* constitutes half of the total chlorophyll-based biomass in the open ocean.

There are several themes here worth exploring beyond the sea. One is the affinity of life with water of any kind. The quest for freshwater has driven great architecture (see "Temples for Water," by Morna Livingston, page 52), and it is liable to drive terrible future wars (see "Hydro Dynamics," by Sandra Postel, page 60).

Life is also drawn to other forms of life. Somewhere in a rainforest, inside a rotting log, lives a colony of termites. Inside the termites live protists and bacteria that digest wood cellulose. Yet the colony not only forages; it also farms. Within the log grow mushrooms, apparently cultivated by the termites for food. Throughout the example run themes of mutual dependence, cooperation among species, habitat made from the tissues of other organisms.

The great champion of this point of view is Lynn Margulis, who joins us in this issue with her thrilling, infectious enthusiasm for the world of the very small (see "Mycological Maestros," by Jessie Gunnard, Andrew Wier, and Margulis, page 22). Margulis has inspired her students for many years with her supreme confidence in their own powers of scientific observation. She firmly believes that armies of biologists must still be trained to bring back to science the secrets of the living Earth. At *Natural History,* we are honored to share her niche, and to bring her words to you. —PETER BROWN

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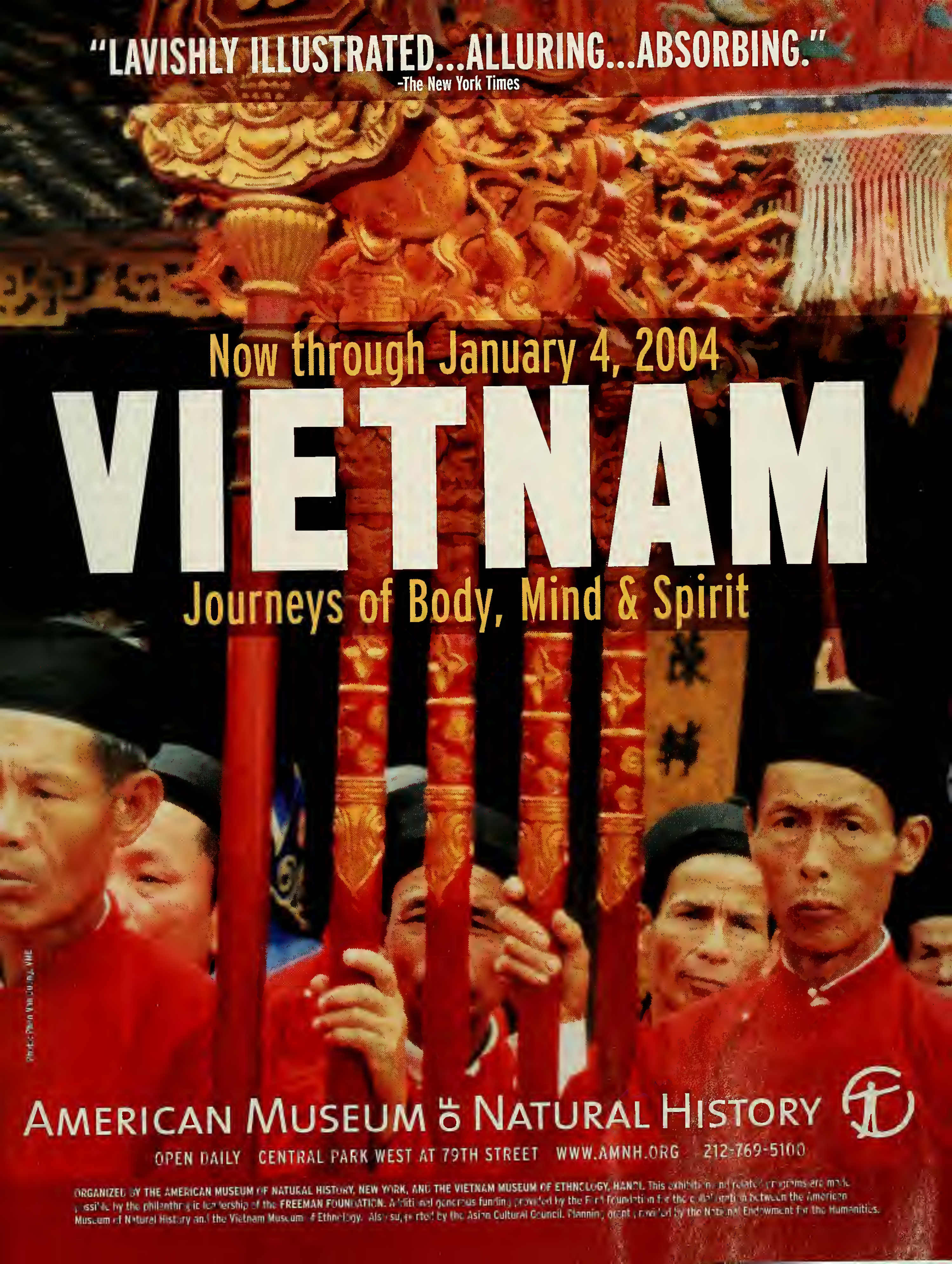
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Rights and Wrongs

In his "Universe" column ["Naming Rights," 2/03], Neil deGrasse Tyson acknowledges that slavery in the United States affected scientific endeavors. But he ignores the fact that many of the Islamic nations whose history he lauds also had questionable records on human rights. He refers to Christian zealots but makes no mention of zealots of any other kind—among them the Islamist zealots who are responsible for the decline in the once-great scientific communities of the Islamic world.
Dawn Bailey
Fayetteville, Arkansas

NEIL DEGRASSE TYSON REPLIES: Dawn Bailey's critique is entirely within reason, but I didn't have space to include each culture's full negative history. In my essay I made two assumptions, both of which derive largely from the way history has been presented in school textbooks in the West: (1) many (if not most) readers are unfamiliar with the Islamic world of the eighth through eleventh centuries, and (2) every reader is familiar with the technological dominance of Europe and the United States.

So to mention that Islam was advanced while Europe was in squalor is more enlightening to the reader than to say that Islam was in squalor while Europe was advanced. And to say that the U.S. participation in the Industrial Revolution was delayed, in part, because of slavery is more enlightening than to say that Islam has zealots today.

The Shadow Knows

Neil deGrasse Tyson's article on low-tech science ["Stick-in-the-Mud Science," 3/03] reminded me of my career in educational television nearly half a century ago. *Sputnik 1* had begun to orbit, and suddenly Americans noticed that their schools were not teaching much science. Auburn University decided to televise a class in science for the upper elementary grades; I was a physical chemist, but I could talk to kids, so they picked me. Because one bake sale could buy a couple of television sets for a school, I soon had thousands of students.

Besides doing four half-hour broadcasts a week, I made a lot of school visits. Among the simple experiments I carried in my purse was the "sun tracker," which included an empty thread spool, a straight pin, and a pencil stub with a bit of eraser remaining. To assemble it, you put the pencil stub into the hole of the spool and stuck the pin straight up in the middle of the eraser. All the class had to provide was a sheet of white paper and a window into which the sun shone at noon.

If you set the spool on the paper on the windowsill, and made a dot on the paper every day at noon where the shadow of the pinhead fell on the paper, you could plot a pretty good analemma in the course of a year.
Charlotte R. Ward
Auburn, Alabama

Φ

Two intriguing properties of phi (ϕ), the golden ratio, did not make it into Mario Livio's article "The Golden Number" [3/03]. Elementary algebra shows that subtracting one from phi yields its reciprocal (1/phi); and the fact that phi + 1 is equal to the square of phi yields, by simple addition, the further fact that the sum of phi and its reciprocal is equal to two times phi.

It is small wonder that many of the ancient Greeks regarded geometry as a form of magic.
Maxwell Manes
Brooksville, Florida

Curiouser and Curiouser

In his book review "The Curious Energy of the Void" [2/03], Donald Goldsmith states: "As the universe expands, . . . more space continuously comes into being, and so the total amount of dark energy also increases proportionately." In effect, energy is continuously created—an assertion that, for me, is quite counterintuitive.

Later he writes, "The amount of radiation generated by the universe in the earliest years of its expansion varies in different directions in space." But that seems to contradict a reference to "the pervasiveness and uniformity of the radiation throughout the universe" made elsewhere in the same issue ("At the Museum").
Howard J. Naftzger
Kensington, California

DONALD GOLDSMITH REPLIES: Howard Naftzger raises two excellent and appropriate questions. He is right to find it counterintuitive that new energy appears as space expands—not to mention that it's a violation of just about every physical rule in the books. That is one reason (and there are more!) conservative cosmologists have been slow to accept the existence of dark energy.

Nevertheless, new results from the Wilkinson Microwave Anisotropy Probe (WMAP) satellite seem to confirm almost beyond a doubt that space does teem with dark energy. Cosmologists like to call the new energy "the ultimate free lunch." If it's any help, according to our conception of physics, the universe as a whole does not have to obey the same rules as a closed, localized system does.

As for the uniformity of the cosmic background radiation, there are two salient facts. First, the background *is* amazingly uniform, arriving in the same amounts and with the same spectrum from all directions. Second, astronomers have now detected extremely small deviations from uniformity—the so-called anisotropies of the cosmic background radiation [*see "Sharper Focus," by Charles Liu, page 70*]. The anisotropies, small as they are, carry large amounts of information about the universe as it existed when the radiation was first set loose, a few hundred thousand years after the big bang.

By measuring the anisotropies on various angular scales, cosmologists can (amazingly) hope to determine the curvature of the universe, which amounts to determining the total quantity of all kinds of matter and energy. My book *The Runaway Universe* deals to some degree with these not-so-simple subjects.

Cattle Call

Daniel G. Bradley concludes that British aurochs did not interbreed with early domestic cattle ["Genetic Hoofprints," 2/03]. But that assertion overlooks that fact that (especially early on) domestication is a social as well as a biological process. Calves born to tame mothers living with humans would either prove tractable and so be kept to breed, or intractable and so escape or be eaten, outcomes that are genetically equivalent. Tractable calves born to wild mothers would only be captured and tamed with some effort; because the early inhabitants of Britain already had domestic cattle, few farmers would have bothered.

In short, a one-way "filter" would be applied to nuclear genes, which Mr. Bradley's work on mitochondrial DNA could not detect. Wild aurochs bulls breeding with domestic cows would contribute nuclear genes, but no mitochondrial genes, to early cattle; as long as such domestic cows gave birth and raised their calves near humans, their calves would likely join the domestic herd.

James J. Moore
University of California, San Diego
La Jolla, California

Daniel Bradley replies: James Moore highlights an important limitation that applies to all genetic evidence based on one marker system: different genes can represent different strands within the history of a population and thus tell different histories. In fact, cattle studies present one of the best examples of uncoupling of maternal and other ancestral strands. The massive influx of *Bos indicus* genes into African cattle seems to have left no maternal legacy: the mitochondrial genes in African cattle seem to have remained *B. taurus*.

Thus I agree that the study of mitochondrial variation alone cannot eliminate the possibility that ephemeral encounters introduced nuclear DNA from British aurochs into the domestic gene pool. Studies of other marker systems, particularly the Y chromosome, will clarify that question. In fact, however, our preliminary data from modern British cattle with Y markers have not revealed any traces of divergent chromosomes that might indicate substantial wild male input.

Natural History*'s e-mail address is nhmag@amnh.org.*

CONTRIBUTORS

DUNCAN MURRELL ("The Natural Moment," page 6) is a naturalist who has been kayaking with Alaskan humpback whales for more than twenty-five years. He will be exploring the marine life around the islands of Sri Lanka and Madagascar in the coming year. His photograph of a bubble-feeding humpback whale was made in Tenakee Inlet of Chichagof Island, Alaska.

As a five-year-old tyke wading in the northern California surf, **EDWARD F. DELONG** ("A Plenitude of Ocean Life," page 40) was knocked down by a large wave and dragged a little way out to sea. He has had a serious interest in—and respect for—the ocean ever since. A senior scientist at the Monterey Bay Aquarium Research Institute in California, DeLong studies the smallest marine microorganisms known, a category called picoplankton. His current research topics include methane cycling in the deep ocean and the application of genomics to the study of microbial communities. DeLong enjoys swimming, hiking, scuba diving, and cross-country skiing, pastimes he puts to good use in his work. Cross-country skiing, for instance, enabled him to crisscross Antarctic ice packs when he set out to collect seawater samples by drilling holes through ice two meters thick.

After receiving her license to teach piano in Germany, **INGRID FRITSCH** ("A Yen for the Traditional," page 48) went on to earn a doctorate in ethnomusicology (with a focus on the Japanese bamboo flute) at Cologne University. She has subsequently done extensive fieldwork on the social and religious organization of guilds of blind musicians and shamans in Japan. Currently Fritsch is a professor at the Institute of Japanology in Cologne, Germany. Her article on *chindonya* is just one aspect of her fascination with the itinerant performers and street artists who have characterized Japanese culture for many centuries.

Architectural photographer and historian **MORNA LIVINGSTON** ("Temples for Water," page 52) has lugged two cameras and assorted photographic accessories from northern Tunisia to southern Tuscany to the arid lands of western India. On her journeys she has visited myriad works of architecture, including ancient Roman baths, Renaissance gardens, and the "water buildings" commissioned by Hindu queens and Muslim sultans that are the subjects of her article and photographs in this issue. Livingston is the author of *Steps to Water: The Ancient Stepwells of India* (Princeton Architectural Press, 2002). When not traveling to villages searching for water buildings to study and photograph, Livingston teaches in the School of Architecture and Design at Philadelphia University.

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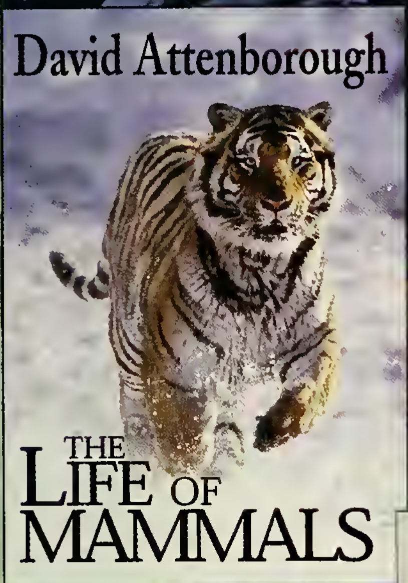

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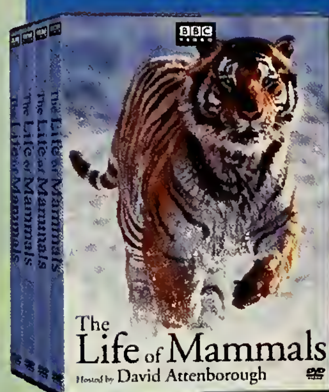

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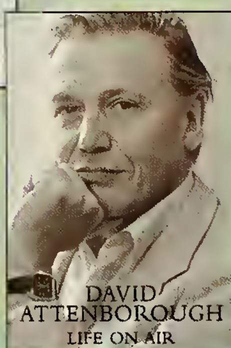

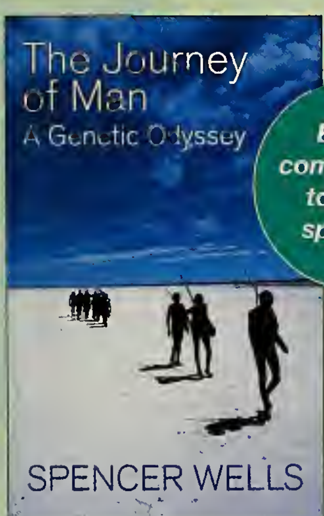

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By Stéphan Reebs

Sperm whales congregating at the surface of the sea

YOU SAY TOMATO, I SAY TOMAHTO Not all members of the same species whistle the same tune. Groups of white-crowned sparrows and killer whales, for instance, may utter different songs or calls on similar occasions. Populations of cetaceans that share a vocalization "dialect" are known as vocal clans.

Now Luke Rendell and Hal Whitehead, both biologists at Dalhousie University in Nova Scotia, Canada, have completed an extensive analysis of the cocktail chatter of thousands of sperm whales, recorded throughout the Pacific and the Caribbean between 1985 and 2000. They identified at least six distinct dialects among the whales—five dialects in the Pacific and one in the Caribbean—some of which extend across thousands of miles and involve thousands of whales.

Sperm whales live in groups of between ten and twenty animals. They communicate through what are called codas—brief series of clicks—distinguished not only by the number of clicks but also by the intervals between the clicks. Some whale groups, for instance, always make five regularly spaced clicks, whereas others always make a longer pause before emitting the final click in the coda.

While moving through the seas, groups of sperm whales gather for days at a time with their counterparts; although groups from different vocal clans may occupy the same general area, each group mingles only with others that click the same dialect. And those dialects are probably learned—the result of a cultural process that, in this case, is literally oceanic in scale. ("Vocal clans in sperm whales *[Physeter macrocephalus]*," *Proceedings of the Royal Society of London* B **270**: 225–31, February 7, 2003)

FOLD THREE TIMES AND DRINK One of the world's most notorious waterborne diseases is cholera, caused by the bacterium *Vibrio cholerae*. For decades bacteriologists have known that the organism lives in close association with zooplankton, particularly the minute crustaceans known as copepods. A single copepod, in fact, can harbor as many as 10,000 *V. cholerae*—just about enough to trigger the disease. Not surprisingly, cholera outbreaks often follow zooplankton blooms.

In rural Bangladesh, where cholera is endemic, villagers drink untreated surface water. Systematic chemical treatment is often too expensive, many wells are heavily contaminated with arsenic, and boiling the water is often difficult and costly. Women (traditionally the water carriers for their households) do filter drinking water through a piece of old cotton sari cloth, but only to remove coarse debris. So the cell biologist Rita R. Colwell, director of the National Science Foundation, and her colleagues suggested that the cloth simply be folded into four to eight thicknesses. (The cloth was also to be washed and sun-dried after each filtration.) That single act, they contended, would drastically reduce the incidence of cholera, because the multiple layers of cloth would provide a mesh fine enough to remove all the zooplankton.

Collecting water in rural Bangladesh

Enlisting the participation of 133,000 people from sixty-five Bangladeshi villages, Colwell and her team recently completed a three-year study of the method. They found not only an impressive rate of compliance—fewer than 1 percent of the households didn't follow instructions—but also a 48 percent reduction in the incidence of the disease, to 0.65 cases a year per thousand people. ("Reduction of cholera in Bangladeshi villages by simple filtration," *Proceedings of the National Academy of Sciences* **100**:1051–55, February 4, 2003)

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NOT GUILTY About 11,500 years ago in North America, people started using fluted stone points for hunting. Archaeologists have called those people "Clovis," after the town in New Mexico where the characteristic stone points were first discovered. That same epoch, 11,500 years ago, appears to coincide with the disappearance of numerous large mammals from North America, including the giant beaver, the mastodon, and various ground sloths. Some people have argued that Clovis hunters were responsible for the extinctions, but the claim has now been disputed by two archaeologists, Donald K. Grayson of the University of Washington in Seattle and David J. Meltzer of Southern Methodist University in Dallas.


An array of Clovis points

The two examined published evidence for seventy-six sites where the association between Clovis people and large mammals was supposedly prominent. Only fourteen of the sites contained secure evidence of killing or butchering, such as impact-fractured projectile points within the animal remains, cut marks on bones, or skeletal dismemberment—and only mammoths or mastodons were present at those sites. Not one site yielded clear evidence that Clovis people had actively hunted any of the other thirty-three mammalian genera that became extinct at about the same time. And although tools made from the bones of large mammals were found at some sites, their presence doesn't prove the animals were hunted; the tools could have been fashioned from the skeletons of scavenged animals.

Grayson and Meltzer also point out that the North American extinctions coincide with similar extinctions in Europe and Asia, yet Clovis hunters didn't live there. The archaeologists thus argue that the Clovis hunter should be exonerated as the cause of the North American extinctions. Perhaps, they suggest, a widespread environmental event such as climate change was responsible. ("Clovis hunting and large mammal extinction: A critical review of the evidence," *Journal of World Prehistory* **16**:313–59, December 2002)


Artificially mineralized egg

EXPERIMENT OF THE MONTH Amid all the fanfare that has accompanied recent discoveries of fossilized Precambrian invertebrate eggs found in China and elsewhere, a few grumbles of disbelief have been heard. After all, invertebrate eggs are made of soft tissue, so shouldn't they decompose long before mineralization begins?

The answer is: not necessarily. Derek Martin, Derek E.G. Briggs, and R. John Parkes, all of the University of Bristol in England, dropped lobster eggs into vials containing seawater and natural sediments, then sealed the vials and incubated them at 59 degrees F. After three weeks the intact eggs were coated with a thin layer of calcium carbonate, which stabilized their shape. Mineralization had begun.

