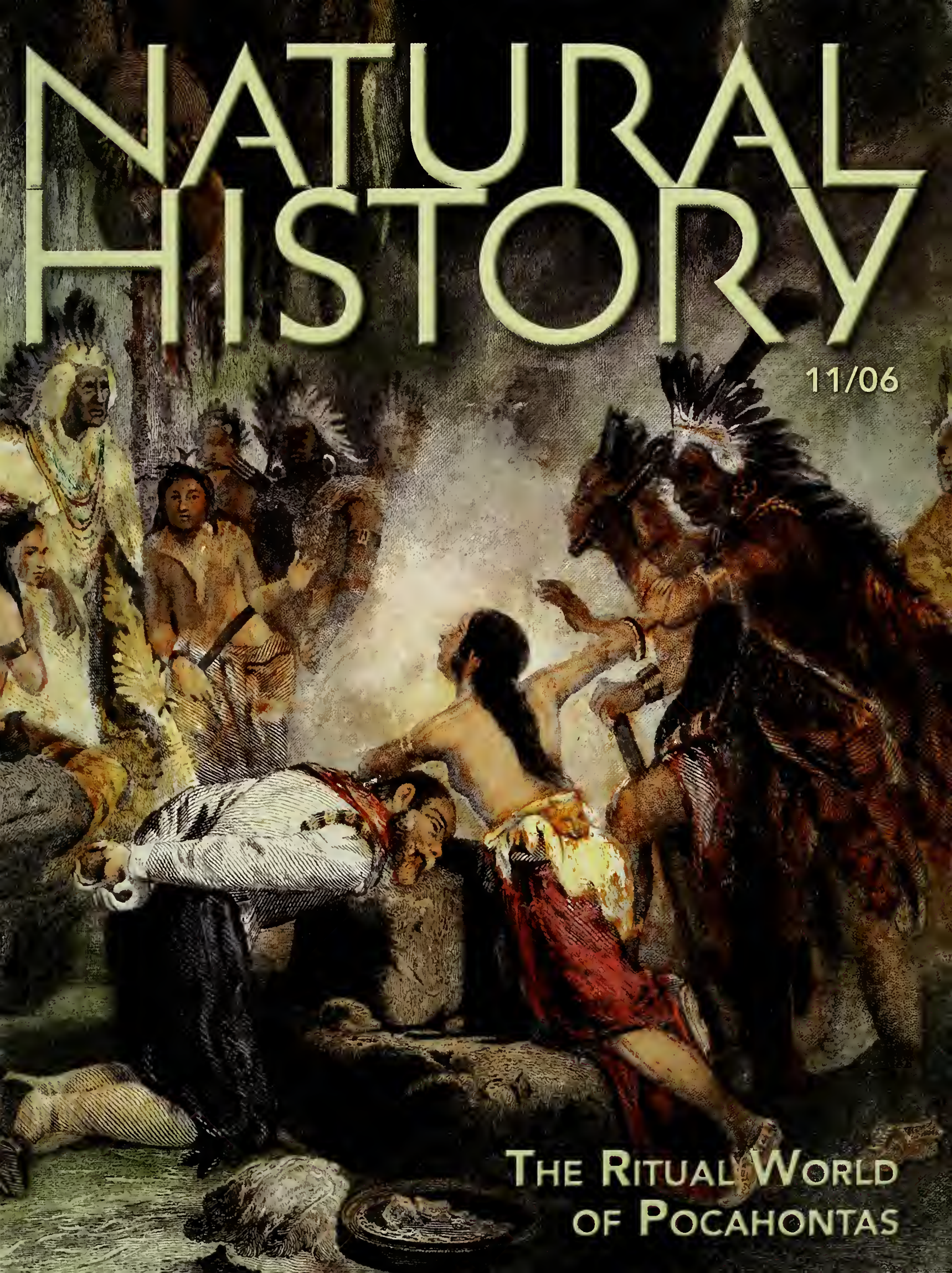
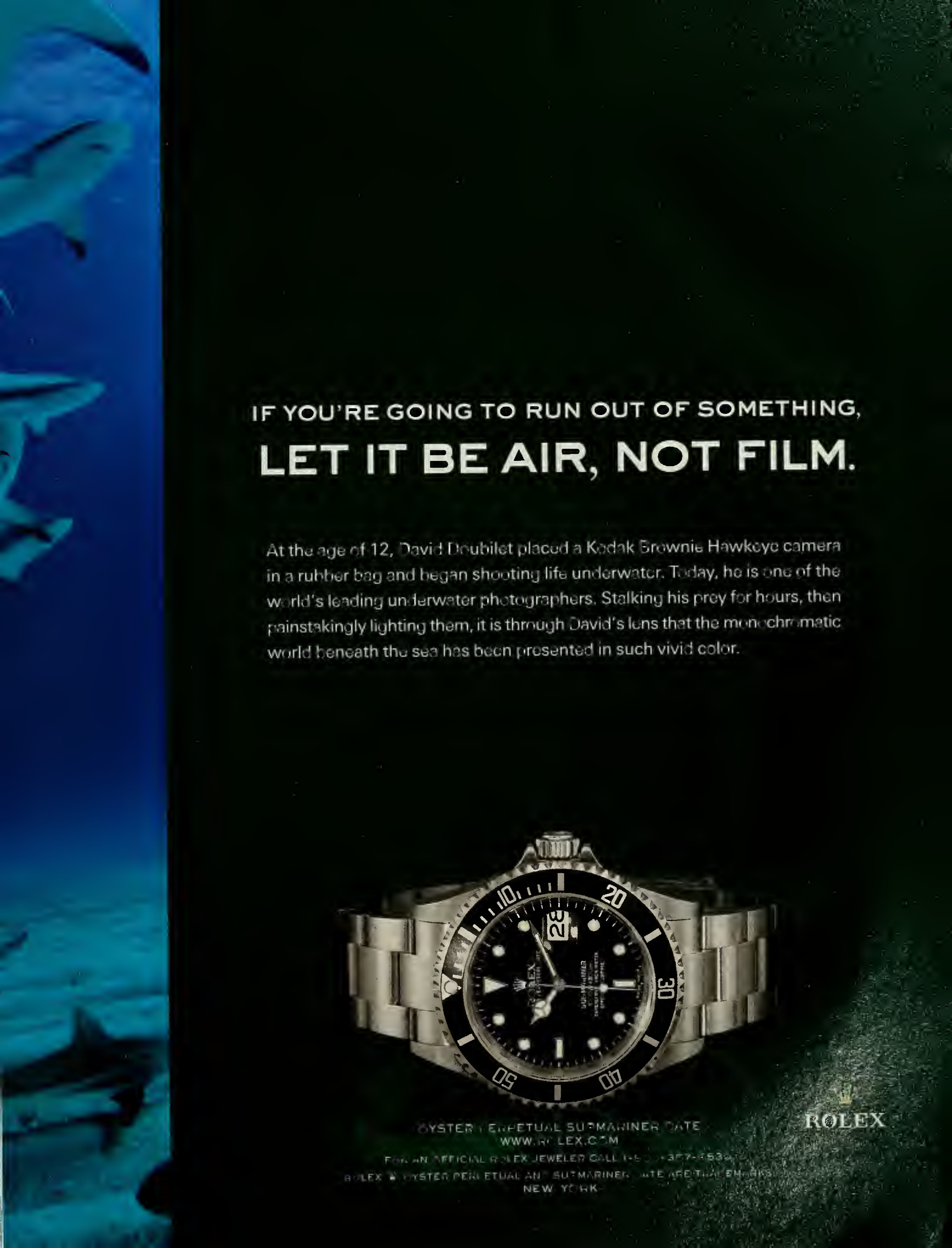
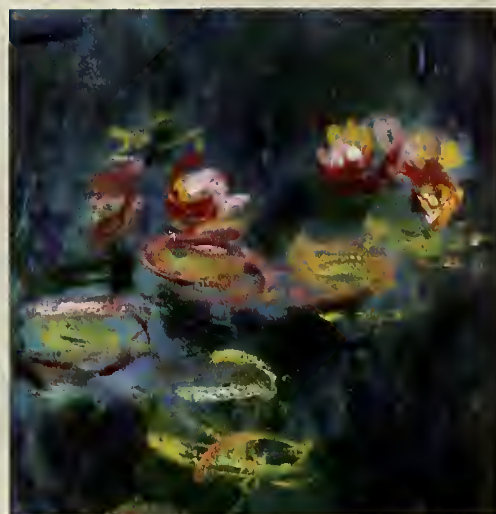