The process depends on two key factors: the lack of oxygen (a gas that speeds decomposition) and the presence of anaerobic bacteria (whose metabolic activity helps make minerals available). Paleontologists had previously thought that invertebrate eggs couldn't be fossilized unless the exoskeleton of a relatively large animal (the mother, for example) lay close enough to serve as a ready source of calcium or phosphorus for the compounds that would constitute the fossil. But the Bristol experiment suggests that orphaned eggs, including those produced by small, soft organisms, could still have become naturally fossilized. ("Experimental mineralization of invertebrate eggs and the preservation of Neoproterozoic embryos," *Geology* **31**:39–42, January 2003)

TRAVELING LIGHT Why do some plant immigrants spread so widely and destructively in their adopted lands, yet remain relatively innocuous back home? Presumably the new host country lacks some of the disease-causing fungi and viruses that afflict the plant in its native land. Hence, as long as the plant can resist the new pathogens it encounters in its adoptive home, it will become . . . a weed.

Charles E. Mitchell and Alison G. Power, both biologists at Cornell University, delved deep into the databases of the U.S. Department of Agriculture and identified 473 plant species introduced (whether by accident or on purpose) into the United States from Europe. They found that, on average, 84 percent fewer fungal species and 24 percent fewer viral species infected the plants in the U.S. than in Europe. And for individual species, the lighter the burden of pathogens, the more states officially listed the plant as a "noxious weed." The few pathogens still afflicting the expatriate plants were an even mix of introduced and indigenous ones. Thus, both their escape from old pathogens and their resistance to new ones contributed to the invaders' success. ("Release of invasive plants from fungal and viral pathogens," *Nature* **421**:625–27, February 6, 2003)

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).*

Dust to Dust

In the darkest regions of the Milky Way are vast interstellar clouds harboring the remains of dead stars and the nurseries for new ones.

By Neil deGrasse Tyson

A casual look at the Milky Way on a dark, clear night reveals a cloudy band of light-and-dark splotches extending from horizon to horizon. With simple binoculars or a backyard telescope, the dark and boring areas of the Milky Way look like, well, dark and boring areas. But the bright areas resolve into countless stars and nebulae.

In a small book titled *Sidereus Nuncius* (The Starry Messenger), published in Venice in 1610, Galileo gives an account of the heavens as seen through a telescope, including the first-ever scientific explanation of the Milky Way's patches of light. Referring to his yet-to-be-named instrument as a "spyglass," he is so excited he can barely contain himself:

> The Milky Way itself, . . . with the aid of the spyglass, may be observed so well that all the disputes that for so many generations have vexed philosophers are destroyed by visible certainty, and we are liberated from wordy arguments. For the Galaxy is nothing else than a congeries of innumerable stars distributed in clusters. To whatever region of it you direct your spyglass, an immense number of stars immediately offer themselves to view.

Surely to Galileo and his contemporaries, the "innumerable stars" were where the action was. Why would anyone care about the dark areas, where stars were presumably absent?

Three centuries would pass before anybody figured out that the dark patches are thick, gigantic clouds of gas and dust, which obscure more distant star fields. Among the first astronomers to address the problem was an American, George Cary Comstock, who wondered why faraway stars are much dimmer than their distance alone would indicate. Following up on Comstock's observations, the Dutch astronomer Jacobus Cornelius Kapteyn named the culprit in 1909, when he presented evidence that clouds of "meteoric dust" in the space between the stars not only absorb the overall light of stars, but do so unevenly across the rainbow of colors in a star's spectrum. Specifically, the clouds attenuate blue light more than red, making the Milky Way's faraway stars look dimmer and, on average, redder than the ones nearby.

If no one knew that stars exist, there would be plenty of reasons to think they should never form.

Ordinary hydrogen and helium, the principal constituents of cosmic gas clouds, don't redden light. But large molecules do—particularly the ones that include atoms of carbon or silicon. And when the aggregations of such atoms and molecules get big enough, we call them dust.

Most people are familiar with dust of the household variety, though few know that, in a closed home, it is made up mostly of dead, sloughed-off human skin cells—plus pet dander, if you have a live-in mammal. Last I checked, nobody's epidermis has gotten into the interstellar dust. But the cosmic clouds do include a remarkable ensemble of complex molecules that emit microwaves, and dust that emits primarily in the infrared part of the spectrum. Not until the last third of the twentieth century, however, did the astrophysicist's tool kit enable us to observe the powerful emissions and chemical richness of the stuff between the stars.

Interstellar clouds are intriguing for yet another reason. Deep within them, through the effects of their internal gravity, the dust and gas become thick enough to condense into clumps of matter. If conditions are just right, those clumps can form larger and larger clumps, and eventually full-fledged stars. In other words, those giant clouds are stellar nurseries.

Gas clouds in the Milky Way are not always capable of starbirth. More often than not, even after a cloud forms, it is confused about what to do next. Actually, we astrophysicists are the confused ones. We know the cloud is trying to collapse under its own weight and make one or more stars. But the cloud's rotation, as well as turbulent motion within it, acts against collapse. So, too, does ordinary gas pressure. Galactic magnetic fields also fight collapse: they penetrate the cloud and, latching onto any charged particles roaming within, restrict how the cloud can respond to its own gravity. What's scary is that if no one knew in advance that stars exist, frontline research could offer plenty of convincing reasons stars should never form.

Like the Milky Way's several hundred billion stars, gas clouds orbit the center of the galaxy. On the galactic scale, stars are minute specks, a few light-seconds across, in a vast ocean of space. In contrast, some gas clouds are huge, spanning hundreds of light-years. Such clouds can be as massive as several million suns. And as they lumber through the galaxy, they often collide with each other, entangling their innards. Sometimes, depending on their relative speeds and their angles of impact, the clouds stick together like hot marshmallows; other times, adding injury to insult, they rip each other apart.

If a gas cloud's temperature drops below about a thousand degrees Kelvin, conditions become favorable for forming complex molecules and dust. Below a hundred, conditions become ideal. Those chemical transitions have consequences for everybody. Dust grains, which are made up of billions of atoms, absorb visible light —strongly attenuating the brightness of stars behind them. The dust then re-emits the energy as infrared radiation, which freely escapes the cloud.

Whatever the forces that make a cloud colder and denser, they may eventually lead to the cloud's gravitational collapse. And that, in turn, leads to the birth of stars. Nature thus poses a paradoxical precondition. To create a star —that is, to heat matter hot enough for it to undergo thermonuclear fusion— the temperature inside the star's parent cloud must first be as cold as possible.

At this point in the life of a cloud, astrophysicists can only gesticulate to show what happens next. Theorists and computer modelers face the challenge of incorporating all the known laws of physics and chemistry into their supercomputer models before they can even think about tracking the turbulent motions of large, massive clouds. A further challenge is the humbling fact that the original cloud is billions of times wider and a hundred sextillion (100×10^{21}) times less dense than the star the models are trying to simulate. And the laws of physics that matter at one size or on one timescale are not necessarily the right things to worry about on another.

Nevertheless, astrophysicists can safely assert that in the deepest, darkest, densest regions of an interstellar cloud, with temperatures around 10 degrees above absolute zero, pockets of gas finally collapse, converting their gravitational energy into heat. The temperature within each collapsing pocket—soon to become the core of a newborn star—rises rapidly, breaking nearby dust grains into their constituent atoms. Eventually, if the collapsing gas heats up to 10 million degrees, the positively charged protons (which are just naked hydrogen atoms that have been stripped of their electrons) move so fast that their natural repulsion no longer keeps them apart. In fact, those protons get close enough to be pulled together by a short-range, attractive, monstrously strong nuclear force (whose technical name is "strong nuclear force").

When protons bond with each other under the influence of that force, the process is known as thermonuclear fusion. The by-product of fusion is the

Neil Folberg, *Sagittarius*, 2000

element helium, whose mass is less than the sum of its parts. The missing mass becomes boatloads of energy, as described by Einstein's famous equation $E=mc^2$, where E is energy, m is mass, and c is the speed of light. As the energy moves outward, the gas becomes self-luminous. And though this crucible remains enclosed, womblike, within the greater cloud, its glow nonetheless announces to the rest of the Milky Way that a star is born.

Astrophysicists know that stars come in a wide range of masses: from a mere tenth to nearly a hundred times that of our Sun. Each giant gas cloud holds a multitude of cold pockets, all of which form at about the same time and each of which gives birth to a star. For every high-mass star that's born, a thousand low-mass stars emerge. But only about 1 percent of all the gas in the original cloud participates in starbirth, and that presents a classic challenge: How and why does the tail (the stars) wag the dog (the cloud)?

The mass limit on the low end is easy to determine. Below about a tenth of the Sun's mass, the pocket of collapsing gas does not have enough gravitational energy to bring its core temperature up to the requisite 10 million degrees. A star is not born.

What forms instead is a "brown dwarf" [*see "When a Star Is Not Born," March 1996*]. With no energy source of its own, a brown dwarf just gets progressively dimmer with time, living off what little heat it was able to generate from its original collapse. With such a feeble luminosity, a brown dwarf is supremely difficult to detect, requiring methods similar to the ones used to discover planets outside the solar system. In fact, only in recent years have enough brown dwarfs been discovered in sky surveys to merit sorting them into categories.

The exact mass limit at the high end isn't well understood, but what astrophysicists do know we can credit to the star's prodigious luminosity. About a hundred times the mass of the Sun seems to be the limit; if any more mass from the parent cloud tries to join the action, it gets pushed away by starlight alone.

So potent is the pressure of intense starlight that the luminosity of just a few high-mass stars can heat up and disperse nearly all the dust and gas from the original cloud. As the cloud dissipates, dozens, if not hundreds, of brand-new stars—siblings of one another, really—are laid bare for the rest of the galaxy to see.

The Great Nebula in Orion—situated below Orion's belt and midway down his sword—is just such a nursery. Within the nebula, thousands of stars are being born, spread among several rich clusters. Four of the most massive stars trace the Orion Trapezium, and they're busy blowing a giant hole in the middle of the cloud from which they formed. New stars are clearly visible in detailed images of the region made by the Hubble Space Telescope, showing many infants swaddled in nascent, protoplanetary disks comprised of dust and other molecules drawn from the original cloud. And within each of those disks a solar system forms.

The highest-mass stars are the brightest and shortest-lived, but they cooked the elements that gave rise to us.

For a while, the cluster of newborn stars stays intact. But eventually, owing to the steady gravitational tugs of enormous passing clouds, the ensemble falls apart, its members scattering into the general pool of stars in the galaxy. The low-mass stars live practically forever—so dim are they, and so meager is their consumption of fuel. The intermediate-mass stars, such as our Sun, sooner or later turn into red giants, swelling a hundredfold in size as they march toward death. In the end, their outermost layers become so tenuously connected to the rest of the star that they drift into space, exposing the spent nuclear fuels that powered their 10-billion-year lives. The gas that returns to space ultimately gets swept up by passing clouds, only to participate in later rounds of star formation.

In spite of the rarity of the highest-mass stars, they hold nearly all the evolutionary cards. They boast the highest luminosity—a million times that of the Sun—and, as a consequence, the shortest lives: only a few million years. The cores are hot enough to cook hydrogen into dozens of heavier elements, starting with helium and proceeding to carbon, nitrogen, oxygen, and so forth, until they get to iron—of all the elements the one whose nucleus has the lowest energy per particle. Any fusion beyond iron will absorb rather than release energy.

With no more nuclear fuel, such stars die spectacular deaths in supernova explosions, making still more elements in their fires and briefly outshining their entire home galaxy. The explosive energy spreads heavy elements across the galaxy, blowing holes in its distribution of gas and enriching nearby clouds with the raw materials to make dust of their own. The blast waves of the supernovas move supersonically through the clouds, compressing the gas and dust, and possibly creating pockets of extremely high density—the preconditions for the formation of stars.

A supernova's greatest gift to the cosmos is to seed clouds with the heavy elements that form planets and protists and people, so that once again, further endowed by the chemical enrichment from an earlier generation of high-mass stars, another star is born.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City and a visiting research scientist at Princeton University.

Mycological Maestros

In the Ecuadorean rainforest, a "missing link" in the evolution of termite agriculture?

By Jessie Gunnard, Andrew Wier, and Lynn Margulis

From the vantage of our laboratory at the University of Massachusetts in Amherst, the eye can wander over the majestic landscape of the Connecticut River Valley. It is a landscape profoundly shaped by cultivation: field boundaries are marked, the soil is tilled and fertilized, and specially selected crops (strawberries, asparagus, tomatoes, apples) grow in patches and rows. Farming has been carried on full tilt by people somewhere in the world for the past 10,000 years.

Some other animals, too, have moved beyond hunting and gathering. In a shoebox-size plastic bin in our laboratory, termites of the species *Heterotermes tenuis* busy themselves in their home, a log flown in from Ecuador. These termites belong to a family of insects that live in symbiotic collaboration with bacteria and swimming protists: the insects ingest wood and the protists living in their bloated abdomens digest the wood particles, mainly the cellulose; some bacteria change the sugars from cellulose to smaller compounds that pass through the intestinal wall. Other bacteria "fix" nitrogen from the air, making it nutritionally available. *H. tenuis* and other termites that depend on their hindgut crew of microorganisms to nourish themselves with wood belong to a group of insects known by the misleading name "lower termites." They would more accurately be called earlier or older termites.

The banks of the Tiputini River in Ecuador—home to a population of the termites Heterotermes tenuis *that was examined by the authors*

Their collaboration is a pretty neat trick, but it differs greatly from the equally remarkable activities of a more recently evolved branch of termites. The latter group of species is part of a broader classification commonly known as the "higher termites," which are termites that do not depend on hindgut protists to digest their food. Some higher termites thrive, instead, by cultivating monocultures of fungi: they farm mushrooms. How and when that behavior evolved in termites has long been an open question. But we suspect the *H. tenuis* in our plastic bin may provide an important clue to the answer. We think that at least one Amazonian population of this species of lower termites engages in some form of fungus cultivation. If our hypothesis is correct, the insects would constitute, in some real sense, a "missing link" of termite evolution.

Such a possibility might sound—to coin what is perhaps an apt phrase—like wood candy: a delight to specialists like us who can digest the stuff, but hardly of more than passing interest to the rest of science. But because they rely completely on other organisms to process the wood they ingest, lower termites are ideal animals for the study of symbiosis. And symbiotic relations—the coexistence, in physical contact, of two (and often more) different species of organisms during most of their lives—place the generally touted mechanisms of evolution in a revealing light. Classic Darwinian evolution—the process whereby heritable variation gives rise to new species—must occur, but how? Permanent symbiotic relations may well be the most important factor underlying


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AUTOMATIC
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rapid evolutionary change, and the study of termite symbioses could offer important insights into the process by which fungal agriculture evolved.

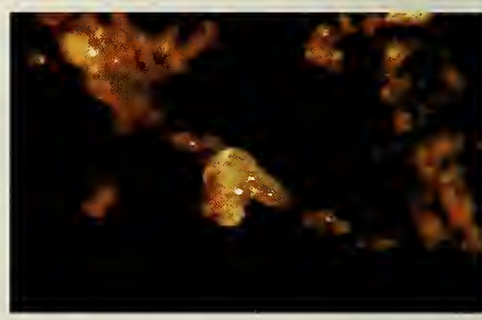
The story of *H. tenuis* began for us in January 1999, when a team of graduate students, including Wier, visited the Tiputini Biodiversity Station in the eastern lowlands of Ecuador. The station, on the Tiputini River deep in the Amazon rainforest, is a biologist's delight. Great buttressed trees tower overhead; epiphytic bromeliads, kin to pineapples, perch on many branches and trunks. By the time sunlight filters through the strangler figs enveloping their host trees, and the few remaining rays meet the diversity of luxuriant palms, there is little light left over for ground cover. The forest floor is almost bare.

Wier had come to study the dangling, clinging vines, the epiphytes, and the colorful fungi of the rainforest. But he also sought to document symbiotic microorganisms: in standing water, in the trees, and associated with termites. He saw termites everywhere in the dead wood surrounding the biodiversity station—even in the hardwood steps built into the muddy trails. Throughout his visit he made photographs of rotting logs covered with cup fungi, and of walking palms, many infested with termites. He didn't know at the time that one colony was *H. tenuis* (that identification was made later by Rudolph H. Scheffrahn of the University of Florida in Fort Lauderdale); but once back in the laboratory, he easily determined that all the insects that looked like white ants in one rotting log carried protist symbionts.

Termites, a group of some 6,000 species, have lived in wood and digested it for at least the past 100 million years. The group's ancestry can be traced to a lineage of wood-ingesting cockroaches.

Presumably, the first termite family to evolve was the cockroach-like Mastotermitidae, the members of which once ranged across the globe. Today only one species remains, and its range is limited to the area around the port city of Darwin, Australia. Other families of lower termites, which rely on both protists and bacterial symbionts to digest their woody food, include the Rhinotermitidae, the familiar subterranean termites that love wooden houses; Hodotermitidae, foraging harvester damp-wood termites, many native to Africa; and Kalotermitidae, which eat and nest in dry wood.

The remaining termites are considered "higher," because of their apparently more complex social organization. They no longer rely on hindgut protists to digest their food. Instead, these animals—by far the majority of termite taxa—have evolved various other food-gathering strategies: some higher termites even enjoy a diet of leaves, fruits, nuts, decaying plant matter, and soil bacteria. Other higher termites, however—though lacking the complex wood-digesting, swimming gut protists of their lower termite relatives—still rely on woody fiber made of cellulose and lignin. To extract the nutrients from the cellulose, they cultivate fungi, which they fertilize with wood chips, then harvest and devour.



This milky white dot, a growth of the fungus Delortia palmicola, *might hold the key to the origins of termite agriculture.*

Whatever the skills of a professional human mushroom grower, they pale next to the virtuosity of the termite farmers. The termites prepare and fertilize the soil; prune the unruly growth of filamentous hyphae, or threads of tissue that make up the

body of the fungi; incessantly weed out a multitude of extraneous fungi, bacteria, and debris in order to grow pure cultures of *Termitomyces* ("termite fungus"); and finally reap their tasty harvest—all with a social dexterity that even the most gifted laboratory team of microbiologists cannot imitate.

In the course of millions of years of practice and extraordinary evolutionary success, fungal agriculture has led to the development of termitaria, mounds that can house as many as several million individual termites and their crops. J. Scott Turner, an animal physiologist at the State University of New York in Syracuse, has studied, at length, the atmospherically regulated mounds of *Macrotermes natalensis,* a southern African mound-building species [*see "A Superorganism's Fuzzy Boundaries," by J. Scott Turner, July/August 2002*]. These termitaria are spectacular structures, rising as high as nine feet in the air, and Turner has documented the many complex ways the termites can regulate the internal environment of the termitaria. For example, such a termitarium maintains levels of carbon dioxide and humidity far above those of the outside air, and it can harness the wind for gas exchange, acting like a lung. The system relies on hundreds of thousands of worker animals, constantly communicating via pheromones, both to build and to maintain the mounds.

The key asset of the entire termite city is its fungus farm. Workers scour the hinterland for wood and other vegetation, then carry it back to the termite city in their guts. Upon returning to the mound's fungal gardens, they excrete their forage: a mash made up of wood, all kinds of fungi (both *Termitomyces* and others that the workers inadvertently swallow as they labor outside), and microorganisms. The mycologist Elio Schaechter, in his charming book *In the Company of Mushrooms,* has closely observed what happens next:

> Once excreted, the fungal mycelium [the mass of hyphae emanating from the fungus] grows into tiny spheres, about the size of a small pinhead. These spheres, packed with fungal spores, are the most prominent feature of the fungus gardens. To the termites, the scene must appear as a field of tightly packed giant puffballs would to us.

Thus the termites do not feed directly on the wood-fungal mash; the wood is fodder for the *Termitomyces.* The termites themselves eat the pinhead-size bits of mycelium for breakfast, lunch, and dinner.

The insects control and restrict the growth of their fungi much the same way a gardener might force the flowering of a bulb indoors, manage fertilization, or train the shape of a shrub. That active care prevents the formation of mushrooms—the sexually mature stage of the fungal group known as Basidiomycota; the presence of mushrooms in a termitarium is a sure sign that the termites have died.

H. tenuis workers and soldiers on a log

Although naturalists first observed the fungus-termite relation as long ago as the late eighteenth century, investigators do not know when, where, or in which species or set of species fungal farming developed. Students of nature know that any termite (whether higher or lower) that swallows wood inevitably swallows fungal spores. But the question of how and when that inadvertent feeding on the part of ancestral lower termites developed into *Macrotermes* farming culture has remained unanswered.

The Ecuadorean *H. tenuis* may hold part of the answer. As we tried to keep the termites alive in our laboratory, a crisis tipped us off to something special. We had been pleased at how well our damp termites were thriving. Then an enthusiastic student inadvertently overwatered the colony just before a weekend, leaving a flood inside the termites' box. Such errors usually kill laboratory colonies of termites of any species. The problem is not so much that the termites drown, but that overwatering encourages fungi to grow so copiously that they overwhelm the boxed-in insects. A pool of water in an incubator can kill a colony of wood-eating termites in a weekend.

The following Monday morning should have been grim. But surprisingly, the flooded *H. tenuis* colonies thrived. To our untrained eyes, their response seemed comparable to the pheromone-driven repair work that *Macrotermes* undertake after an abundant rainfall. Flooding, it seems clear in retrospect, must be commonplace in the termites' Ecuadorean habitat. The colonies that actively respond to their ravages are the ones that survive to leave offspring.

And there was more. Less than a week after the flood, minuscule, translucent dots, the color of skim milk, began covering the rotten wood of the log. Within two weeks the dots grew to the size of pinheads, and stayed that way for months. Under the microscope we could see that the pinheads were almost pure cultures of a single distinctive type of fungal spore—much purer than the mixture of species that one would usually expect to find growing in a natural sample. The spores themselves were made up of three cells clumped close together [*see photograph on page 74*], all turgid and, indeed, nearly bursting

(Continued on page 74)





SCENIC BYWAYS

things to see and do on the road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Fort Ticonderoga


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NEW YORK STATE

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For more information about both of these Scenic Byways in New York State, visit http://www.byways.org.


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The Hopewell Rocks, Hopewell Cape, at High Tide

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The Hopewell Rocks, Hopewell Cape, at Low Tide

Kings Landing Historical Settlement, Prince William

Irving Eco-Centre, La Dune de Bouctouche, Saint-Édouard-de-Kent

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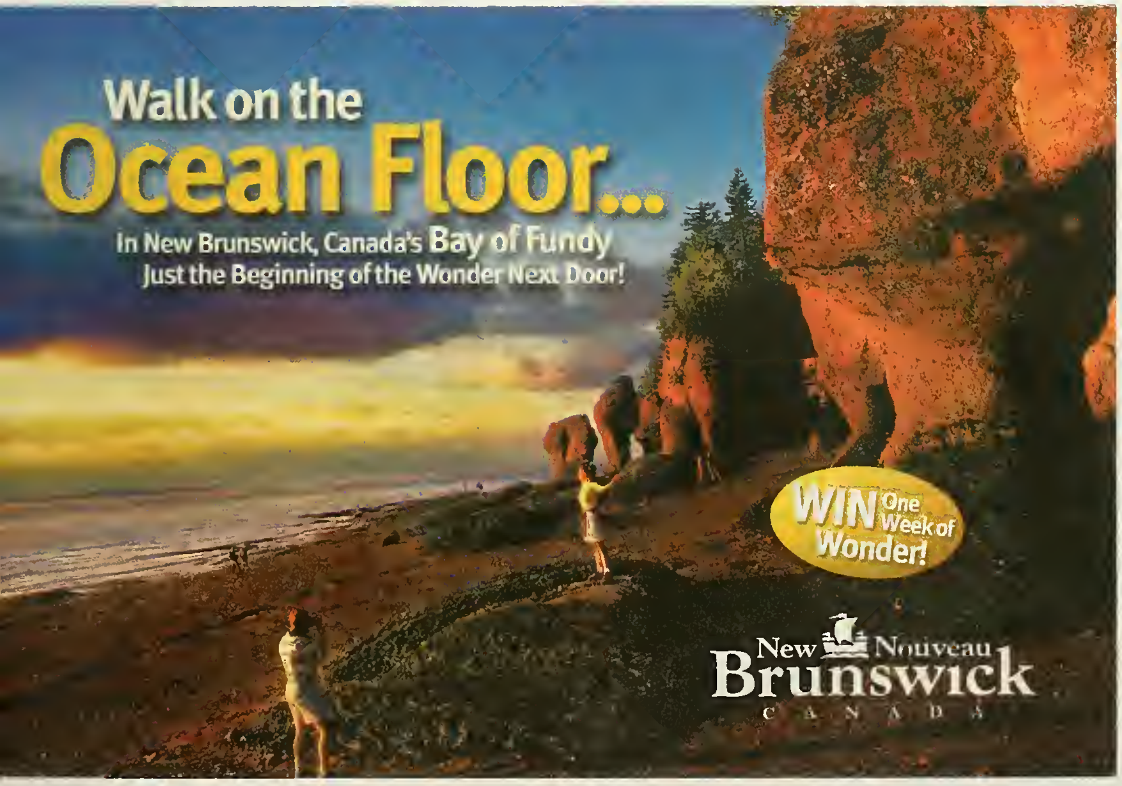
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WYOMING

Wyoming has 14 scenic byways or "backways," including what many would call the most beautiful highway in America—the Beartooth Highway (U.S. 212), built in the 1930s. From the Custer National Forest to Yellowstone National Park, the Beartooth Highway is one of the most spectacular National Forest routes on this continent. The Beartooth offers travelers the ultimate high-country experience as it winds through the Custer, Shoshone, and Gallatin National Forests.

Photos courtesy of USFS and National Scenic Byways Online

The highway's sixty-nine miles cross from lush forests to alpine tundra. The rugged Beartooth area boasts 20 peaks reaching over 12,000 feet in elevation. Glaciers are found on the north flank of nearly every mountain peak that is over 11,500 feet high. Stop along this byway to hike across broad plateaus and to admire Rocky Mountain goats, moose, black bears, grizzly bears, marmots, and mule deer.

Points of interest include the spectacular Yellowstone National Park, the country's first and largest national park, and Shoshone National Forest, which sprawls along Yellowstone's eastern border.

Learn more about the Beartooth at www.byways.org.

A R I

The Grand Canyon State's scenic byways and historic roads transport visitors to all of its natural wonders and many hidden treasures off the beaten path.

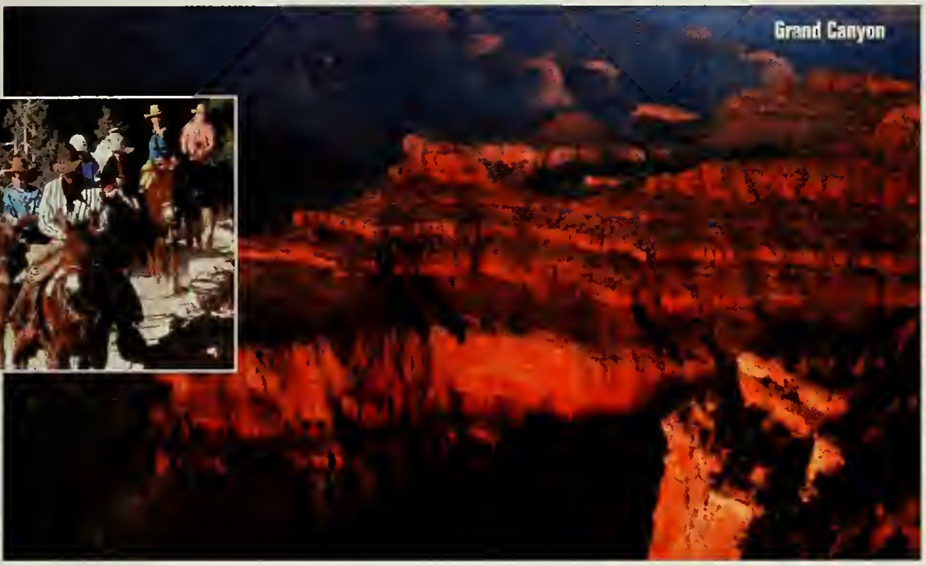
Get your kicks on Route 66, probably Arizona's most famous road, which crisscrosses the state from east to west. Although portions have been replaced by an interstate, this historic route still manages to convey what it was like to travel across the United States in the 1920s. Route 66 crosses the Navajo Indian Reservation and nears the Hopi Indian Reservation, where you might pick up some Native American crafts. The road is also not far from Canyon de Chelly, Walnut Canyon, Meteor Crater, and the Homolovi Ruins.

The Kaibab Plateau–North Rim Parkway, a national Scenic Byway, crosses over the gorgeous Kaibab Plateau and travels through two forests: the Kaibab National Forest and the Grand Canyon National Park. There are plenty of places to hike and camp along the route. Groves of golden aspen, flowery meadows, ponds, and outcrops of limestone break up the dominance of the regal coniferous forest. This byway travels to the brink of the spectacular north rim of the Grand Canyon, which is 1,000

Arizona Office of Tourism

Z O N A

feet higher than the south rim. Wildlife is abundant across the Kaibab Plateau, which is over 8,000 feet in elevation. Allow at least an hour to explore this 42-mile-long Scenic Byway. For more information, visit www.ArizonaScenicRoads.com.



Arizona Office of Tourism

Michel Bonato

Bonoit Chalifour

QUEBEC

For a vacation site that's secluded, beautiful, and undiscovered, head to the Îles de la Madeleine Islands. These islands are located in the middle of the Gulf of St. Lawrence, a five-hour ferry ride from Prince Edward Island (Souris). You can also take a ferry cruise directly from Montreal. However you get there, these lovely barrier islands are worth the trip. Part of Maritime Quebec, the Îles de la Madeleine will enchant you with their unspoiled white beaches and fragile dunes, green valleys, and red cliffs. The steel-gray ocean surrounds the islands and is visible from just about every house.

Michel Bonato

The main road, Route 199, connects the six main islands. Most of the road's 65-mile length crosses long stretches of dune landscape, where motorists spy sandpipers, plovers, and seagulls along the beaches, and the red sandstone cliffs that form much of the islands' coastline. Small, wooden houses, often painted in bright colors, dot the landscape. Fishing is a way of life here, as can be seen by the multitude of lobster boats in the harbor at Grande-Entrée, which locals call the "Lobster Capital of Quebec." Try a lobster roll dipped in butter or a fine gourmet meal of snow crabs or scallops at one of the islands' many restaurants.

Harbor and gray seals are fairly common around the Îles de la Madeleine and can be easily spotted in their natural habitat. About 200 species of birds, mostly marine and shorebirds, live or pass through the islands. The best times for birding are in the spring and fall during the nesting and migration seasons. Many of the nesting birds live in colonies: the northern gannet, the blacklegged kittiwake, the heron, the double-crested shag, the thick-billed murre, the Atlantic puffin, and the razorbill. The endangered piping plover, found nowhere else in Quebec, nests on the islands' beaches.

The Îles de la Madeleine have two nature reserves: Île Brion, whose stunted forests are home to over 140 bird species, and Pointe de l'Est in Grosse Île, an essential stopping point for migratory shorebirds and ducks. Rocher aux Oiseaux, an elevated rock northeast of Grosse Île, is difficult to reach (reserve a boat tour), but worth the effort: this refuge for colonies of petrels, northern gannets, razorbills, murres, and gulls is one of the most important bird watching sites in the gulf.

For more information, visit www.tourismeilesdelamadeleine.com or call 1-877-624-4437.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Ferry service available daily from Prince Edward Island too.
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A paradise tree snake flares its ribs and curves itself into an S as it glides through the air.

Serpents in the Air

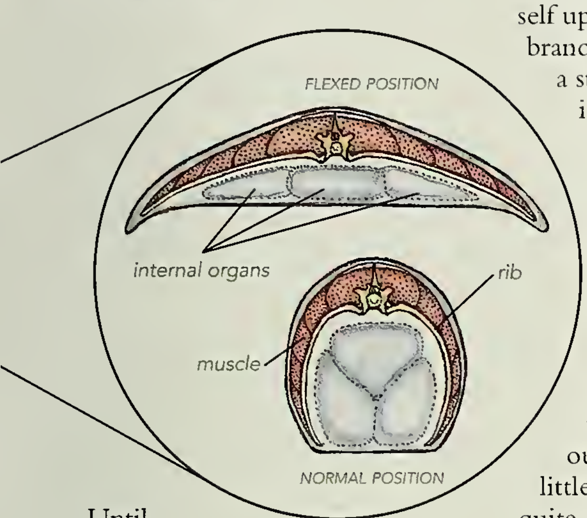
A little contortionist can go a long way.

Story by Adam Summers ~ Illustration by Patricia J. Wynne

The ophiophobe worries, somewhat irrationally, about snakes—whether they're slithering across the sidewalk, lurking in laundry hampers, or even appearing on television. If you, too, are burdened by such anxieties, you might just skip this month's "Biomechanics." There's plenty to engage you in the rest of the magazine, and what you'll undoubtedly retain from this column will be just one more item in the list of directions from which snakes can suddenly appear: from above.

Although as a group snakes appear singularly unsuited for aerial exploits, herpetologists (those intrepid biologists who specialize in reptiles and amphibians) have heard credible accounts of "flying" snakes for more than a hundred years. Only lately, however, has one investigator begun to exhaustively document the extent and mechanics of those animals' aeronautical talents.

To most people, any airborne snake is a flying snake—why bother with fine distinctions when the very idea of an airborne snake is probably unnerving enough to contemplate in the first place? But to biologists, an animal is properly called a flier only if it can generate enough force to gain altitude in still air. A critter is a glider (but not a flier) if it can manage at least a foot of horizontal travel for every foot it falls. An animal that moves less in a horizontal direction than it does in the vertical is said to "parachute" (unless it jumps or falls). A passive aerialist, of course, might catch an updraft and so soar to a higher altitude, but the lack of actively generated upward force still technically disqualifies it as a flier.



Until recently herpetologists thought all flying snakes were parachutists, barely able to slow their descent, let alone to take active control of their own direction and altitude. After all, such control would seem to require a body part in the shape of an airfoil, and tubular snakes apparently lack the broad, thin surfaces that guide the descent of such better-known gliders as flying squirrels, colugos (flying lemurs), frogs, and lizards. But John J. "Jake" Socha, a biomechanist who recently received his doctorate from the University of Chicago, has, by reconstructing the three-dimensional flight path and mechanics of the snakes' glides, discovered that it doesn't necessarily take webbed legs—or limbs at all—for an animal to turn a fall into a long glide.

In fact, explaining what it takes for a snake to glide sounds a bit like an episode of *Sesame Street:* today's program is brought to you by the letters J, S, and C. Socha worked with the paradise tree snake, *Chrysopelea paradisi,* a native of Southeast Asia, on the grounds of the Singapore Zoological Gardens. To get the snakes to jump, he induced them to slither out on a perch more than thirty feet above the ground. When a flying snake prepares to jump, it dangles like the letter J from a branch. It then flings itself upward and away from the branch, only to begin falling at such a steep angle that few would call it anything but a plummet.

Yet after falling less than ten feet, the two-foot-long snake assumes an S shape and begins to undulate, much as if it were crawling across the ground, albeit more slowly and with more lateral movement. At the same time, the angle of its trajectory begins to flatten out, eventually decreasing to as little as 13 degrees. The snake—quite deft at avoiding obstacles—seems to swim through the air; in Socha's tests the snakes landed as far as sixty-nine feet from the thirty-foot-high launch point. In the shallowest moments of their glide (when their fall angle has decreased to its minimum), the snakes can travel nearly four times farther horizontally than they fall vertically, which easily surpasses the one-to-one benchmark of a gliding animal.

One of the most important factors in the snake's midair shift from free fall to glide is a dramatic increase in the width of the animal's body. Like most other snakes, a flying snake is roughly circular in cross section. But while a member of *Chrysopelea* is falling after launch, it flares its ribs so far outward that its belly becomes concave. With its body molded into a highly flattened C, the area of the snake's ventral silhouette—that is, its silhouette when seen from below—nearly doubles. It's as though the hood present on some cobras were extended along the entire length of the paradise tree snake's body.

The flattening of the snake essentially turns the animal into an airfoil: the increase in body width effectively halves the ratio of the snake's body weight to the area of its underside, a measure known as wing loading, and a crucial indicator of aerobatic talent. For example, the wing loading of a highly maneuverable bird such as the chimney swift is ten times smaller than that of the aeronautically challenged common loon. Wing loading in the paradise tree snake falls between those two extremes, but it's closer to that of the swift.

Experts in aerodynamics have also suggested that the snake's tight S-bends make its entire body act like a highly slotted wing. In airplanes, slotted wings have gaps that run along their entire length, from fuselage to wingtip; because of the way air flows through the gaps, such wings develop more lift at low speeds. Flaps along the trailing edge of airplane wings have the same effect. That principle is also at work in the spread between the feathers on the wing tips of the best low-speed gliders, such as vultures and hawks. The gaps between the bends of the S-shaped snake in flight could produce more lift than the snake would have if it shot, arrowlike, through the air. Any extra lift is crucial for maneuvering while gliding.

The advantages of gliding for a snake seem obvious: moving through the air from tree to tree bypasses a host of earth-bound predators, and a flying snake threatened by an arboreal animal can just launch itself out of the tree. But the paradise tree snake glides so expertly that it could, in principle, mount an airborne attack, either on a passing bird or on some more pedestrian prey that, like the ophiophobe, is expecting anything but a snake assault from above.

Adam Summers (asummers@uci.edu) is an assistant professor of ecology and evolutionary biology at the University of California, Irvine, and he once caused a snake to appear unexpectedly in a laundry hamper.

A Plenitude of Ocean Life

A new census of the sea is revealing that microbial cells thrive in undreamed-of numbers. They form an essential part of the food web.

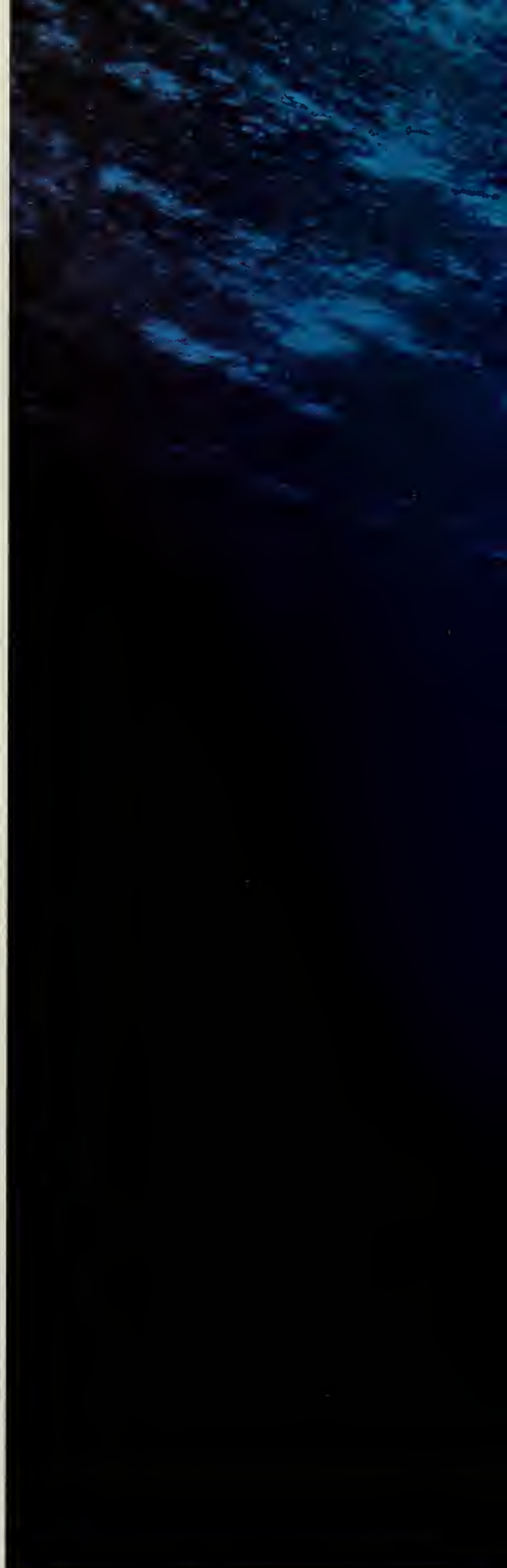
By Edward F. DeLong

Pyrocystis lunula, *a dinoflagellate*

The *Polar Duke,* our ice-worthy Norwegian vessel, was immobilized—beset, to use the correct nautical term—by enormous sheets of sea ice. It was early August 1995, late winter in Antarctica, and the two-meter skin of frozen seawater that enveloped us was a seasonal expression of the Southern Ocean. Our destination was Palmer Station, a research station run by the National Science Foundation and situated on Anvers Island, off the Antarctic Peninsula. Evidently, though, our group of American scientists and support staff had set out just a little too soon. It took ten days for a change in wind and the breakup of the ice pack to free the ship, but by then we were low on fuel and forced to return to Chile to be resupplied. When we finally made it to Palmer Station, we were a month behind schedule. Only two months were left of our field season, and that was spent largely on cross-country skis, hauling sleds laden with carboys full of seawater.

So went the first visit of my research group to Antarctica. Our aim was to search out and quantify the range and biomass of a peculiar group of microorganisms known as archaea. The wisdom of the day was that the critters should not be present at all in the cold, oxygen-rich waters of the Southern Ocean. But a sample of Antarctic seawater collected in early 1990 at Palmer Station, carried to California, and given to us for analysis suggested otherwise. We hoped to show that archaea were major players even below the pack ice.

Archaea (originally dubbed archaebacteria) were not even recognized as a separate branch of life until the 1970s, when the microbiologist Carl R. Woese and his colleagues at the University of Illinois at Urbana-Cham-



A crack in the sea ice in the Antarctic. The frigid waters of the Southern Ocean harbor vastly more microorganisms than was once believed.