NATURAL HISTORY
11/06
THE RITUAL WORLD
OF POCAHONTAS


IF YOU'RE GOING TO RUN OUT OF SOMETHING,
LET IT BE AIR, NOT FILM.
At the age of 12, David Doubilet placed a Kodak Brownie Hawkeye camera in a rubber bag and began shooting life underwater. Today, he is one of the world's leading underwater photographers. Stalking his prey for hours, then painstakingly lighting them, it is through David's lens that the monochromatic world beneath the sea has been presented in such vivid color.
ROLEX
OYSTER PERPETUAL SUBMARINER DATE
WWW.ROLEX.COM
FOR AN OFFICIAL ROLEX JEWELER CALL
ROLEX, OYSTER PERPETUAL AND SUBMARINER DATE ARE TRADEMARKS.
NEW YORK
ROLEX

NATURAL HISTORY

NOVEMBER 2006 VOLUME 115 NUMBER 9

FEATURES



ON THE COVER:
Pocahontas saving the life of Captain John Smith. Steel engraving, circa 1870, after a painting by Alonzo Chappel

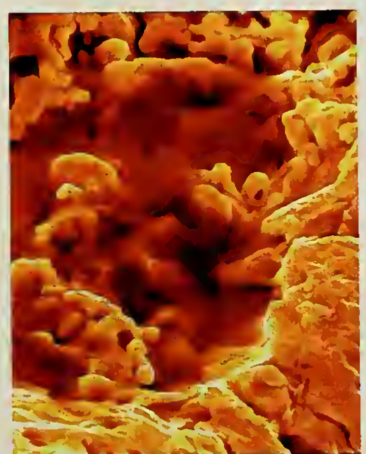
NATURAL HISTORY

21

62

DEPARTMENTS

6

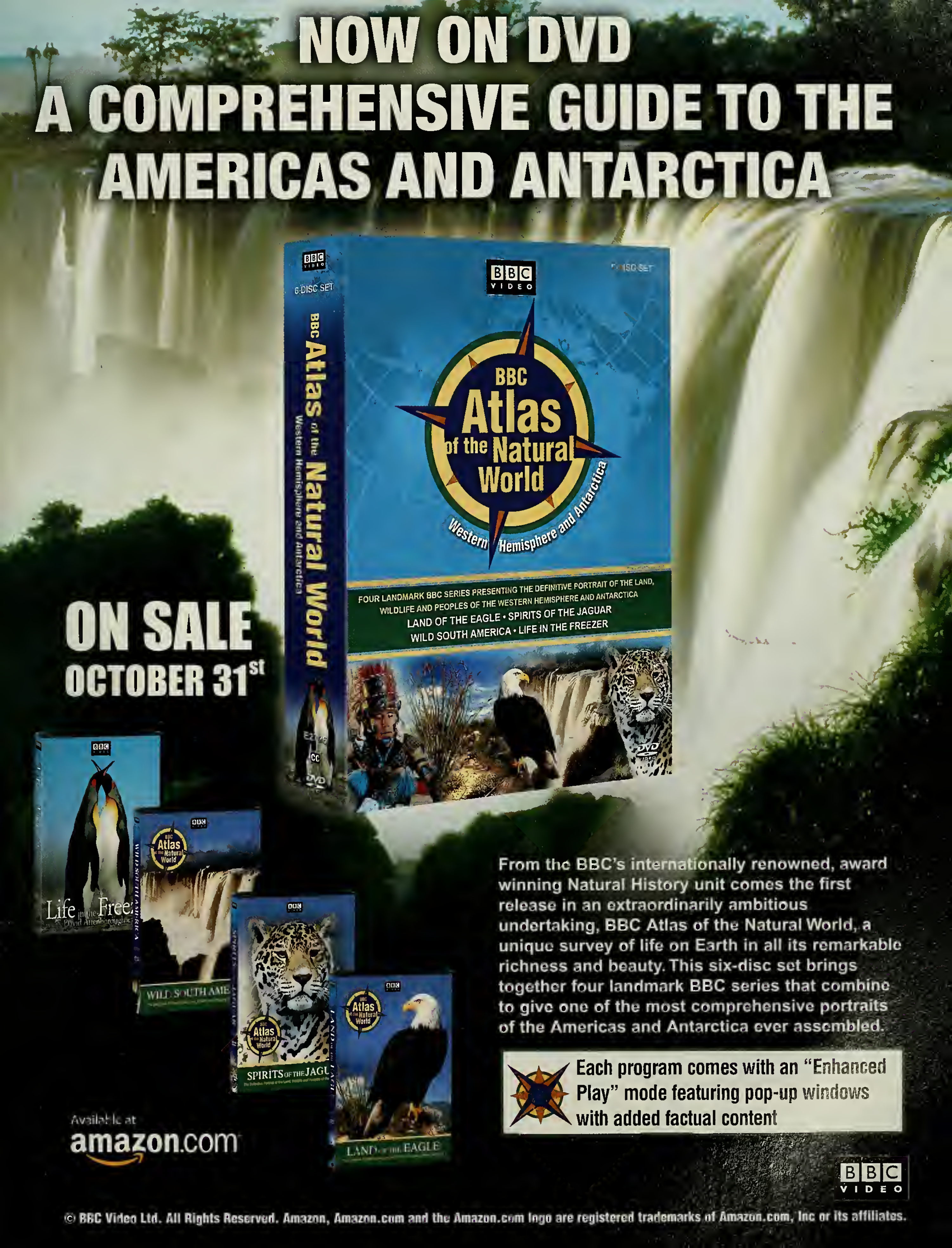


14

60

PICTURE CREDITS: Page 65

Visit our Web site at www.naturalhistorymag.com



NOW ON DVD
A COMPREHENSIVE GUIDE TO THE AMERICAS AND ANTARCTICA
BBC VIDEO
6-DISC SET
BBC Atlas of the Natural World
Western Hemisphere and Antarctica
FOUR LANDMARK BBC SERIES PRESENTING THE DEFINITIVE PORTRAIT OF THE LAND, WILDLIFE AND PEOPLES OF THE WESTERN HEMISPHERE AND ANTARCTICA
LAND OF THE EAGLE • SPIRITS OF THE JAGUAR
WILD SOUTH AMERICA • LIFE IN THE FREEZER
ON SALE
OCTOBER 31st
Life in the Freez
WILD SOUTH AME