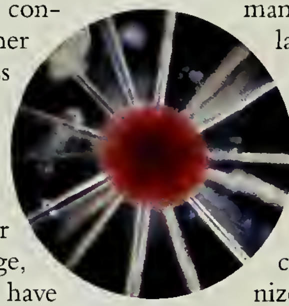
paign made a thorough analysis of their ribosomal RNA. This kind of RNA, which plays a role in protein synthesis, occurs in the small structures called ribosomes that exist in every known kind of cell. Because of its ubiquity, ribosomal RNA can serve as a kind of universal bar code for all organisms, placing them in proper historical relation to one another on a single evolutionary tree. Woese concluded that Archaea is one of three major evolutionary branches of life, as deeply rooted as Bacteria and Eukarya. (Eukarya, whose cells contain a nucleus and other structures, encompass plants, animals, fungi, and protists—protozoa, algae, and lower fungi.)

Apart from their evolutionary heritage, archaea appeared to have one thing in common: they thrived in extreme environments. At the time of our expedition, we knew some lived in saline lakes five times saltier than the ocean; some lived in anaerobic (oxygen-free) habitats, where even trace amounts of oxygen would prove lethal; and some lived in hot geothermal environments that would cook most organisms to a crisp. Among them was *Pyrolobus fumarii,* which could grow in anaerobic deep-sea hydrothermal vents at temperatures as high as 235 degrees Fahrenheit.

Our surveys of the frigid, aerobic Antarctic waters turned up archaea in great and unexpected numbers. Indeed, we have learned that cold-adapted cousins of heat-loving archaea appear to be flourishing in marine waters both shallow and deep and at all latitudes—polar, temperate, and tropical. They turn up in the guts of abyssal sea cucumbers and in sediments at the bottom of the sea. Quantitative surveys now show that archaea comprise between 20 and 30 percent of all the microbial cells in the ocean.

Plankton, sea life that drifts with the currents, ranges from the macroscopic to the microscopic. The so-called picoplankton comprises cells between 0.2 and 2.0 microns across. Anything smaller (such as a virus) is part of the so-called femtoplankton.

The discovery and enhanced understanding of so many new microbial groups stems not only from the quest to look in new places. Modern-day microbe hunters also have new, high-tech tools for identifying and counting microbial life. In the past the method of choice had simply been to culture a sample of, say, seawater and then see what grew. Although that approach is still being perfected, many cells stubbornly refuse to grow under laboratory conditions. The new techniques, some based on the tricks of molecular biology, enable biologists to find out what is in the samples by direct observation.


Radiolarian

Microbial life is proving to be far more diverse than cultured samples could suggest. A lot of the newly recognized life in the oceans is so small that its size is reflected in its name: picoplankton. The plankton comprises the floating "wanderers" of the sea, single-celled and multicelled plants and animals (including many immature larval forms) that move primarily by drifting with the currents [*see illustration at left*]. Anything smaller than 0.05 millimeter but larger than 2.0 microns, capable of passing through fine-mesh nets, is considered nanoplankton (the prefixes "nano-" and "pico-" do not literally correspond to such measurement units as the nanometer or the picometer; they arise instead from naming traditions in marine biology). The picoplankton comprises the smallest cells, ranging between 0.2 and 2.0 microns across (between 1/500th and 1/50th the diameter of a human hair).


Ditylum brightwellii diatoms

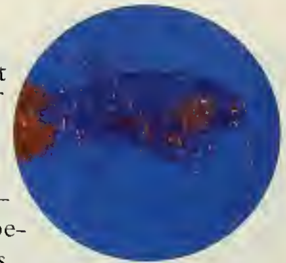
Until the 1970s, picoplankton was thought to be an insignificant element of the marine microbial food web; its biomass seemed much too low to play a primary role. But estimates of the numbers of microscopic planktonic organisms climbed dramatically in the late 1970s, when the so-called epifluorescence microscope was developed. This instrument, coupled with the use of fluorescent dyes that cause individual microbial cells to glow under ultraviolet light, enables the cells to be easily seen and counted. Technically, the process is an easy one. You simply add the dye, which binds to DNA in a sample of seawater, wait five minutes, collect the seagoing microorganisms on a filter, and observe them under the microscope. It is now known that the density of microorganisms ranges from tens of thousands per milliliter in the deep ocean to millions per milliliter in the energy-rich waters near the surface.

Corethron, a genus of phytoplankton

One might object that such a technique could not distinguish live cells from a lot of dead detritus floating around in the water. Studies in the early 1980s, however, which drew on biomedical techniques to measure the synthesis of DNA and protein, showed that marine picoplankton can double in biomass every day or so. So the cells observed with fluorescent dyes are very much alive and metabolically active. (In fact, the only reason the seagoing populations of picoplankton stay roughly constant is that protist predators are busily grazing on them at about the same rate as the picoplankton reproduces.)

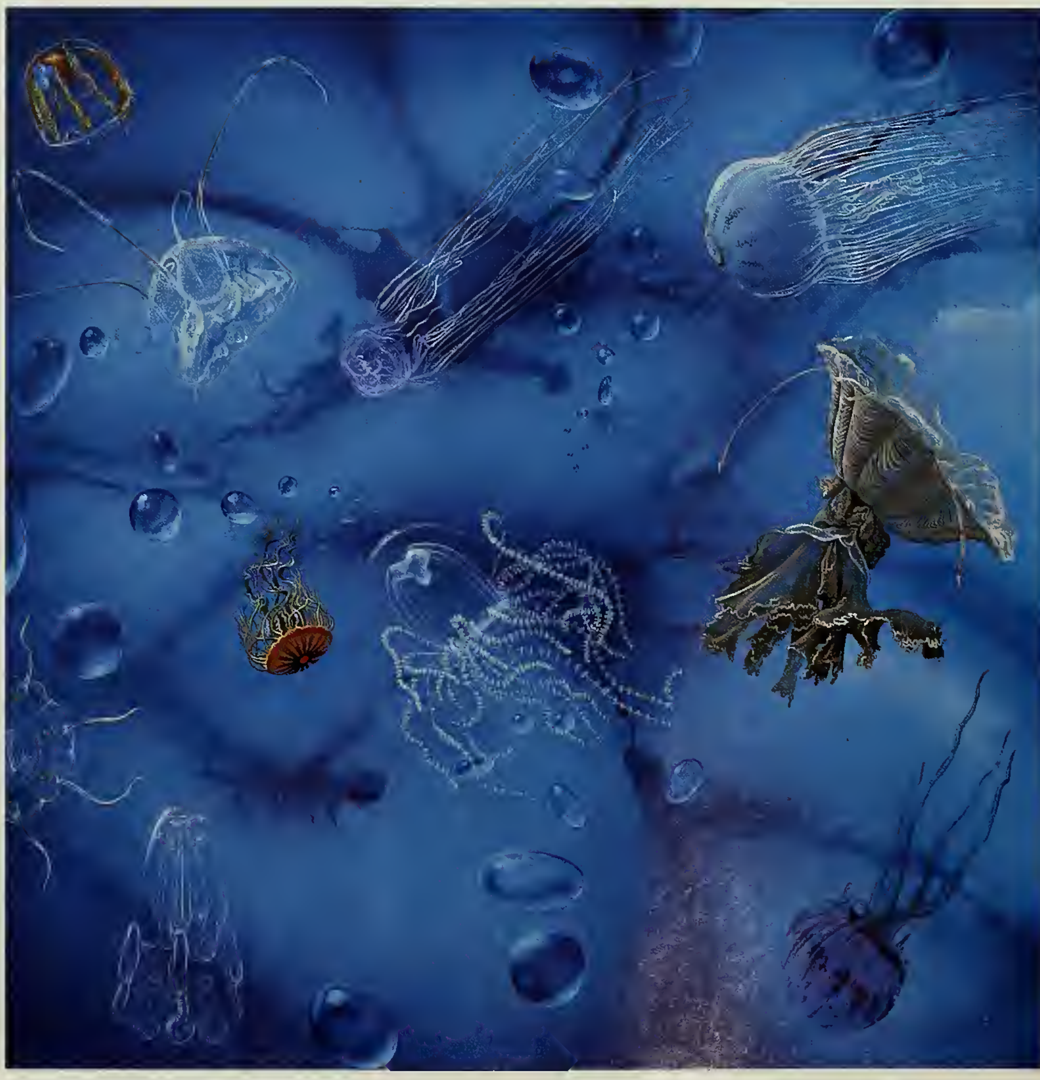
The metabolic activity within the huge biomass of picoplankton represents a massive flow of carbon and energy. Some of the carbon is given off as carbon dioxide gas, but much of it remains locked up in organic molecules that help sustain the rest of the food web. Particularly important to the carbon cycle as well as to the entire oceanic food web are the microorganisms that live at or near the ocean's surface: the forests of the sea are microscopic.

It has been known for some time that the top 600 feet of the water column in the oceans is a region of intense photosynthetic activity. Carbon dioxide is combined with the energy of sunlight to produce a rich food harvest that supports all the other inhabitants of the ocean's surface, and most denizens of the deep as well. As recently as twenty-five years ago, all that productivity was credited to eukaryotic algal species, including diatoms, dinoflagellates, and their relatives. That now turns out to have been a faulty conclusion that arose from a major oversight.



Copepod with two egg sacs in tow

Shortly after epifluorescence microscopy was developed, the first of a new kind of photosynthetic microorganism was discovered: marine picoplanktonic cyanobacteria of the genus *Synechococcus*. Biologists were already familiar with cyanobacteria—they used to be called blue-green algae—because some kinds collect into so many individuals that they are visible in the aggregate. But the new cyanobacteria were much smaller,



Alexis Rockman, *Ice Shelf*, 2003

A "black smoker," or hydrothermal vent. Heat-tolerant microorganisms survive here, providing nutrition for other forms of life.

more abundant, and far more widely distributed than any previously known kind of "algae."

Like plants and genuine algae, cyanobacteria possess a kind of chlorophyll—so-called chlorophyll *a*—that enables them to "fix" carbon in the presence of sunlight, that is, to remove the carbon atoms from carbon dioxide gas and incorporate them into organic molecules. In the process the cyanobacteria give off oxygen, as do all plants that contain chlorophyll. Unlike plants, though, cyanobacteria lack a second kind of chlorophyll, known as chlorophyll *b*, which in concert with chlorophyll *a* helps plants capture light.

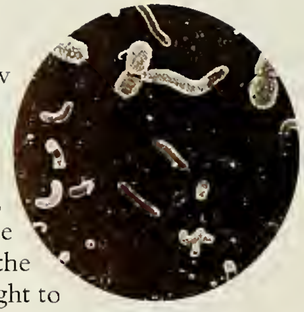
Mantis shrimp larva

But cyanobacteria do harbor certain other pigmented proteins that help them harvest light energy. The proteins, known as phycobiliproteins, fluoresce red under the epifluorescence microscope, and that is how the new, tiny cyanobacteria were so easily detected and enumerated. By 1979, John B. Waterbury of the Woods Hole Oceanographic Institution in Massachusetts and John McNeil Sieburth of the University of Rhode Island on Narragansett Bay had shown that *Synechococcus* was extremely abundant in coastal and open-ocean environments, reaching densities greater than 100,000 cells per milliliter. Later experiments showed that at certain times and places these cells can be responsible for as much as half of the primary production of food in the ocean.

Ceratium longipes, a dinoflagellate

Then, in the late 1980s, the oceanographers Sallie W. Chisholm of the Massachusetts Institute of Technology and Robert Olson of Woods Hole discovered another small (less than a micron in diameter), red-fluorescing kind of cell that was even more abundant than *Synechococcus.*

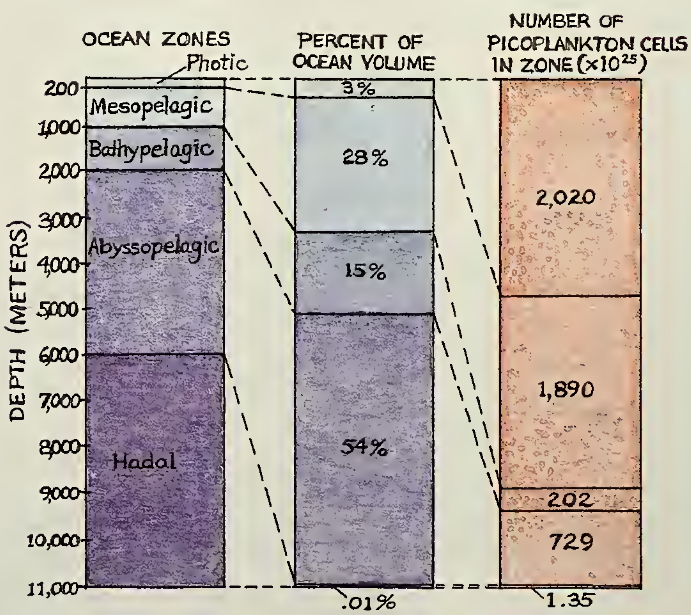
The new cells—in size, also a kind of picoplankton—were eventually cultured and isolated in the laboratory and given the genus name *Prochlorococcus.* They turn out to be closely related to *Synechococcus,* but the two genera differ in their pigment composition. Chisholm and her coworkers at MIT have now also determined the entire genome sequences of two *Prochlorococcus* strains, which represent high- and low-light-adapted "ecotypes." The low-light-adapted strain has significantly more genes than the high-light strain, perhaps because it needs more accessory proteins to efficiently gather light that is in short supply.



Picoplankton

Field experiments have now shown that in the open ocean *Prochlorococcus* cells reach concentrations of hundreds of thousands per milliliter of seawater. In fact, *Prochlorococcus* constitutes half of the total chlorophyll-based biomass in the ocean. So picoplankton, once thought to be sparse and functioning mainly to recycle organic matter back into plant nutrients, proves to be much more central to the carbon cycle. The fact that picoplanktonic cells circulate in such vast numbers and are grazed upon by protists means that they supply nutrients directly to larger organisms. This microscopic portion of the food web has been dubbed the "microbial loop."

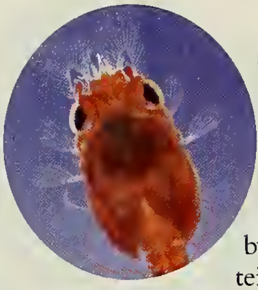
In our laboratory at the Monterey Bay Aquarium Research Institute, my colleagues and I are exploring a new technique of archiving the



Although the photic zone represents a small percentage of the ocean's volume, it contains the highest concentration of picoplankton cells. The smallest ocean zone by volume is the Hadal, named after Hades for its great depth.

genomes of microorganisms en masse. The idea is to get a better understanding of the genetic, biochemical, and physiological properties of the organisms, as well as of their natural history.

Large DNA fragments, as long as 200,000 base pairs, are gathered higgledy-piggledy from mixed microbial populations and then cloned to create, in effect, an archive of microbial genetic diversity. Such



Mysis shrimp larva

a "library" serves as a repository of all the genes and genomes present in the original microbial population that was sampled. We can quickly search such libraries for the presence of particular genes—and by extension, the presence of the proteins and metabolic functions that the genes encode. We can also screen our libraries for markers that identify just which species of microorganism the genes belong to. In addition, proteins encoded by individual genes can be readily produced, making it possible to study their structure, function, and role in the natural world.

Unexpectedly, when we created one of our libraries, we discovered a previously unknown kind of photoprotein. The protein molecule, which came from the genome of a widespread planktonic bacterium, absorbs light of a characteristic wavelength—much as does rhodopsin, the light-sensitive pigment in the human eye. Indeed, the new photoprotein is chemically related to the

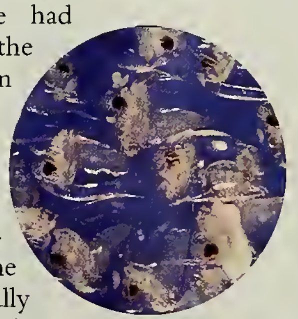
From the study of fossils known as stromatolites, a residue of the larger forms of cyanobacteria, biologists have long known that microorganisms have played key roles in the natural history of the Earth. Cyanobacteria were among the early actors on the stage of life; their capacity for photosynthesis and the oxygen they generated forever altered the global environment. They essentially paved the way for the evolution of other forms of life. Given the abundance of newly discovered cyanobacteria, one can only begin to appreciate what an important role they continue to play in the carbon cycle.

And the cyanobacteria exemplify just one way that marine microorganisms support the biosphere. Bacteria, archaea, and other microorganisms are also vital to the nitrogen cycle: they break down organic nitrogen to produce ammonia; they convert ammonia to nitrate, an essential plant nutrient; and they recycle nitrate into other nitrogen-containing compounds in oxygen-poor zones such as marine sediments. Some cyanobacteria can even

Carbon, nitrogen, and other elements get cycled through the biosphere thanks to a host of microorganisms, but we hardly notice the job they do.

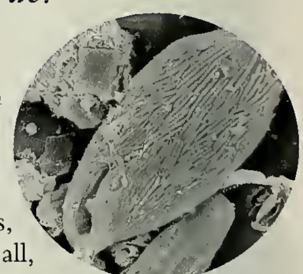
rhodopsin family. And we have shown that, like rhodopsin, it can convert light into energy usable by the microbial cell. The function it serves for the bacteria—whether, for example, it enables them to fix carbon dioxide the way plants do, or is used to garner more energy for other cellular purposes—remains an open question.

Searching in Monterey Bay, from which the original genetic sample had come, we found that the novel form of rhodopsin occurs in natural communities of marine picoplankton. Further surveys in the oceans from Antarctica to Hawaii revealed that variants of the photoprotein exist virtually everywhere, in varying colors. In deep waters the photoprotein is "tuned" to absorb the blue wavelengths of light most abundant there. In shallower waters, it absorbs the more energetic green light available at the surface. It never fails: every time we dip into the living ocean, we find something new.



Shrimp-like species, order Cladocera

synthesize organic nitrogen compounds used to build new cells from simple nitrogen gas. In short, without microorganisms, nitrogen wouldn't cycle at all, and neither would most other elements.



Euglenozoan covered with symbiotic bacteria

It is important to recognize that such transformations depend on an entire community of microorganisms; no single species can carry out all of them on its own. Their interrelations are fantastically complex, forming systems that have been tuned by evolution in ways that work together. Therein lie the reasons for much of our ignorance about them. When they are going about their jobs, when everything is in balance and seemingly normal, we are least likely to notice them. It's only when something breaks down—when, say, excess nitrate in runoff waters creates a noxious algal bloom—that we begin to pay attention.

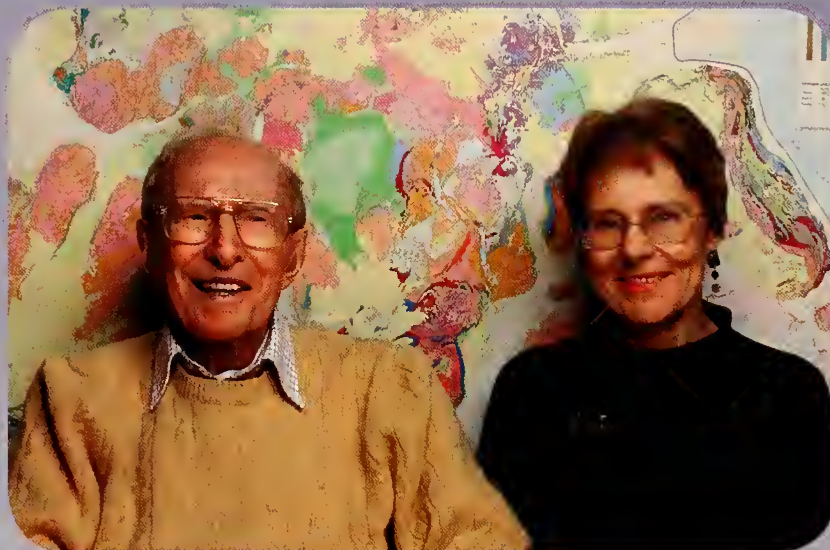
Microorganisms have been our planetary engineers, the biological stewards of the Earth, for as long as the world has had oceans, at least 3.5 billion years. They still have a lot to teach us. □

MUSEUM CURATOR AND HIS WIFE SUPPORT SCIENTISTS OF THE FUTURE — AND THEIR OWN RETIREMENT

A well-loved member of the American Museum of Natural History community since 1945, Dr. Norman Newell is a distinguished specialist on the long history of life on earth. Focusing on major past extinctions, he was in the vanguard of scientists warning against the destruction of the environment leading to the extinction of many species today. Now Curator Emeritus of Fossil Invertebrates, he continues his research, ably assisted by his wife Gillian.

Among the many graduate students whose careers Norman helped to launch was the late Dr. Stephen Jay Gould, whose articles delighted *Natural History* readers. With their belief in supporting the training of young scientists, he and Gillian have included a bequest in their wills for research fellows at the Museum. "I love the Museum very much," Norman says, "and I love my profession, so this is a way to help both."

Recently Norman and Gillian discovered a new way to add to their future gift for the Museum through a Charitable Gift Annuity. Pleasantly surprised by the annuity rates, Gillian commented, "This is a great plan, especially now!"



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A Yen for the Traditional

In modern Japan, street performers sell ritual and nostalgia to compete with high-tech advertising.

By Ingrid Fritsch

Two chindonya performers, hired from Osaka, drum up business for a local shop in Tokyo.

The good old *chindonya,* changing the world from dark to light, people both young and old clap their hands, *chinchira dondon chin dondon. . . .*

—Lyrics from a chindonya troupe in Kumayama, Japan

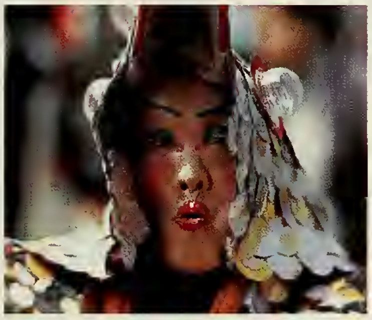
When I tell Japanese people of a certain age that I am an anthropologist interested in *chindonya,* my questions invariably prompt a smile accompanied by a slightly embarrassed giggle. After my informants have reassured themselves that I really mean chindonya, they often ask, "Are they still around? I remember them from my youth."

The characters of my curiosity—the chindonya—are troupes of elaborately costumed street musicians hired to draw customers to shops, stores, cabarets, and *pachinko* (pinball game) parlors. Members of these troupes, made up of at least three

people, parade through the streets playing an assortment of Japanese and Western musical instruments. Once their music has attracted a crowd, the chindonya—who also sport sandwich boards or carry banners displaying their employers' advertisements—deliver sales messages, distribute flyers, or perform short dramatic routines such as sword dances.

Their main instrument, the *chindon,* is made up of a small metal gong (the "chin" sound) and two traditional Japanese drums (the "don" sound), mounted together on a wooden frame [*see photograph on opposite page*]. The instrument, developed at the beginning of the twentieth century, is usually played by a man. Accompanying it is a large cylindrical drum, the *gorosu,* generally played by a woman. A clarinet, trumpet, saxophone, or accordion carries the melody. The repertoire includes military marches, old Japanese ditties, songs from kabuki theaters or *yose* variety theaters, and sometimes jazz.

Chindonya still work the streets for advertisers, though their live promotional performances may seem old-fashioned and out of place in Japan's highly industrialized mass-media society. But throughout their history the performers have struggled against obsolescence in the face of social trends, discrimination, world events, and new technological developments. The current resurgence of interest in chindonya has benefited from the cultural need for ritual—and from favorable media attention linking chindonya to "the good old days." Yet even the waves of nostalgia have failed to create any real increase in the demand for their services. Unless the chindonya figure out how to evolve or change with the times, it seems unlikely they will be able to preserve the traditions of their profession in Japanese society.



I first encountered chindonya during a stay in Japan some years ago. On a pleasant day in April, while strolling around the city of Toyama looking for cherry blossoms, I approached the city hall, where a crowd had gathered for the annual national chindonya competition. Suddenly, about twenty-five groups of performers appeared, wearing gaudy makeup and wigs, and costumed as old-fashioned samurai, geisha, and clowns. Before parading, the groups jointly played "Take ni suzume" (Sparrow on the bamboo), an old variety-hall tune now thought of as a kind of theme song of the chindonya. It is one of the few musical pieces common to troupes all over the country.

In the past, becoming a member of a chindonya troupe was a last resort for people who had no prospects in the regular job market. Chindonya were tolerated, but looked upon with disdain. These days the social standing of the performers has improved, partly because of the sentimentalizing of the Japanese folk arts, but also because the chindonya themselves view their occupation in a more favorable light.

Chindonya troupes date back to the end of the nineteenth century, when the Japanese way of life was rapidly becoming industrialized and westernized, and manufacturers decided it was essential to advertise new products. In 1845 in Osaka, a candy salesman named Amekatsu offered his special oratorical and theatrical talents to advertise for a local variety theater. That episode is accepted as the birth of chindonya (though the term does not appear until the early twentieth century), because it is the first documented case of advertising for someone else's products in Japan. Later, under Amekatsu's followers, the activity became known as *tōzaiya,* for the

Troupe members of the Chindon Tsûshinsha agency in Toyama, Japan, display their traditional costumes.

The traditional chindon drum pictured above is named for the sound of the instrument's gong (chin) and of its drums (don).

street vendors' attention-getting cries of *"tōzai, tōzai"* (literally "east-west," the Japanese equivalent of "Hear ye, hear ye!"). In 1885 in Tokyo, a similar advertising business known as *hiromeya* (wide eyes) recruited brass bands to march through the streets, sometimes for weeklong parades, to advertise new consumer products such as beer, cigarettes, and toothpaste.

For the past century chindonya troupes have undergone many cycles of waxing and waning. By 1910, when newspapers and other means of advertising had become widespread, many of the performers left their troupes to work as "commentators" *(benshi)* or musicians in silent-movie theaters. When talkies were introduced less than two decades later, many turned back to street performance, joined by touring actors and variety-hall artists put out of work by the popularity of the movies. During the Second World War street performances were prohibited altogether; afterwards, when the economy had recovered somewhat but advertising media lagged, street advertising blossomed again. In those days many circus artists also joined up, and it is estimated there were as many as 2,500 chindonya in Japan in the 1950s and 1960s.

As television commercials became more widely used, the popularity of street-advertising troupes once again subsided. The oil crisis of 1973 and the ensuing recession reduced the number of chindonya even more drastically. In 1989, when the emperor Shōwa lay dying, all outdoor public performances were prohibited for several months, and the younger chindonya who were able to find other jobs changed their professions.

Today, only thirty to thirty-five chindonya troupes still exist in Japan, and most of their members are more than sixty years old. The majority of the troupes are based in and around Tokyo, where fifteen specialized talent agencies operate. Almost all are family businesses run by chindonya. A few businesses have taken on young apprentices, but most cannot afford to hire outsiders as permanent employees. A number of young performers who have studied with the masters dream of starting advertising agencies themselves, but jobs nowadays are scarce.

Whereas traditional chindonya troupes are still declining, a new

The oyakata (leader and owner) of a chindonya agency in Osaka dips gracefully on the streets of Kyoto.

trend has been successfully promoted by one Osaka-based agency, Chindon Tsōshinsha. Besides doing advertising for small clothing boutiques, restaurants, video shops, or beauty parlors, the firm, which procures about 700 job engagements per year, also carries out campaigns for politicians, city officials, and large companies. In addition, there is a great demand for chindonya to perform onstage at company celebrations, wedding parties, and summer festivals in communities in and around Osaka. By taking on engagements from Japanese businesses with foreign offices, as well as from festivals based abroad, the performers in the agency have also made appearances in Europe, New Zealand, the United States, and in Asian countries outside Japan. Since 1997 the firm has released two CDs and two videotapes.

According to Hayashi Kōjirō, founder of Chindon Tsōshinsha, the role of the chindonya at some events goes beyond mere entertainment and approaches the religious function formerly filled by practitioners of ancient folk rituals. Virtually no practitioners of those old art forms are left today, and so the chindonya are called on to administer cleansing rites for new homes and to perform songs and dances of benediction. Wearing fairly traditional costumes, chindonya can create an auspicious atmosphere, though in fact they are closer in character to cabaret artists than to folk artists.

Whether or not such initiatives can give the chindonya another chance for survival remains to be seen. Veterans and young members alike complain about the emphasis on formal social events and folkloric performances. Such practices, they say, will bring about the downfall of the traditional role of the chindonya: street advertising. That may happen anyway; it would be rash to predict otherwise, given the economic realities of marketing in modern Japan. But it would be just as unwise to predict that the waves of nostalgia and continued antiquarian interest in chindonya will come to an end anytime soon. □

A handbill from 1900 shows a musical band advertising a local miso soup shop.

Temples for Water

The stepwells of western India were a magnificent architectural solution to the seasonality of the water supply.

Text and photographs by Morna Livingston

Interior of the Ambapur Stepwell at Budthal, in the state of Gujarat, India, built in approximately A.D. 1500. When the water table is high, the well's bottom story is underwater.

For all of recorded history the land that is now western India has been seasonally arid. The western monsoon sharply divides the annual cycle into wet and dry, making the earth glisten with rain for three months, then leaving the surface parched for the remaining nine. In the dry months the rivers shrink to a trickle or even disappear.

Small relief sculpture of a swirling shrub, Vadthal Stepwell, 16th century

Millennia ago, to make it possible to survive with such a drastically variable water supply, the region's inhabitants began to devise ways of managing and mediating the resource. In southwestern Gujarat, in the late sixth and early seventh centuries A.D., anonymous masons dug deep trenches into the earth to reach dependable, year-round groundwater. Building upward, they lined the walls of the trenches with huge stone blocks, laid without mortar, and paved the slope of each trench with stone stairs leading up from the water. Thus were built the first stepwells—visible architecture that gave access to an invisible landscape of underground aquifers.

The idea proved immensely practical, and so it soon spread northward to what is now the state of Rajasthan, to areas barely moist enough to farm. Ultimately, several thousand stepwells were built in the towns and villages of western India. The grandest period of stepwell construction spanned half a millennium—from the late eleventh through the sixteenth century—dotting the countryside with exquisitely embellished public monuments, the most extravagant of which is the Rani ki Vav, or Queen's Stepwell, at Patan, Gujarat.

Owing to its delightful qualities and lucid design, the stone stepwell remained the state of the art in Indian water management for more than a thousand years. Yet with the onset of the British Raj in India in the nineteenth century—and with it, the installation of pipes and taps for drawing and distributing water—stepwells fell on hard times. The demise of the stepwell as a source of water, as a gathering place, and as a focal point for many of the deepest feelings of the local people has brought about a tangled mix of environmental, social, and even religious consequences that continue to unfold to this day.

In concept, the Indian stepwell is cunningly simple. Monsoon rain is caught in a depression or behind a handbuilt earthen dam. The rainwater percolates down through fine silt, which screens out particulates, until the water reaches an impermeable layer of compact clay that keeps it from sinking deeper into the ground. In that way the muddy runoff of the monsoon is stored near the surface as a giant sheet of clear water: an underground aquifer.

A Gujarati stepwell simply penetrates the aquifer. It is filled by seepage; there is no obvious water current. The fall and rise of the water level at the bottom of the well reflects the droughts and deluges at the surface. A long staircase, punctuated with landings, leads down to the well at the bottom. When the water table is high, during and shortly after the monsoon, the visitor descends only a few steps to drink or bathe or fill the household vessel; when the water is low, she must descend farther, as deep as nine stories down, to where the final flight disappears into clear, dark water. At each landing is an open porch, supported by columns and protected from exposure to the broiling sun, where the visitor can pause to enjoy a quiet moment in the cool shade.

Much of the soil in the stepwell region is a fine alluvium (which is what makes it such an effective water filter), eroded from the western Himalaya, far to the north. Broken down as it travels, and broken down further by 5,000 years of farming, the soil holds few rocks. Hence the stone for constructing the stepwells had to be brought on wooden-wheeled oxcarts from distant quarries to the chosen sites. Brahmin theologians planned the monuments; low-caste artisans called *somparas* did the engineering and hard labor. Diggers moved the dirt with hoes and lifted it in baskets; masons plied their trade with poles and ropes, hammers and chisels. Some of the workers were women—a practice still evident in the region today.

The heavy blocks of stone were marked with hand-size, deeply carved numbers and letters to indicate their intended placement; the *somparas*, though illiterate, were nonetheless highly skilled at interpreting the marks and then fitting the muddy blocks together by touch, in accordance with the building plan. All the effort and expense were supported by a flourishing trade in such items as indigo dye, perfume ingredients, and locally printed fine cotton cloth. Stepwells were prestigious public gifts, and the financing of them was worthy of great and wealthy patrons: queens, wives of prominent traders, even successful prostitutes.

A stepwell was host not only to people but also to entire communities of bees, fish, lizards, palm squirrels, parrots, pigeons, and turtles. Images of fish, shrimp, and snakes were carved into half-hidden walls and obscure nooks, delighting anyone who encountered them. With the arrival of every monsoon, the whole world joined the stepwell in hatching, sprouting, recharging, and refreshing. But even the pleasures of water cannot explain the staying power of the stepwell as an institution: its almost unvarying form, its appeal to donors, its astounding beauty. Those persistent qualities derived from its role as a dramatic and imaginative metaphor for the Ganges, the greatest of India's rivers: Gujarati stepwell inscriptions explicitly declare that the water found in them comes from the Ganges. Thus to bathe in a stepwell was to take a ritual bath in that sacred river, and thus to attain the Hindu pilgrim's dream of reaching the sacred city of Varanasi.

Reflection in clear water, Ankol Mata Stepwell, Davad, 11th century

In the heat of the day men rested in the cool pavilions of stepwells, but women were the ones most deeply associated with water. Throughout the region they collected water in a *lhota,* a round-bottomed, short-necked jar with a wide lip that kept the liquid from spilling. They carried the jar, often for long distances, atop a cloth ring that cushioned their heads. (Even today, when most villages have communal water taps, the water must still be carried home.)

But going to the well was not simply an onerous task. Often it was the lone independent activity young women were permitted, and so in fact it was a welcome respite. (To this day in much of India, when a bride moves into the home of her husband's family, she does a good deal of the work.) At least at the stepwell she could laugh and joke and splash with other young women who were equally isolated by the strict patriarchy that prevailed in much of South Asia.

Women also frequented stepwells as an indirect consequence of a Hindu doctrine holding married women solely responsible for the gender of their children. As is still the case today, women remained low in the family hierarchy until they gave birth to a boy, and so even unmarried girls performed rituals intended to make them mothers of men.

Going to the well was often the lone independent activity permitted to young women.

For both girls and women embedded in this set of beliefs, one of the few comforting acts was to beg for help from the mother goddess, Devi, who lived in every stepwell. They could worship Devi by bathing—for water is believed to be one of the forms the goddess takes—or by invoking her name while pouring water over their heads. Not surprisingly, then, most stepwells included shrines to Devi, adorned with garlands of fresh flowers, strips of silk, oil lamps, incense, jewelry, and vermilion pigment. Women even sprinkled milk on the walls around the shrine and on the parapet surrounding the top of the well—in hopes that their symbolic act would bring them plenty of good breast milk for their children [*see photograph at top of page 56*]. The mother goddess is central to women's lives, and the term *Mata,* or Mother, figures in the names of perhaps a third of the stepwells—Mata Bhavani, Matri Mata, Bhadrakali Mata.

Women born into the lower castes, however, were excluded from the stepwells. Traditionally, all low-caste individuals would have obtained drinking water from muddy pools near the boundary of a village—unless someone from a higher caste drew it for them as an act of charity. Such restrictions on access to a nominally public water source throw into sharp relief the age-old contradictions between the demands of doctrine and the necessities of life.

Religious differences—generally such an explosive and destructive issue—played a creative role in the development of the stepwell. Beginning in the mid-eighth century, Muslims began to wrest control of various Hindu kingdoms through many small conquests. By the end of the twelfth century, Muslim sultans had come to ascen-

Seeing the sky from four stories down: The Rani ki Vav, or Queen's Stepwell, Patan, late 11th century

dancy in Gujarat, marking the onset of many centuries of Islamic power in the region—and the end of the glory days of the Hindu stepwell. By the early fifteenth century India's medieval Hindu kingdoms had largely dissolved. Yet the stepwell itself lived on.

India's Muslims were cosmopolitan people, more interested in politics, war, and trade than in agriculture; their soldiers operated under a mandate, amounting to a religious injunction, never to harm a stepwell, even in war. The Muslims brought to India the secular, social traditions of the *hamam,* or bathhouse, and the geometric, nonfigurative traditions of Islamic ornamentation. In 1411 the sultans established Ahmadabad as their first Indian capital; soon afterward they built a series of elegant stepwells nearby. Among them are Queen Rudabai's Stepwell at Adalaj and the Ambapur Stepwell at Budthal, the most majestic ever built.

It was only with the British rise to power in India in the early nineteenth century, that opposition to stepwells as key elements of the Indian water system emerged. To the British, stepwells were a sanitary disaster. The installation of rural taps became a top priority of the Raj. Not without reason, the British colonialists feared disease from the mixing of bathing and drinking water; moreover, the stepwells hosted a waterborne parasite, the guinea worm.

Postcolonial, independent India continued the

Walls surrounding shrines to Devi, the mother goddess, are often white with dried milk.

British policy of promoting taps instead of stepwells. But to bring water to those taps, the Indian government embarked on the construction of gargantuan dams. Partly by accident and partly by design, those projects have helped cause the destruction of an important but unsung component of the medieval water system: the many thousands of earth-walled dams that slowed the monsoon runoff, protecting topsoil and giving rainwater time to seep into the ground and replenish the aquifers. As for the stepwells themselves, some became repositories for trash and old tires, a few became the basements of new buildings, others became latrines. In Mehmadabad, Gujarat, a large apartment block collapsed into a stepwell near the market. Yet scores of wells remain usable. Gujarat's stepwells rode out a magnitude 7.6 earthquake that struck the Indian state on January 26, 2001; their large, flat stones, superbly joined and weighted down by the stones above them, are hard to rock [*see "Shaken to the Core," by Susan Hough and Roger Bilham, February 2003*]. Much more destructive to the stepwells in the long run have been powerful pumps and increased irrigation, both of which can lower the water table until a stepwell no longer reaches it, or until salt, saltpeter, or petroleum contaminate the water, permanently ruining its taste. Today the once-wholesome water—proclaimed by some of the inscriptions in the stepwells to be "as sweet as milk"—is just a memory.

Nowadays the consensus is that, once upon a time, stepwells were a fine thing. Villagers still look upon them fondly, not as water wells but as open, public spaces. No longer interested in drinking from them or bathing in them, the villagers are repossessing and rehabilitating them as homes for Devi. They ornament the stepwell shrines to the goddess in much the same colorful way as they decorate their own homes for festivals, imbuing otherwise austere, monochrome stepwell entrances with a festival air.

At the same time, historians and preservationists have begun to recognize the value of stepwells as superb works of architecture, ancient monuments that deserve to be left intact and be protected. Their potential for tourism, moreover, has not gone unnoticed by the government: officials from the Archaeological Survey of India have begun to charge admission. Those "official" uses, of course, run head-on into conflict with the more exuberant ways that villagers have been incorporating the buildings into their own popular culture.

A newly adopted stepwell is quickly embellished with welded metal—considered, in all its forms, a symbol of status. The government leans toward installing metal fences, gates, and tollbooths, whereas the villagers prefer shrine doors, turnstiles, handrails, and occasionally a pergola. The government's color choice is gray or rust, and its additions always have a lock and key; the village work is multicolored and does not prevent entry. Even when electricity is installed, it conveys the differences in cultural perspective: near government stepwells it lights a toll booth; at village stepwells it enables the locals to see the goddess more clearly.

Regardless of which patron gains the upper hand, though, none is likely to reintroduce the stepwell as a way to mitigate the chronic water shortages that continue to plague this part of the Indian subcontinent. Disputes over water rights in the dry season have become almost daily news. Today the stepwells are more like footnotes to a missing text—a vanishing way of life—than solutions to the water problem. What they offer the modern age is their beauty, their solidity, and the intelligence of their engineering, all of which speak volumes about how people were once willing to match their demands to the renewable capacities of the planet. □

Secondary staircase in the Rani ki Vav


Stairway to the water at Narayan Rao Stepwell in Idar, also in the state of Gujarat, India

Bogs and Burning Woods

Small variations in elevation create the strange habitats of New Jersey's pine barrens.

By Robert H. Mohlenbrock

At frequent intervals between 135 million and five million years ago, the sea covered what is now the coastal plain of New Jersey, depositing clays, silts, sands, and gravels. The sandy soil covering the plain today is acidic and low in fertility; it also retains little water, creating arid conditions that give rise to fires. Most plants cannot survive in such a hostile environment, but the ones that do make up a distinctive forest called the pine barrens.

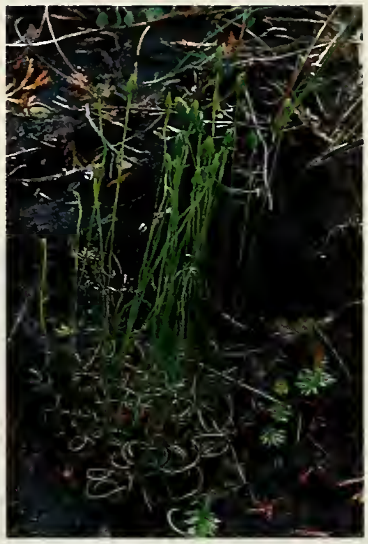
Extending as far inland as fifty miles, the coastal plain comprises two sections. The wide, outer plain gradually rises from the New Jersey coast to a crest of low hills. Beyond that, a narrower but more fertile inner plain slopes down to the bank of the Delaware River. The pine barrens comprises more than 2,000 square miles of the outer coastal plain, about a fourth of the state. Much of it is uninhabited, but because of the acidity of the soil, some zones have been cleared for raising commercial crops of blueberries and cranberries. Here and there towns and villages have also been established. In 1978, concerned that development would obliterate the natural environment, the U.S. Congress designated the area the New Jersey Pinelands, the first so-called national reserve.