SPIRITS OF THE JAGU
LAND OF THE EAGLE
From the BBC's internationally renowned, award winning Natural History unit comes the first release in an extraordinarily ambitious undertaking, BBC Atlas of the Natural World, a unique survey of life on Earth in all its remarkable richness and beauty. This six-disc set brings together four landmark BBC series that combine to give one of the most comprehensive portraits of the Americas and Antarctica ever assembled.
Each program comes with an "Enhanced Play" mode featuring pop-up windows with added factual content
Available at
amazon.com
BBC VIDEO
© BBC Video Ltd. All Rights Reserved. Amazon, Amazon.com and the Amazon.com logo are registered trademarks of Amazon.com, Inc or its affiliates.

Turning the Tables

Photograph by Staffan Widstrand

◄ *See preceding two pages*

Scavengers vie for elbow room around a carcass in Staffan Widstrand's photograph of what seems an irresistibly sweet role-reversal as the holidays approach: a meal in which the birds pick the meat from a mammal. Here several birds feast competitively on a roe deer. The largest of the scroungers is a sea eagle, also known as a white-tailed eagle. With a wingspan of more than seven feet, the bird dominates the gathering. Several hooded crows cautiously look to obtain a share. Occasionally one of them resorts to nipping the sea eagle's tail feathers, distracting the large bird just long enough for some of the other half-pints to edge in for a taste.

Widstrand observed the dinner drama not far from the Norwegian Sea, near Flatanger, Norway. The carcass had been roadkill, pulled aside to provide the sea eagles with some extra food (and allow observers to watch from a nearby blind). Pollutant-contaminated prey drove the birds' already small population to dangerously low levels in the 1970s. Now, thanks in part to such feeding supplements, breeding pairs are on the rise in Europe. This past May a pair was found nesting in the Netherlands—a celebrated first in the country's history.

The sea eagle that Widstrand photographed was a two-year-old juvenile. The youngster should soon show signs of maturity: choosing a lifelong mate, growing a full head of pale feathers, and catching more of its food on the fly—though it will never outgrow its taste for stuffing itself with carrion.

—*Erin Espelie*

UP FRONT

Changing Times

The story of Captain John Smith's capture by the Powhatan Indians in December 1607 and his subsequent rescue by the Powhatan chief's daughter Pocahontas is the iconic event in Year One of Jamestown, the first permanent English colony in what was to become the United States. With the approaching 400th anniversary of the founding of Jamestown, we asked Frederic W. Gleach, a Cornell University anthropologist, to take a close look at that colorful episode.

Many layers of fairly innocent mythmaking and romanticizing have accumulated around the original historical event, but Gleach documents a much more fundamental misunderstanding. According to Gleach's research (see "The Ritual World of Pocahontas," page 40), the "rescue" was misinterpreted from the very beginning. Smith's capture, rescue, and release were actually part of an elaborate ritual and a sophisticated exercise in tribal statecraft, all intended to incorporate the English colony within the Powhatan Confederation of local Indian tribes.

• • •

Life is short. Yet life goes on. Can scientific theory and observation make any meaningful additions to either one of those aphorisms? In fact, questions about the rate of evolutionary change, not to mention the pace and span of individual lives, are being addressed in surprisingly detailed, if provisional, ways.

In "Sex among the Flowers" (page 48), William E. Friedman reports on recent fossil finds and genetic breakthroughs in botany that have rewritten the history of the rise and early evolution of flowering plants. Among the most important innovations of the flowering plants were their experiments with various kinds of chromosomal fusion—in short, with sex. Does sex explain what Darwin called the "abominable mystery" of their explosive evolution or their blooming diversity today? There's good reason to think so, but much more to be learned.

Two other stories in this month's issue complement each other in describing how forces great and small constrain the pace of life. Robert L. Jaffe ("Times of Our Lives," page 26) provocatively explores how the expanding quantity of "dark energy" and the weakness of gravity have helped determine when life could evolve in the universe, and even how long an individual life can last. John Tyler Bonner ("Matters of Size," page 54) puts flesh on Jaffe's bare-bones arguments about life span. Gravity affects an organism's size and shape, for instance, and those in turn affect its metabolic rate, in part because of the diffusion rate of gases. The bottom line: if you're *grande,* like an elephant, rather than *chiquito,* like a mouse, you're likely to compensate by slowing down.

• • •

The importance of global warming to the fate of our planet is fundamental, and so this month we're introducing into our news pages the first of an occasional roundup of scientific studies that bear on the topic (see "Samplings: The Warming Earth," page 18). The stories this month, and no doubt in the months to come, show how pervasive and unpredictable are the consequences of the changing planetary climate.

—Peter Brown

CONTRIBUTORS

Photographer and writer **STAFFAN WIDSTRAND** ("The Natural Moment," page 6) lives in Jarfalla, Sweden, just north of Stockholm, but his picture of a feasting sea eagle was captured on the Norwegian coast of the Scandinavian Peninsula. Widstrand has won ten prizes in the BG/BBC Wildlife Photographer of the Year competition. Two books he has co-authored are available in English: *Eco-Touring: The Ultimate Guide* (Firefly Books, 1997) and *The Big Five* (Bokförlaget Max Ström, 2002). A selection of his images can be viewed on his Web site (www.staffanwidstrand.se).