The pine barrens terrain is relatively flat, never rising more than 200 feet above sea level. But minor differences in elevation create four identifiable habitats. Highest are two kinds of dry forests, one dominated by pitch pine and one dominated by oaks. Bogs (the third habitat) and cedar swamps (the fourth) occur in the lowlands. All four natural communities appear here and there throughout the national reserve, but large continuous acreages of the pine barrens are also administered by the state: Wharton State Forest, Brendan T. Byrne (formerly Lebanon) State Forest, and Belleplain State Forest.

Historically, fire has helped maintain the dry forests, striking at least once every twenty to forty years (large fires are becoming less frequent, however, because of increased control). The characteristic species are fire tolerant, usually surviving because they have extensive underground root or rhizome systems. In one twenty-square-mile zone of pitch-pine forest, the fires have burned every ten to twenty years, and the pitch pines and associated species grow only four to ten feet tall. Such stands are known as pine plains or dwarf pine forests. East of Brendan T. Byrne State Forest, along State Route 72 just west of its junction with County Road 539, the trees are only a few feet tall. Standing among them, the average adult can feel like a giant.

About seven and a half miles north of the same junction is Webb's Mill Bog, one of my favorite bogs in the pine barrens. It is the most accessible because it is surrounded by a metal walkway. Bogs develop in low depressions where as much as two feet of

Atlantic white cedars inhabit a lowland zone.

Pitch pines, above left, withstand arid conditions. Above right: Curly grass (a fern) grows in Webb's Mill Bog.

standing water collects. Atlantic white cedars scattered amid the other vegetation remain stunted as long as the water is deep, growing no more than four feet tall. As a bog fills in with dead vegetation, including the highly acidic cedar leaves, however, the water becomes increasingly acidic, discouraging the growth of some plant species. At the same time, the area starts to dry out, and the cedars begin to grow straight up as high as seventy-five feet, shading (and thereby stunting or killing) many of the small plants beneath them. The habitat is thus transformed into a cedar swamp.

The pine barrens of New Jersey is the northernmost range of 109 southern plant species. Among them are turkey beard, golden-crest, and yellow asphodel. Botanists have also discovered fourteen species of plants more common farther north that reach their southernmost limit in the pine barrens. Rarest and most unexpected of those are broom crowberry, a wiry shrub with crowded, quarter-inch-long leaves and black berries, and curly grass, a fern that has small curly leaves that look like immature grass.

HABITATS

Pitch-pine forest Made up primarily of pitch pine or a mixture of pitch pine and shortleaf pine, this kind of forest often includes a few broad-leaved trees, particularly blackjack oak, post oak, and chinquapin oak. Several low-growing shrubs, such as lowbush blueberry and black huckleberry, are common. The few non-woody species include little bluestem, wintergreen, Virginia tephrosia, wild indigo, tall oatgrass, cowwheat, low frost weed, turkey beard, and bracken fern.

Oak forest Scarlet oak, white oak, black oak, and chestnut oak prevail in the canopy; pitch pine is a secondary species. Other trees are blackjack oak, post oak, and sassafras. The shrub layer includes lowbush blueberry, black huckleberry, dangleberry, staggerbush, inkberry, and sheep laurel. The forest floor is home to the same species that grow in pitch-pine forests.

Dwarf-pine forest Pitch pine is the main tree, but blackjack oak, bear oak, and chestnut oak are also common. Shrubs include broom crowberry, mountain laurel, sheep laurel, sand myrtle, golden heather, black huckleberry, and lowbush blueberry. Other species include trailing arbutus, bearberry, wintergreen, inkberry, sweet fern, flowering pixie moss, and cowwheat.

Bogs Interspersed with stunted Atlantic white cedars are hummocks bearing purple pitcher plant, three kinds of sundews, tuberous grasspink, snakemouth orchid, racemed milkwort, golden-crest, a pink Saint-John's-wort, and two creeping species of wild cranberry. A large, yellow-flowered bladderwort sends stems several inches above the surface of the water, and the yellow asphodel is spectacular in late June and early July. Here and there are patches of American white water lily and Engelmann's arrowhead. The curly grass fern can be found curled up on mounds of sphagnum.

Cedar Swamp Although the principal tree is Atlantic white cedar, the canopy also includes red maple, sweet bay magnolia, gray birch, and black gum. Coastal sweet pepperbush, highbush blueberry, and swamp azalea are the predominant shrubs. Beneath the woody plants grow netted chain fern, cinnamon fern, sensitive fern, and various sedges and rushes.

For visitor information, contact:
Wharton State Forest
4110 Nesco Road
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REVIEW

Hydro Dynamics

Forget oil. Sharing freshwater equitably poses political conundrums as explosive and far-reaching as global climate change.

By Sandra Postel

Almost all the water on our planet—more than 97 percent—is undrinkably salty. Of the remainder, more than two-thirds is locked up in glaciers and ice caps. Only a minute share of Earth's water, less than one-hundredth of 1 percent, is both fresh and renewed each year—a total of 110,300 cubic kilometers of freshwater that circulates annually among the sea, air, and land in an endless cycle, driven by the Sun. After it falls as rain or snow, much of this water returns to the atmosphere through evaporation, or by transpiration from plants. Only a bit more than a third of the total, about 40,700 cubic kilometers a year, runs back to the sea via rivers, streams, and underground aquifers.

That portion of a portion is all the runoff available for irrigating crops, powering turbines, supporting industries, and quenching people's thirst. It also sustains fish and other aquatic life, dilutes pollution, moves sediment to deltas, delivers nutrients to productive coastal estuaries, and performs a host of other ecological jobs collectively worth hundreds of billions of dollars a year. Freshwater is therefore much more than a strategic resource such as oil or uranium; it is a fundamental life support, and the part of it that people can sustainably access is much smaller than all the blue on a world map would suggest.

In fact, freshwater is a uniquely important resource because, for most of its uses, it is not replaceable by any other substance. And, unlike most resources, it does not stand still until people come along to mine it or move it. Water flows naturally across national and other political boundaries, creating unique political problems. Those problems are only going to increase. By 2025 some three billion people will live in places where it will be difficult or impossible to get enough freshwater to satisfy all of their industrial, food, and household needs. In their different ways, the new books by Robert Kandel and Diane Raines Ward each offer a useful perspective on this fact of life in the twenty-first century: the world is entering an unprecedented period of water stress.

> ***Water from Heaven: The Story of Water from the Big Bang to the Rise of Civilization, and Beyond***
> *by Robert Kandel*
> *Columbia University Press, 2003; $27.95*
>
> ***Water Wars: Drought, Flood, Folly, and the Politics of Thirst***
> *by Diana Raines Ward*
> *Riverhead Books, 2002; $24.95*

The Tigris-Euphrates river basin, that all-too-familiar geopolitical hot spot, gives a hint of things to come. The Euphrates River originates, like the Tigris, in the mountains of eastern Turkey; it then flows southward through Syria and Iraq before emptying into the Persian Gulf. In January 1990 Turkey flexed its water muscle in a big new way: it stopped the Euphrates from flowing into Syria and Iraq for a month in order to fill the reservoir behind the Ataturk Dam, the centerpiece of a massive irrigation and hydropower scheme in Turkey's impoverished southeastern region.

Turkey had warned its downstream neighbors the preceding November that it would soon start filling the reservoir, and offered to increase river flows for several weeks so that the two countries could store additional supplies beforehand. Instead, Syria and Iraq protested the river stoppage. Turgut Ozal, then president of Turkey, promised his neighbors that his nation would never use its control of the river to "coerce or threaten them," an assurance that undoubtedly rang hollow, given his government's veiled threat just a few months earlier to cut the Euphrates' flow because of Syria's support of Kurdish insurgents. (In fact, the perpetual lack of agreement between the two nations on water was reported to be part of Syria's motive for helping the Kurdish separatists in the first place.)

The Ataturk Dam was just the beginning. Turkey's $32 billion Southeastern Anatolia Project includes twenty-two dams on the Euphrates and Tigris Rivers, the irrigation of 4.2 million acres of land (an area larger than the state of Connecticut), and the generation of 27 billion kilowatt-hours of electricity annually. At full scale the project could reduce the Euphrates' flow into Syria by 35 percent in normal years and by substantially more in dry ones—not to mention polluting the river downstream with

David Goldes, *Collecting water from table*, 2002

salts and chemicals. Iraq, third in line for Euphrates water, would see a drop as well. Those two rivers, the fluid backbone of the ancient Sumerian, Assyrian, and Babylonian civilizations, are in for a colossal change—and so are the region's politics.

The same unfolding story line is being played out, with different actors and at different intensities, in many other parts of the world—including the U.S. Southwest, southern Africa, the basin of Central Asia's Aral Sea, and the Nile and Jordan river basins, to name a few. Most of the planet's large rivers, in fact, are already controlled by *Homo sapiens,* not by nature. A river has a distinctive pattern of high and low flows, a flow signature that reflects the climate, geology, vegetation, and other natural features of its watershed. Through the seasons of the year and over the decades, those natural variations have created the habitat conditions to which the life within that river system has adapted. Floods cue fish to spawn, for instance, and trigger certain insects to begin a new phase in their life cycles. Floods also bring seasons of life to a river's floodplain, creating habitats crucial to the breeding and feeding of fish, waterfowl, and other river-dependent species. Yet with our dams, reservoirs, and diversion canals, we human beings have dramatically altered the quantity and timing of natural river flows. It will take the best of science, technology, management, and ethical awareness to figure out how to meet the water and food needs of the burgeoning human population while leaving enough for nature's needs.

In *Water from Heaven,* Kandel, a senior scientist with the French National Scientific Research Agency, begins at the beginning. He takes us all the way back to the big bang and through the creation of our solar system. He explains in fascinating detail the origins of water on planet Earth and how the molecules of water have circulated throughout time.

Liquid water has been on our planet for at least three billion years. Nowadays the stock of water is fixed (though there may be "cosmic snowballs"—small comets made of water—that smash into the Earth and so add to the planet's water supply). Water moves in closed cycles that operate over vastly different scales of time and space.

Some water molecules are trapped deep within the Earth and remain there for millions of years, then burst suddenly into the atmosphere through an erupting volcano. Others stay close to Earth's surface, changing back and forth from liquid to vapor to liquid again as they move from sea to air to land and back to the sea. There are water molecules that reside for millennia in deep underground aquifers—until, perhaps, some desert agriculturalist pumps them up to irrigate thirsty crops. And there are water molecules trapped in glaciers and mountain snowpacks for many decades, released only when they melt into rivers that flow toward the sea. "Whenever you eat an apple or drink a glass of wine," Kandel explains,

> you are absorbing water that has cycled through the atmosphere thousands of times since you were born. But you are also absorbing some water molecules that have only been out in the open air for a few days or weeks, after tens or hundreds of millions of years beneath the Earth's crust.

One might think such an impressive history would engender a sense of awe and respect for nature's water cycles. Instead, we take it all for granted. For the past several thousand years people have altered those cycles in innumerable ways to satisfy their needs and wants.

The earliest to do so on a substantial scale were probably the Sumerians, who migrated out of the Mesopotamian highlands some 5,500 years ago and settled in the Fertile Crescent's lowland plains (present-day southern Iraq). Their new climate was sunnier, and kinder to their crops, but it lacked rainfall at critical times during the growing season. So they built canals to siphon water from the Euphrates River and transport it to their fields, giving rise to the world's first irrigation-based society.

The morphing of technological accomplishment into potential disaster is a recurring theme in Ward's account of large-scale water projects.

Unfortunately, the Sumerians were also among the first to experience the scourge of salinization—salt accumulation as a result of the evaporation and transpiration of irrigation water. (Even today, one out of five acres of irrigated land suffers from the buildup of salts in the soil.) Ancient Mesopotamia also sustained the earliest, and some would say the only true, water war—a battle some 4,500 years ago between the city-states of Lagash and Umma.

So the patterns of modern water-related threats to both agricultural sustainability and regional peace were already unfolding thousands of years ago. But only within the past century, and particularly within the past fifty years, has the scale of human impacts on the Earth's water cycles and freshwater systems reached global proportions. By 1950, civil engineers had constructed some 5,000 dams higher than fifty feet on rivers around the world. Today such large dams number some 45,000. On average throughout the world, people have built two large dams a day, every day, for the past half century.

That monumental scale of water development and the drudgery and disease suffered daily by the 1.1 billion people who still lack safe drinking water are what preoccupy Diane Raines Ward, a writer based in New York City. Ward's interest in water politics stems from interviews she conducted for the international edition of *Newsweek* in the late 1980s in Turkey, where she first learned about the Southeastern Anatolia Project. In *Water Wars* she takes the reader on a whirlwind tour of big-dam projects, large irrigation schemes, and potential flashpoints of water tensions around the world. Her superb storytelling, enriched by scores of fascinating interviews, more than makes up for what the book lacks in analytical exactitude.

Ward illuminates the promise and pitfalls of large-scale water development with stories from Australia, Brazil, China, India, Pakistan, Turkey, and the United States. She describes in some detail the Tennessee Valley Authority (TVA), which carried out one of the earliest big-dam development schemes and became a model for many that came later. Even today, engineers in India and Pakistan proudly state that the vast engineering works of the Indus River basin, which include the largest contiguous irrigation scheme in the world, drew on the TVA's approach.

Yet the unsustainability of many of those large schemes is increasingly apparent. In the Indus basin, heavy diversions of river water, overpumping of groundwater, and, most important, soil salinization pose serious threats to farm productivity in the coming decades. The morphing of technological accomplishment into unthinkable potential disaster is a recurring theme of Ward's account: "We began the mighty engineering works of the twentieth century in environmental ignorance," she writes, "and ended the century in environmental crisis."

In spite of the title of Ward's book, relatively little space is devoted to water wars in the conventional sense of that term. Both Ward and Kandel confine their discussions of modern hydropolitics largely to the Jordan, Nile, and Tigris-Euphrates river basins.

Perhaps, though, they have good reason to limit and so sharpen their focus: in none of these hot spots of water dispute is there yet a basin-wide treaty that clearly and fairly allocates the available water among all the parties. Thanks to lands acquired during the Arab-Israeli wars, Israel controls the lion's share of the water in the Jordan basin, including important reserves of groundwater under the West Bank. Because Israel's per capita water use far exceeds that of its neighbors (even in the occupied territories, Israeli settlers consume about five times more water per capita than the Palestinians do), any hope for lasting peace in the region will have to include a more equitable apportionment.

As for the Euphrates, Syria and Iraq

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have had an agreement since 1990 to share the flow that crosses the Turkish-Syrian border; so far, that has amounted to about half the average annual natural flow of the river. Turkey, however, has only a temporary agreement with Syria, and has had no serious negotiations with Iraq for more than a decade—effectively ignoring the two downstream nations' calls for a final settlement of their water dispute. Turkey was just one of three countries (along with China and Burundi) to vote against a 1997 United Nations convention that established two key principles to guide international water-sharing: first, the idea of "equitable and reasonable use" and, second, the obligation not to cause "significant harm" to one's neighbors.

Turkey apparently has different ideas about water-sharing. In response to Syria's 1992 requests for more Euphrates River water, Suleyman Demirel, then Turkey's prime minister, reportedly remarked, "We don't say we share their oil resources. They can't say they share our water resources." Turkey does, however, want to sell some of its water. There is a plan to export water from another river, the Manavgat, to Israel—an idea the Israeli government has recently warmed to.

In the years ahead tensions over water may flare in regions outside the Middle East as well. Worldwide, there are 261 rivers shared by two or more countries, yet in most of those river basins there is no treaty that divides the water equitably among all the parties. In more than twenty of them, disputes could erupt or intensify in the next decade, as nations decide unilaterally to begin constructing large dams and water projects—just as Egypt, Israel, and Turkey have done in their respective basins. Countries whose water flows are disrupted would end up suffering from reduced agricultural potential, urban and industrial water shortages, and environmental degradation; in the worst cases, water shortages could spark the flight of ecological refugees, or cause similar humanitarian disasters.

River basins to watch include the Mekong and Salween in Southeast Asia; the Kura-Araks in western Asia; and six basins in southern Africa, including the Incomati, Okavango, and Zambezi. Although countries in some of those basins are building stronger institutions to promote cooperation over their shared waters, most of them have a long way to go.

As if sharing water with each other will not be arduous enough, we must also share water with nature. The same fixed supply supports hundreds of thousands of other species, as well as the ecosystems on which our economies depend—a theme neither Kandel's book nor Ward's adequately addresses. Meeting that challenge is likely to dominate water management in this century just as much as the problem of climate change.

In the past decade investigators have amassed a large body of evidence that the modification of river flows is driving many species to extinction and disrupting natural cycles of great value to human activities. At least 20 percent of the Earth's 10,000 freshwater fish species are now endangered, threatened with extinction, or already extinct. The prospects for the estimated 100,000 species of invertebrates and the thousands of species of algae, bacteria, and protozoa that live in freshwater sediments are uncertain, but biologists have no doubt that these organisms are extremely sensitive to shifting water levels, flow magnitudes, and other hydrologic alterations.

Water shortages could spark the flight of ecological refugees, or cause similar humanitarian disasters.

Each species plays a role in the web

of life that keeps the biosphere functioning. Through Kandel's long lens of geologic time, the loss of species and changes in natural cycles may not be particularly consequential, but they matter a great deal on the human time scales that affect us and our descendants. Restoring some of the natural flow of rivers—by operating dams differently and even by taking some down—is crucial to the harmonization of human needs with nature's requirements.

Both Kandel and Ward devote only limited space to those issues, and both books (particularly Ward's) could have done a better job of analyzing and setting priorities for the proposed solutions. Reducing the human pressures on the Earth's finite water supplies will require much stronger efforts to conserve and recycle water and to use it more efficiently. For example, by irrigating with drip methods that deliver water directly to the roots of plants, farmers can double or triple their crop yields per unit of water consumed. Personal choices make a difference too: it takes twice as much water to provide the food for the average American's diet as it does to produce a nutritious vegetarian diet.

Ultimately, though, it may take a deeper respect for the beauty and mystery of natural water cycles to prevent us from further manipulating them—to inspire us instead to use our scientific knowledge and technical know-how to live more in harmony with nature, just as our earthly companions do. The story of water on Earth will flow on, with us or without us. But unless we assimilate a bigger dose of ecological wisdom, the human chapter of that story is unlikely to have a happy ending.

Sandra Postel directs the Global Water Policy Project in Amherst, Massachusetts. She is the author of Pillar of Sand: Can the Irrigation Miracle Last? *(W.W. Norton 1999) and coauthor of* Rivers for Life: Managing Water for People and Nature, *which will be published by Island Press this summer.*

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By Robert Anderson

Freshwater doesn't always flow freely (and free of charge) from a tap, and it's probably worth knowing, in these days of uncertainty, just where it comes from and how precious it is. The Web site "Water Science for Schools" (ga.water.usgs.gov/edu/) is a great place to start. Although the U.S. Geological Survey (USGS), which monitors the nation's water resources, created the site for classroom use, anyone with a general question about water will find it answered here.

More intrepid web surfers should click on the site's "Water" link (click on "Links," then, in the listings of "Organizations involved with water," click on "Water," or go to www.sbu.ac.uk/water/index) for a look at Martin Chaplin's "Water structure and behavior." A professor of applied science at London's South Bank University, Chaplin offers his own eclectic collection of "Water related links."

Another USGS site ("Water Watch," at water.usgs.gov/waterwatch/) enables you to check the conditions of current water resources around the country. Play around with the options on the drop-down menus at the top of the page: you can learn where droughts are developing (click on "Drought Watch"); view a map showing stream flows in real time (click on "Real-Time Streamflow"); watch map animations of changing water flow over the course of a month (use the second menu to click on "Map Animation—Day of the Year"). If your community draws its water from under the ground, you may want to explore the descriptions of water resources presented in the "Ground Water Atlas of the United States" (go to capp.water.usgs.gov/gwa and click on "Archive").

For the global perspective, try UNESCO's "Water" site (www.unesco.org/water/). Click on "WWAP" on the list at the left of the page to find out what events are planned through the rest of 2003 to celebrate the "International Year of Freshwater." Those interested in water issues in hot spots such as the Middle East—where allotment becomes increasingly contentious as populations expand—can access the list's "Water Links" to browse by geographic region [*see also "Hydro Dynamics," by Sandra Postel, page 60*]. And for more insight into conflicts and tensions over water use worldwide, go to "The World's Water" (worldwater.org) and click on "Water Conflict Chronology." I learned there that in 1924 my own water supply, the Los Angeles Valley aqueduct, was the target of bombings by a group opposed to the diversion of water from Owens Valley.

David Goldes, *Vortex #1*, 1995

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

By Laurence A. Marschall

Hawks Rest: A Season in the Remote Heart of Yellowstone
by Gary Ferguson
National Geographic Adventure Press, 2003; $15.00

Measured by its distance from roads, the Bridger Wilderness, just southeast of Yellowstone National Park, is one of the most remote spots in the lower forty-eight states. It was there, in a small two-room cabin called Hawks Rest, that nature writer Gary Ferguson spent an eventful eleven weeks last year, enjoying the views of Bridger Lake and the sound of the Yellowstone River rushing nearby. The U.S. Forest Service, which hired Ferguson and a friend named LaVoy Tolbert to patch up the place, wound up at the end of the summer with renovated living space, a repaired water supply, and a neatly fenced meadow. More important, lovers of outdoor writing wound up with a rousing and evocative look at the charms and trials of life in the way-out-of-doors.

Thomas Moran, *The Grand Canyon of the Yellowstone*, 1872

But *Hawks Rest* is not your usual idyll about the beauty of untrammeled wilderness. Sure, there are plenty of passages that make you want to head for places such as Fall Creek:

> Dropping 5,000 feet in about five miles. . . . the creek [is] a series of nearly vertical drops broken by icy blue-green pools. The south wall of the canyon is hung with thin waterfalls dropping off the lips of volcanic ledges, while on the north side the streams are more substantial, rocketing off stony chutes, launching themselves into space like kids jumping off their swings.

Surprisingly, though, for a book about the farthest and the wildest, *Hawks Rest* is mostly about people.

To Ferguson's bemusement, Hawks Rest (the place) is plenty trammeled. It's a kind of Grand Central Station of the U.S. outback, a crossroads for all kinds of unlikely characters. Some are eccentrics, such as Lone Eagle Woman, who hikes the woods every summer, communing with the beasts and the trees. Some are trail-worn twenty-somethings from the Forest Service, who turn up to dig out a rockslide, cut back a deadfall, or rescue a stranded hiker. Rangers from neighboring cabin outposts stop by, eager to swap stories of close encounters with grizzlies or—arguably more dangerous—run-ins with poachers and angry hunters.

Many in the passing crowd are professional outfitters, heavy pistols on their belts, wrangling their parties of Eastern dudes who view the out-of-doors as a combination adventure ride-cum-shopping mall for trophy heads. The only times Ferguson and LaVoy are truly alone are when they hike away from Hawks Rest, up to some windswept mountain vista far from the steady traffic of backcountry life.

Where there are people, there is politics—though politics in the wild usually centers on the relations between people (who make policy) and animals (who don't). Often it comes down to the question, Who gets to shoot what and when? So, are the grizzlies treasures or menaces? Have the wolves reintroduced into Yellowstone enhanced its wildness and its balance of predator and prey, or do they pose too great a threat to game animals? Should the Forest Service vigorously discourage the use of salt licks outside of Yellowstone (where hunters take potshots at the elk in exchange for a hefty fee to the outfitters who plant the licks to lure the game)?

Ferguson leans "green" on these issues, a view quite different from that of the gun-toting outfitters and ranchers who derive both income and identity from the wilderness. He tries to be evenhanded, but it's easy to see where his sympathies lie—and if you're well disposed to his engaging and elucidating prose, it's not hard to go along with him. So if you favor color-coordinated Gore-Tex and carry an internal-frame backpack, you'll love this book. But if your gear tends toward canvas and "camo," you'll find Ferguson a bit irritating. In any case, you will get a sharp and ironic sense of what it's like to live in the American outback, twenty-first-century style.

Voyages of Delusion: The Quest for the Northwest Passage
by Glyn Williams
Yale University Press, 2003; $29.95

In this age of technical marvels, when satellite images of the globe are only a mouse click away (see, for instance, terraserver.microsoft.com), it comes as a shock to see how sketchy are the outlines of continents on maps of the 1700s. More than two centuries had passed since Columbus's voyages, but so little of the world had been charted that geography was more a matter of speculation than of science. Western sailors knew about just a few islands in the Pacific, had a passing idea of the location of Australia, and only half-believed the rumors of a giant continent in the remote south and an ice-free ocean around the North Pole (only one of which, of course, turned out to be true).

As for the New World itself, a vast northwestern quadrant remained unexplored. Some maps—if they showed anything at all west of the Great Lakes—placed the "Isle of

California" off the western coast of North America. Others charted Alaska as the largest island in the Aleutian Islands chain.

The speculative European and American geography of the eighteenth century, according to maritime historian Glyn Williams, was guided by a seductive assumption: an easy, ice-free passage connected the Atlantic and Pacific Oceans. But the evidence was scanty; the vastness of the North American continent hindered overland exploration, and ice seemed to block all the sea routes around the continent to the north.

Boat with corpses of Franklin Expedition, c. 1900

One exception seemed to be Hudson Bay, accessible from the Atlantic Ocean by a strait that, in a good year, remained open throughout July and August. There was tantalizing evidence that beyond the bay was a passage to the Pacific Ocean. Whales, earnestly believed to have swum from the Pacific, had been sighted along the bay's western shores, and some reports of the height and direction of its tides seemed to indicate its connection to a larger body of water.

If you read those signs optimistically, as did the Irish legislator Arthur Dobbs (an ardent advocate of a Northwest Passage), all you needed was persistence. Follow the indented western shoreline of Hudson Bay and an inlet would soon be found that led, after at most a few hundred miles, into the balmy Pacific. Dobbs, who never came anywhere near Hudson Bay, managed to persuade the British government that his fantasy was a worthwhile enterprise, and two small ships, under the command of Christopher Middleton, set sail in early June 1741. With an optimism typical of the age, they carried orders not only to find the passage but also to negotiate treaties with the "populous Nations" of the Pacific.

Middleton's expedition, and all others to Hudson Bay in the decades that followed, came to naught. Promising inlets always ended abruptly, ships got stuck in the ice, and men froze, starved, and died of scurvy. It was no better for explorers who, trying a different tack, sought the outlet of the Northwest Passage on the Pacific side. James Cook, on his last voyage around the world, followed numerous fjords into the deeply indented Alaskan coast, meeting nothing but frustration.

Williams's history stops in the 1790s, but, as he notes in his final pages, the disastrous Arctic voyages continued for another hundred years. During that time, however, all the poking and prodding had some effect on geographic knowledge. When Lewis and Clark set out to explore the Louisiana Territory in 1803, the true extent of the North American monolith was beginning to appear on maps, and the hope of the mercantile world for a shortcut through the continent had faded. The dream of an open polar sea replaced the dream of a channel through the continent.

It was not until 1906, by drifting for four years among crushing pack ice, that the Norwegian polar explorer Roald Amundsen managed to navigate an arduous northern route from the Atlantic to the Pacific. By then, Arctic travel was regarded as an expensive and heroic stunt, and the search for a Northwest Passage had become a lesson in the folly of wishful thinking.

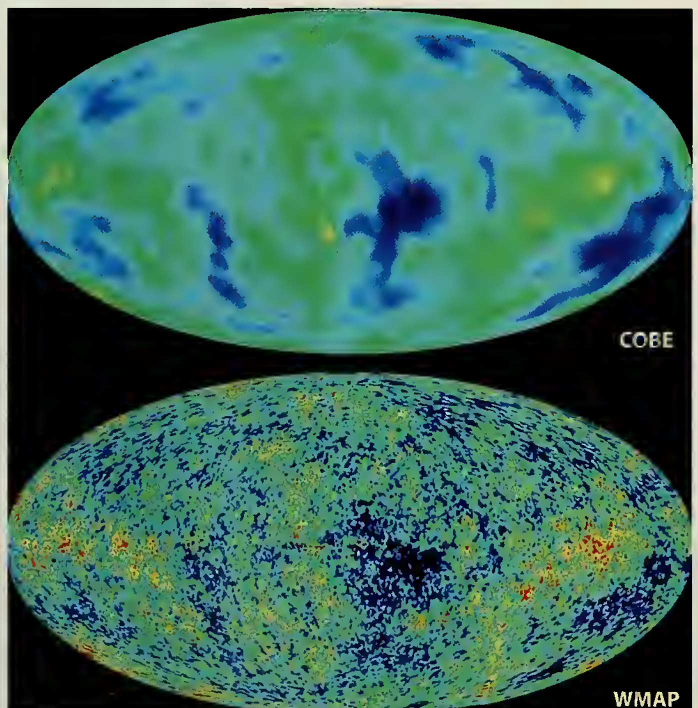
Laurence A. Marschall, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

Sharper Focus

Resolving the details of the cosmic microwave background has brought new precision to our picture of the cosmos.

By Charles Liu

For the first third of a million years or so after the big bang, matter and energy in the universe moved in lockstep. Wherever matter was relatively dense, so was energy. Then, as space expanded enough to accommodate the independent motions of material particles and of photons of light energy, the two gradually extricated themselves from their mutual grip. By the end of that process, matter could move and coalesce on its own, forming planets and stars, as well as galaxies, clusters, and superclusters. Light, on the other hand, simply radiated outward in its original configuration, permeating the expanding universe with a warm, omnipresent glow.



Two maps of the cosmic microwave background, which permeates space in all directions, highlight recent improvements in the resolution of satellite observatories that enable astronomers to peer ever more clearly into the origins and fate of the universe. The map by the Cosmic Background Explorer (top), the state-of-the-art observatory just a few years ago, is now far surpassed in detail by the more recent map by the Wilkinson Microwave Anisotropy Probe (bottom).

That glow has steadily faded and cooled ever since, diffusing through ever-expanding space. The temperature of the space-filling radiation (about 3,000 degrees Celsius when light and matter separated) has by now cooled to a frosty 2.7 degrees above absolute zero. And to say the radiation cooled is just another way of saying that the average wavelength of the radiation is no longer fairly short, like the glow of a blast furnace, but much longer, about the same length as the microwaves picked up by an ordinary radio. Astronomers call that radiation the cosmic microwave background, or CMB. In fact, if you tune your radio between two AM stations, about 10 percent of the static you hear is the hiss of the CMB.

In spite of the expansion of the CMB, it has remained otherwise unchanged. By contrast, the structure of the matter in the universe has changed dramatically. The CMB, then, is essentially a partial picture of the universe in its infancy. Not surprisingly, we astronomers have been mapping it for decades, as precisely as our technology allows, hoping to uncover the secrets it has preserved for nearly all of cosmic time.

The results of our latest effort—by the Wilkinson Microwave Anisotropy Probe (WMAP)—made headlines this past February, when cosmologists unveiled the most detailed picture of the CMB ever made. Among all the discoveries reported, one number stood out. WMAP had enabled cosmologists to measure the present age of the universe with unprecedented precision: 13,700,000,000 years.

But what the news reports didn't emphasize was that—though astronomers obviously care how old the universe might be—arriving merely at that number would not have justified all the time, effort, and resources that went into WMAP. Increasingly accurate observational and theoretical efforts to measure and deduce the age of the universe have been going on for a long, long time; one more measurement is, at this point, just one more measurement. What's really exciting is that the cosmic microwave background hides, within its fossilized patterns of light and dark, evidence of many of the fundamental parameters of the universe—its matter density, its energy density, its rate of expansion, and more. From those parameters, astronomers can infer key details about the earliest moments of the cosmos, and derive a wealth of other properties, including its present age, as well as its geometric curvature and its most likely final fate.

The methods for mapping the CMB were as impressive and sophisticated as one would expect of a multi-year, multimillion-dollar project. The WMAP results were announced February 11, and on that day alone, thirteen papers describing the mission were submitted for publication. Six of those are primarily devoted to the technical details of data extraction. In a nutshell, WMAP scans the sky continuously from the vantage of one of the Earth's Lagrange points [*see "The Five Points of Lagrange," by Neil deGrasse Tyson, April 2002*], mapping patterns of hot and cold in the CMB across the entire sky twice each year. That is no mean feat: the hottest and coldest parts of the CMB differ in temperature by roughly four ten-thousandths of a degree. (That's like measuring sand-size bumps on a perfectly flat living-room floor.)

To achieve that level of precision, WMAP simultaneously measures the CMB temperature of two widely separated patches of sky, then subtracts one from the other. The process enables the satellite to cancel out any contaminating background signals and to map the sizes and shapes of the CMB's hot and cold patches with the highest possible contrast. The ultimate goal is to determine the direct imprint of the structure of the nascent universe on the CMB.

So what's the bottom line? Before the WMAP results, the general scientific consensus was that the universe was between 11 billion and 15 billion years old. Now, we're pretty sure that the universe is between 13.4 billion and 13.9 billion years old. The increased accuracy of the result is certainly welcome: it's a strong, independent confirmation of previous measurements, and it sinks another strong pillar into the foundation—or is it the firmament?—of modern cosmology. But the measurement doesn't really change any basic scientific conclusions.

And ironically, that's what many of my colleagues feel is WMAP's main contribution: it has confirmed most of what we already suspected about the cosmos, and has lent more precision to what has been a rather inexact science. So, in a way, the really exciting part of this discovery may be that it's hardly exciting at all.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

By Joe Rao

Two "three-star" events draw the eye to the sky this month: a transit of Mercury and a total eclipse of the Moon.

At sunrise on the 7th, properly equipped viewers in parts of the eastern United States and Canada can catch the final minutes of the transit of Mercury—astronomical lingo for the apparent movement of a planet across the solar disk. The event is essentially a solar "eclipse" by a body (either Mercury or Venus) too far from the Earth to blot out the Sun's light.

A transit of Mercury was once a scientific event of the first magnitude—to astronomers, literally worth a trip to the ends of the Earth. Careful observations and timing of the transits helped confirm Einstein's general theory of relativity. Transits of Mercury are pretty rare, too: only fourteen of them will take place this century. Watching this one from the U.S., though, isn't the best option. You won't see it at all unless you're east of a line running from roughly Sault Ste. Marie, Michigan, to Charleston, South Carolina—and even if you are, you'll catch only the closing stages of the event. If you want a better look at the entire show—lasting five hours, nineteen minutes—you should plan on more serious travel: to central and western Asia, the Arctic, central and eastern Africa, or Europe (save for Portugal and western Spain, where the transit is under way at sunrise).

Transits of Mercury cannot be seen with the naked eye. You'll need at least a fifty-power telescope to bring out the "dark dot" of Mercury silhouetted against the Sun's disk. Eye safety is always a prime concern when dealing with the Sun. *Never look directly at the Sun through a telescope!* Rather, hold a white card or screen behind the eyepiece, and you'll see an enlarged image of the Sun's disk projected on the card or screen. Your observing site should have a low horizon just to the north of due east. Check the Sun's rising point a day or two beforehand to make sure no trees or buildings block your view.

When the Sun rises in North America, the planet has already begun its passage across the solar disk. As the duo creeps above the horizon, Mercury should be recognizable near the Sun's upper right limb as a small black dot. The dot will reach the edge of the Sun at 6:29:45 A.M., then take another four and a half minutes to move completely off the Sun's disk.

The mortal moon hath her eclipse endured
—*Shakespeare (Sonnet 107)*

On the night of May 15–16 a total lunar eclipse is visible from start to finish from eastern North America and from all of South America. In most of central Canada and the United States the eclipse is already under way when the Moon rises; over the Pacific Northwest and some parts of western Canada, the Moon rises entirely in the Earth's shadow. Observers in western Europe can see much of the event before moonset and dawn on May 16.

The Moon begins to enter the Earth's outer shadow, or penumbra, at 9:06 P.M. But the penumbra is so faint that it cannot be recognized until just before the Moon enters the Earth's dark central shadow, the umbra. By 9:55 P.M. the Moon appears distinctly smudged or soiled on its lower left edge, even to the most casual observer.

The umbra begins to nibble at the Moon's lower left-hand edge at 10:03 P.M., then slowly engulfs our satellite.

During the total phase the Moon does not usually disappear from view. Although the Earth blocks out all direct sunlight, Earth's atmosphere refracts some of the Sun's rays into the shadow. The blue light of the daytime sky is scattered, but the red light of sunrise and sunset is more penetrating and thus can still shine on the eclipsed Moon. As a result, during the total phase (from 11:14 P.M. until 12:07 A.M.) the Moon should not disappear, but should instead glow with an eerie, coppery hue.

The umbra appears to slide completely off the Moon by 1:18 A.M., and the last vestige of any shadow will probably disappear by 1:30 A.M., leaving the full Moon to shine brightly for the rest of the night (and perhaps give poets the light to work by).

Vain Venus rises in the east about an hour before the Sun, as it has all spring. But the lengthening morning twilight of late spring reduces the planet's visibility this month.

Mars rises in the southeast at about 2:00 A.M. local daylight time on the 1st, shining at zero magnitude. By the end of the month its rise comes more than an hour earlier, bringing it close to the meridian at sunrise. Its brightness at that point is −0.7.

Jupiter, crabby or not, is in the constellation Cancer, the crab. The brightest evening "star," it appears toward the west at sunset, fairly high in the sky, and sets in the west-northwest after midnight.

Saturn clings to the horizon in May. The planet remains low in the west-northwest at dusk early in the month; ultimately, evening twilight renders it invisible. Saturn crosses Orion's club at midmonth.

The Moon is new on the 1st at 8:15 A.M. It waxes to first quarter on the 9th at 7:53 A.M., reaches full on the 15th at 11:36 P.M., and wanes to last quarter on the 22nd at 8:31 P.M. The Moon becomes new again on the 31st at 12:20 A.M. On the same day a ring-shaped, or annular, eclipse of the Sun will be visible from central Greenland and from Iceland and northern Scotland.

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

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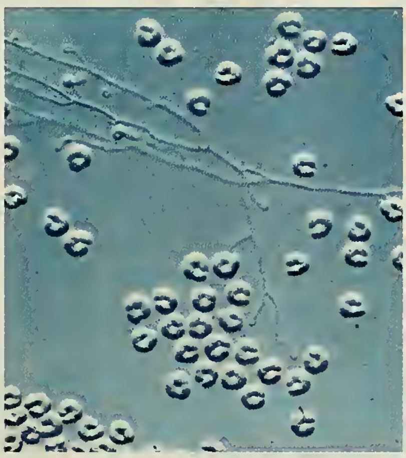
(Continued from page 26)
with nutrient. Both the large hyphae and the three-celled spores that bud from the hyphal ends seem well suited to being eaten, but not to dispersal.

In spite of their large, conspicuous shape, the spores were a mystery to us; none of our reference books on fungi were any help in identifying them. We sent our information and observations to Kris A. Pirozynski, a mycologist who is now retired from the Canadian Museum of Nature in Ottawa. When Pirozynski got our letter, he called us excitedly. The spores were *Delortia palmicola,* he said, but


Three-celled spores of Delortia palmicola

what kind of tree had the wood come from? Could the tree have been a palm? Several times, he told us, he had spotted dried and shriveled remnants of *Delortia* on dead palm trees in East Africa. The fungus, he felt sure, was associated with insects, but he had never found any insect associations himself.

Our observations, together with Pirozynski's identification, began to make sense. The Tiputini collection site was thick with palm trees, so our termites' log was probably from such a plant (unfortunately, the rotten log had been beyond identification ever since Wier first encountered it). The remnants of *D. palmicola* that Pirozynski had included in his East African fungal survey had probably been eaten by termites, too, even though the insects had done so out of his sight. Then, a routine observation that we overlooked at first suddenly stirred much more of our interest. We checked again several times by removing more hindguts. Our *Heterotermes*' swollen intestines always held wood-digesting protists and myriad bacteria, but we also spotted three-celled *Delortia* spores. Just to be sure, in the laboratory we transferred translucent fungal dots to a medium of cellulose-rich palm-tree extract. The spores that developed on those fungal hyphae were also those of *Delortia.*

Not only had the termites found a way to control the spread of dangerous fungi in their nests; apparently, the insects had also discovered that those fat fungal spores could be used as food.

It is easy to imagine what gave rise to such a state of affairs. Fungi and rain were an ever-present threat to the rainforest ancestors of our population of *H. tenuis*. Only those ancestral termites that could cope with inadvertently eating the fungal intruder would have survived. Perhaps the *Heterotermes* ancestors even derived some benefit from the fungus. *Delortia* might harbor cellulase, an enzyme that breaks down the cellulose in wood. If so, a *Heterotermes* termite that ate *Delortia* would get from the fungus both food—consumable nitrogen, carbon, and other nutrients—and cellulases, to help digest wood.

Yet there is no question that, despite the option for casual fungus farming, *H. tenuis* is a lower termite. The presence of certain species of wood-digesting, swimming protists inside *H. tenuis* is a sure sign that the protists digest wood that the termite eats. No doubt, like all of its many *Heterotermes* relatives, our Ecuadorean population can rely entirely on the nutrients digested by the protists. *Heterotermes* termites are not related directly to any of the Old World termites that depend on fungus farming for their food. Evolutionarily speaking, the association between fungus and termite in Ecuador must have begun quite recently.

Thus, we hypothesize, termite agriculture preceded termite cities. The antecedents to higher termites and their termitaria were protist-infested lower termites fighting off heavy rains and encroaching fungi. This defense prompted the growth of palatable dots—masses of fungal hyphae and their spores—on the surface of their resident logs. The activity of *H. tenuis* now makes it clear that termites developed the techniques of fungal culture before mound building evolved. And over time, fungi-tending termites lost their ability to host wood-eating protists. Eventually, some of those became, as the African *Macrotermes* have, completely dependent on their fungi for food.

Today's *H. tenuis* may not be on the road to becoming a protist-free, city-dwelling higher termite. Evolution, after all, is unpredictable in detail. But the insect's behavior in the face of flooding and luxuriant fungal growth must be remarkably similar to that of its Mesozoic ancestors, which did take such a route. Whether the Ecuadorean termites are only analogous, or genuinely homologous, to the lower termites that were the ancestors of the mound builders, we have no idea. But with the discovery of incipient farming in severely threatened *H. tenuis,* one pathway from lower to higher has been happily inferred.

Jessie Gunnard, a candidate for her Master's degree in the Department of Geosciences at the University of Massachusetts in Amherst, hopes to study next fall in the science writing diploma program at the University of California, Santa Cruz. Andrew Wier, a doctoral candidate at the University of Wisconsin–Milwaukee, collects and studies a variety of live bacteria near hot spring vents in Yellowstone Lake. This summer he will dive again in Yellowstone National Park. Lynn Margulis is Distinguished University Professor at the University of Massachusetts in Amherst, where she continues to work out her ideas on the evolution of nucleated cells by symbiosis nearly forty years after she first presented it to fellow biologists and geologists. She is a member of the National Academy of Sciences.

EXPLORER GUIDE

R. MICKENS/AMNH

Model of an octopus

Irma and Paul Milstein Family Hall of Ocean Life Reopens

One of New York City's grandest spaces, the Museum's beloved Hall of Ocean Life, reopens this May after a major renovation, its first in over 30 years. Current scientific research and cutting-edge exhibition technology have been combined with the restored Beaux-Arts elegance.

The 29,000-square-foot hall is still dominated by the famous blue whale, one of the Museum's star attractions, which now floats in a "virtual ocean" created through dramatic lighting, video, and sound effects that include whale songs. The 94-foot female—the largest model of the largest animal on Earth—has been modified to reflect current scientific knowledge of living blue whales. Above the whale, skylights gently illuminated by shimmering blue lights contribute to the illusion of being submerged in the depths of the sea.

ARNOLD IMAGING ©AMNH

Exhibition designers have fabricated over 600 new models, ranging from tiny green bubble algae to a 14-foot-long whale shark to computerized bioluminescent fishes and invertebrates. Joining the renovated ocean dioramas created in the 1930s and 1960s will be an 18 x 8-foot wall of video combining high-definition footage of undersea life, animations, graphics, and an evocative soundtrack that will transport visitors further into the heart of the ocean realm.

The classic dioramas on the lower level have been cleaned and restored, with new lighting brightening areas formerly obscured. In some cases, new backgrounds have been painted from sketches made in the field by exhibition staff. New exhibit text reflects the latest information about the elephant seals on Guadalupe Island, a school of leaping dolphins, and northern sea lions from Alaska's Pribiloff Island, to name just a few.

In particular, the spectacular Andros Coral Reef diorama, the only two-level diorama in North America, underwent a complete overhaul to enhance its visibility. The diorama's upper level, covered for the last 30 years, depicts life above the coral reef. It has been opened for display, repaired and restored, and now offers visitors a breathtaking complete view of the coral reef system below the ocean level and above, a perspective not possible in nature.

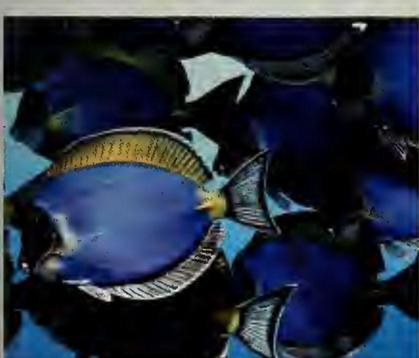
The mezzanine level of the hall now features new exhibits on the major ocean ecosystems, including estuaries, mangrove forests, the polar seas, continental shelves, coral reefs, kelp forests, the deep water column, and the deep-sea floor. High-definition video of the ecosystems shot on location around the world combines with explanatory text and newly handcrafted models alongside historical models to depict the tremendous diversity of the Earth's seas and the life therein.

Two new "Spectrum of Life" walls flank the entrance to the hall. They reinforce the idea that all life is connected through an intricate web of evolutionary and ecological relationships. One wall depicts vertebrate life including fishes, reptiles, and amphibians (and even a human), while the other showcases a profusion of invertebrates and plants. Interactive computer stations in front of each wall provide details about the biology and taxonomy of the organisms represented on the wall, as well as information about their "place" in the ocean.

Three of the Museum's classic dioramas depicting life in the oceans of the Ordovician, Permian, and Cretaceous periods—from 450 to 70 million years ago—have been meticulously restored to highlight the history of life in the primordial oceans. The exhibit features an ancient seafloor slab from the Jurassic Period containing the fossilized remains of a horseshoe crab and the tracks of its last journey. Special panels will showcase several fossil specimens, including cyanobacteria, the first-known life form to emerge in the sea 3.5 billion years ago.

Life on Earth emerged in the oceans and much of it stayed there—scientists estimate that 80 percent of all living organisms may live under water. Over 70 percent of the Earth is covered with water and yet very little is known about the complexity and diversity of life in the oceans. What is known, however, is that the oceans play a vital role in supporting life on Earth. The aim of the renovation of the Milstein Family Hall of Ocean Life is to open a window onto the spectacular ocean ecosystems, to bring current scientific knowledge about the oceans to the public, and to reveal the mysteries and diversity of this, Earth's final frontier.

The Milstein Family Hall of Ocean Life was designed, developed, and produced by the Museum's Exhibition Department. The lead curator is Melanie L. J. Stiassny, Axelrod Research Curator, Division of Vertebrate Zoology, working with a team of cocurators including Mark Siddall, Associate Curator, Division of Invertebrate Zoology; Paula M. Mikkelsen, Assistant Curator, Division of Invertebrate Zoology; Neil H. Landman, Curator, Division of Paleontology; and Robert S. Voss, Associate Curator, Division of Vertebrate Zoology.



R. MICKENS/AMNH

Models of powderblue surgeonfish in the Coral Reef ecosystem exhibit

Milsteins' Gift Makes New Hall a Reality

As dedicated supporters of educational initiatives throughout New York City, Irma and Paul Milstein have been involved with the American Museum of Natural History for over a decade, with Irma joining the Museum's Board of Trustees in 1995. Together, they have generously and enthusiastically supported a number of the Museum's special projects and campaigns as lead benefactors, including the Milstein Hall of Advanced Mammals; the Milstein Family Vertebrate Paleontology Moveable Museum, which some 80,000 children have visited since its launch in 1999; and most recently, the Irma and Paul Milstein Family Hall of Ocean Life.

The Milsteins appreciate the importance of educating people of all ages about the wonders, mysteries, and threats to our planet's oceans. "It has been a wonderfully satisfying experience for the whole family to be associated with the Museum, which we believe is one of New York City's most fabulous educational resources for children and adults. Paul, our 4 children, our 11 grandchildren, and I look forward to the Hall of Ocean Life's reopening and to seeing our planet's largest creature of all time—the blue whale—in its newly beautified home," said Irma Milstein. According to Museum President Ellen V. Futter, "With the help of Irma and Paul Milstein, the Museum was able to bring out the best in one of our most beloved treasures, enlivening the hall for millions of visitors today and for generations to come. The new Milstein Family Hall of Ocean Life places a spotlight on the critical role of ocean ecosystems in maintaining the balance of life on Earth, and educates the public about the last great frontier on Earth—the marine world. We are so very grateful to the Milsteins for enabling us to share the beauty, the science, and the majesty of our 'blue planet,' and for providing such a magnificent model for others who love the Museum."

D. FINNIN/AMNH

Irma and Paul Milstein (second from left and second from right) join Museum President Ellen V. Futter (center) and Vice Presidents David Harvey and Barbara Gunn in the hall.

A project of this magnitude would not have been possible without an extraordinary public-private partnership. The American Museum of Natural History wishes to acknowledge the following donors for enabling us to undertake the magnificent restoration and rejuvenation of the Milstein Family Hall of Ocean Life.

We are enormously grateful to lead benefactors Irma and Paul Milstein, long-standing friends and patrons of the Museum, whose spirited passion for education and our world's oceans launched this historic project.

The Museum gratefully acknowledges the important public support that has been provided by the City of New York, the New York City Council, the Department of Cultural Affairs, and the Borough President of Manhattan in the realization of this project.

The Museum deeply appreciates major support from Edwin Thorne and from Swiss Re.

Significant support also has been provided by The Marc Haas Foundation, Ruth Unterberg, MetLife Foundation, and Mikimoto.

Additional generous funding was provided by Jennifer Smith Huntley, Patricia Stryker Joseph, William H. Kearns Foundation, Denise R. Sobel and Norman K. Keller, Mrs. Frits Markus, Jane and James Moore, David Netto, Mrs. John Ungar, and the Bristol-Myers Squibb Foundation, Inc.

We are also grateful for the funding of educational programs provided by The Atlantic Philanthropies, The Bodman Foundation, and The Louis Calder Foundation.

MUSEUM EVENTS

EXHIBITIONS

Vietnam: Journeys of Body, Mind & Spirit

Through January 4, 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.

C. CHESEK/AMNH

Paper votive goods like these are burned for use by the dead.

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.*

Discovering Vietnam's Biodiversity

Through January 4, 2004
Akeley Gallery, second floor
This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.

KEVIN FREY/CBC,AMNH

Gold-throated barbet, Ngoc Linh, Vietnam

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

Einstein

Through August 10, 2003
Gallery 4, fourth floor
This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial and groundbreaking that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein *is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.*

The Butterfly Conservatory

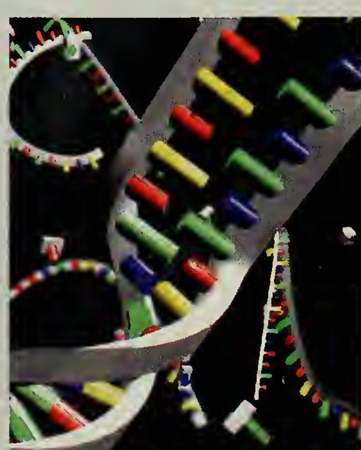
Through May 26, 2003
More than 500 live butterflies fly freely in an enclosed tropical habitat where visitors can mingle with them.

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

LECTURES AND DISCUSSIONS

James Watson on the Double Helix

Thursday, 5/1, 7:00 p.m.
Watson will speak about Francis Crick, the Human Genome Project, and the direction of current research on DNA.



The Fate of the Mammoth: Fossils, Myth, and History

Tuesday, 5/13, 7:00 p.m.
Claudine Cohen considers the history of paleontology through the study of the mammoth.

Vietnam: War and Memory

Wednesday, 5/14, 7:00 p.m.
Panelists share their memories and examine the ways in which the Vietnam War drives their current efforts.

Einstein Papers Project

Monday, 5/19, 7:30 p.m.
A panel discussion on one of the most important scholastic achievements of the 20th century, the publication of Albert Einstein's collected papers.

Vietnamese American Contemporary Arts Roundtable

Monday, 5/19, 7:00 p.m.
Artists present their work and discuss how their experiences as Vietnamese Americans have affected it.

Exposing the Deep: Technology and the Art of Underwater Photography

Thursday, 5/29, 7:00 p.m.
Spectacular 3-D photographs of underwater scenes.

Experience the sights and sounds of a bustling

Vietnamese Marketplace

at the Museum, throughout the run of the *Vietnam* exhibition. Sample traditional foods and take home a one-of-a-kind handicraft.

77TH STREET LOBBY, FIRST FLOOR

THE CONTENTS OF THESE PAGES ARE PROVIDED TO *NATURAL HISTORY* BY THE AMERICAN MUSEUM OF NATURAL HISTORY.

FILM SCREENING

The Deserted Valley
Saturday, 5/10, 2:00 p.m.
(In Vietnamese with English subtitles)
Stunning cinematography paired with minimal dialogue eloquently depicts this universal story set in a remote village in Vietnam's highlands. Post-screening discussion.

PERFORMANCES

Starry Nights
Friday, 5/2, 5:30 and 7:00 p.m.
Dave Stryker and Blue to the Bone

ArtSynergy: Finding Connections through Music
Saturday, 5/3, 7:00 p.m.
New works from Kimo Williams and Nguyen Van Nam, followed by a discussion.

Nguyen Dinh Nghia and Family
Sunday, 5/11, 1:30 or 3:30 p.m.
Traditional Vietnamese music.

SPECIAL PROGRAM

Whale Watch 2003
Friday–Sunday, 5/16–18
A weekend expedition with naturalists and educators.

CHILDREN'S PROGRAMS

Paper-Making Workshop
Saturday, 5/10, 12:00 or 3:30 p.m.
(Ages 8 and up)

Journey through the Solar System
Sunday, 5/11, 12:00–1:30 or 2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Solar System Adventures
Saturday, 5/17, 1:00–2:30 p.m.
(Ages 7–9)

Undersea Neighbors
Sunday, 5/18, 10:30–11:30 a.m.
(Ages 6–7)

I Want to Be an Astronaut
Sunday, 5/18, 12:00–1:30 p.m.
(Ages 4–6, each child with one adult)

Fly Me to the Moon
Sunday, 5/18, 2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Astronaut Susan J. Helms aboard the International Space Station

Humans in Space
Saturday, 5/24, 1:00–3:00 p.m.
(Ages 10–12)

Space Explorers
Eclipses of the Sun and Moon
Tuesday, 5/13, 4:30–5:45 p.m.
(Ages 12 and up)

HAYDEN PLANETARIUM PROGRAMS

Mapping the Universe
Monday, 5/12, 7:30 p.m.
With Brent Tully, Institute for Astronomy, University of Hawaii.

Celestial Highlights
Tuesday, 5/27, 6:30–7:30 p.m.
Find out what's happening in the June sky.

SPACE SHOWS

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

Passport to the Universe
Narrated by Tom Hanks

Look Up!
Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6 and under)

LARGE-FORMAT FILMS

In the Samuel J. and Ethel LeFrak IMAX® Theater

Coral Reef Adventure
A fantastic underwater journey to document some of the world's largest and most beautiful—and most threatened—reefs.

Pulse: a STOMP Odyssey
Take a rhythmic voyage of discovery around the world of percussion and movement.

INFORMATION

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

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 8:00 a.m.–5:00 p.m., and Saturday, 10:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.

All programs are subject to change.

Of Mice and Masai

By Richard Milner

After several pairs of house mice determined that my Manhattan flat was a suitable place to raise their families, they gleefully moved in. Rather than scurry furtively along baseboards or hide out until the dead of night, they chased one another in afternoon courtship on my kitchen floor, then brazenly danced up to the table to forage for crumbs. I thought of hantavirus and the Black Plague, yet my first inclinations were kindly: I bought "humane" box traps to capture and relocate my unwanted guests. The next day I found that the mice had taken my bait but had managed not to get humanely caught.

Inevitably, though, the squeals and pitter-patter of the burgeoning rodent families increased, and I gave in. Reluctantly, I purchased some deadly spring traps "baited" with yellow bits of perforated plastic. None of my little roommates fell for the faux Swiss cheese; the mice went on dancing, dancing, dancing. . . .


Game board, circa 1885

Next I bought glue traps, resolving to conk the critters as soon as they were caught. (A slow death in a glue trap, I earnestly believe, should disturb any thinking, feeling person.) I thought of Tom and Jerry, Mickey Mouse, Stuart Little, and Robert Burns's line about "the best laid schemes o' mice and men." Guiltily, I set out the dreadful glue traps, along with a few spring traps for good measure, and went to bed.

Later that night I was awakened by a knock on the door. Two Masai gentlemen stood at my threshold, dressed in their traditional robes.

"*Jambo,*" said one. "Hello. We beg your pardon for the intrusion, sir, but we understand that you are killing animals here."

"What business is that of yours?" I bristled. "You live a world away."

"Yes, sir, but we have come on an urgent mission, to show you how to live with your mice."

"First of all, they're not *my* mice," I replied testily. "I did not invite them. They disturb my sleep, they invade my space, they even defecate near my food. Disgusting. If I don't stop them, they will continue to propagate, carry in fleas and disease, and displace me from my home."

"*Rafiki,*" said the other one. "We come as friends. Your people have been visiting Africa for years, teaching us that we must live with our wild animals, that killing them is not always the correct answer.

"Now we are returning the favor. If you are bothered by squeaks and footfalls in the night, remember that my family must listen to hungry lions roaring nearby at midnight. And believe me, sir, you don't know what it is to have your food soiled until an elephant has relieved himself on your vegetable garden."

Suddenly, he pulled a small video camera from the wide pocket of his robe.

"Do you mind, sir, if I place a bit of cheese on the counter, so I can try to get a sequence of your mice? Most folks back home have never seen the New York City rodents, which are world famous, so I'm making a documentary."

"Look, Otwani," said the other excitedly, pointing to the window. "It's a rock dove, what the locals call a pigeon, just there on that ledge."

The two of them rushed to the window. "My gosh," one shrieked, "I don't believe it—squirrels!" And with that, both ran out of the place, slamming the door behind them. WHAM!

I woke up. One of the traps had sprung.

Richard Milner is an associate in anthropology at the American Museum of Natural History and a contributing editor of this magazine.

Restful Sleep Technology

Get in the zone with the mattress topper that molds to your body's contours

The Memory Foam Ultra mattress topper is cut into a grid pattern combining six different zones for variable support, and a better night's sleep.

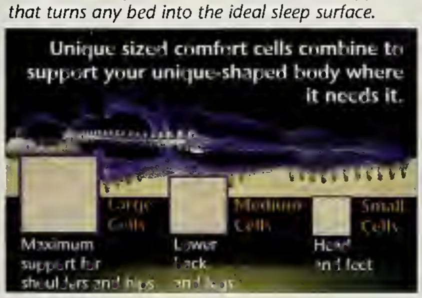
The 2-inch thick temperature-smart foam adjusts to your shape.

It's 3 a.m. You have exactly two hours until you have to get up for work, and you still can't seem to fall asleep. At this point, the phrase "tossing and turning" begins to take on a whole new meaning for people whose mattresses simply aren't giving proper support anymore. Your mattress may dictate your quality of sleep. Even if you merely suspect that your mattress may be outdated, that's when you need to take action. Some mattresses fail to support your spine properly, which can result in increased pressure on certain parts of your body. Other mattresses, sporting certain degrees of visco-elastic foam, can sometimes cost you well over $1000. Now, one of the world's leading manufacturers of foam products has developed an incredibly affordable mattress topper that can actually change the way you sleep. Introducing the future of a better night's sleep: The Memory Foam Ultra Mattress Topper.

Wake up to a better morning. The Memory Foam Ultra mattress topper is designed to give you a better sleep surface. Not only does it support each region of your body, but it's also temperature sensitive. With its various-sized "comfort cells," the 2-inch thick Memory Foam Ultra mattress topper combines six zones to support specific body area weight, which promotes a better night's sleep. The largest cells support your lower back and midsection, while the medium-sized cells support the shoulders, lower back and legs. The smallest cells support your head and feet. Combined, these zones provide variable support from head to toe. By using visco-elastic foam, the Memory Foam Ultra mattress topper also molds to your body contours to help prevent tossing and turning during the night. When you lie down on this amazing material, the heat and pressure sensitive foam reacts to your body's weight and temperature, so that it molds to your exact body shape. This means that whether you sleep on your back, stomach or side, your weight is evenly distributed and your spine remains in a neutral position. Other surfaces support your body at the shoulders, hips and legs only. This causes your spine to sag in other areas, which can often result in discomfort, and even back pain. You'll wake up rested, relaxed and ready to take on the day. Anyone who suffers from insomnia and back pain can benefit from this technology.

What could be wrong with your present bed?

The ideal position is a neutral body posture in which the different parts of the human body are supported individually and evenly. This is the secret behind Memory Foam Ultra, the mattress topper that turns any bed into the ideal sleep surface.



FREE heavyweight mattress pad included. Included with the Memory Foam Ultra mattress topper is a fitted mattress pad. It's heavyweight and quilted, and made of 200-count 100% cotton with a 15-inch deep fitted spandex skirt to fit a mattress up to 21 inches thick. The size of the mattress pad is determined by the size mattress topper you order.

Try it for yourself today! The Memory Foam Ultra mattress topper can change the way you sleep. Promote proper spine positioning, while enjoying relief from insomnia and back pain with this full-body support. It comes with a five-year manufacturer's limited warranty and TechnoScout's exclusive in-home trial. If you are not completely satisfied, simply return it within 30 days for the full purchase price, less shipping and handling.

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