How Native Americans perceived and interacted with Europeans shortly after the first contact, as well as how they have since maintained their ethnic identity are prime research interests of **FREDERIC W. GLEACH** ("The Ritual World of Pocahontas," page 40). Initially trained as an anthropological archaeologist, Gleach emphasizes visual and material culture and the use of archival sources in his research. His most extensive work has been on the Powhatans of Virginia, but he also pursues similar investigations in Puerto Rico and in Alaska. He earned his Ph.D. from the University of Chicago, and he is a senior lecturer and curator of the anthropology collections at Cornell University. Gleach is the author of *Powhatan's World and Colonial Virginia: A Conflict of Cultures* (University of Nebraska Press, 1997) and founding co-editor of *Histories of Anthropology Annual,* also published by the University of Nebraska Press. His current projects include documenting the silversmiths of Ithaca, New York, and the life of the legendary Latina performer Diosa Costello.

WILLIAM E. FRIEDMAN ("Sex among the Flowers," page 48) has spent twenty-five years pondering Darwin's "abominable mystery"—the broad and rapid diversification of flowering plants since they appeared 130 million years ago. Friedman earned his Ph.D. in botany at the University of California, Berkeley, and he teaches ecology and evolutionary biology at the University of Colorado, Boulder. He is also the principal investigator of a National Science Foundation Research Coordination Network called MORPH (Molecular and Organismic Research in Plant History). Friedman has lectured worldwide on topics ranging from the evolutionary history of photosynthetic life to the history of evolutionary thought before Charles Darwin.

"Implicit in most of my writings," says biologist **JOHN TYLER BONNER** ("Matters of Size," page 54), "is the role of size in biology." In fact, he wrote on that very subject for *Natural History* back in January 1969. In this issue he summarizes many years of additional thought on the basic subject of biological size. Bonner earned his Ph.D. at Harvard in 1947, then moved to Princeton, where he has remained throughout his career. He is now a professor emeritus. His research has taken two main directions. One has been to do experimental work on the developmental biology of the social amoebas known as cellular slime molds. The second has been to examine some of the grander themes of biology, writing books on such topics as the development of form, the evolution of complexity, the evolution of multicellularity, and the evolution of culture. His essay in this issue is adapted from his recent book, *Why Size Matters: From Bacteria to Blue Whales,* which is being published this month by Princeton University Press.

NATURAL HISTORY

PETER BROWN *Editor-in-Chief*

Mary Beth Aberlin *Executive Editor*
Steven R. Black *Art Director*

Board of Editors
Erin Espelie, Rebecca Kessler, Mary Knight, Vittorio Maestro, Dolly Setton

Geoffrey Wowk *Assistant Art Director*
Graciela Flores *Editor-at-Large*

Contributing Editors
Robert Anderson, Avis Lang, Charles Liu, Laurence A. Marschall, Richard Milner, Robert H. Mohlenbrock, Joe Rao, Stéphan Reebs, Judy A. Rice, Adam Summers, Neil deGrasse Tyson

CHARLES E. HARRIS *Publisher*

Edgar L. Harrison *Advertising Director*
Maria Volpe *Promotion Director*
Sonia W. Paratore *National Advertising Manager*
Rachel Swartwout *Advertising Services Manager*
Meredith Miller *Production Manager*
Michael Shectman *Fulfillment Manager*

For advertising information call 646-356-6508

Advertising Sales Representatives
Detroit—Barron Media Sales, LLC, 313-268-3996
Chicago—Robert Purdy & Associates, 312-726-7800
West Coast—On Course Media Sales, 310-710-7414; Peter Scott & Associates, 415-421-7950
Toronto—American Publishers Representatives Ltd., 416-363-1388
Atlanta and Miami—Rickles and Co., 770-664-4567
South America—Netcorp Media, 51-1-222-8038
National Direct Response—Smyth Media Group, 914-693-8700

TODD HAPPER *Vice President, Science Education*

Educational Advisory Board
Myles Gordon *American Museum of Natural History*
David Chesebrough *COSI Columbus*
Stephanie Ratcliffe *Natural History Museum of the Adirondacks*
Ronen Mir *SciTech Hands On Museum*
Carol Valenta *St. Louis Science Center*

NATURAL HISTORY MAGAZINE, INC.
CHARLES E. HARRIS *President, Chief Executive Officer*
JUDY BULLER *General Manager*
CECILE WASHINGTON *General Manager*
CHARLES RODIN *Publishing Advisor*

To contact us regarding your subscription, to order a new subscription, or to change your address, please visit our Web site www.naturalhistorymag.com or write to us at

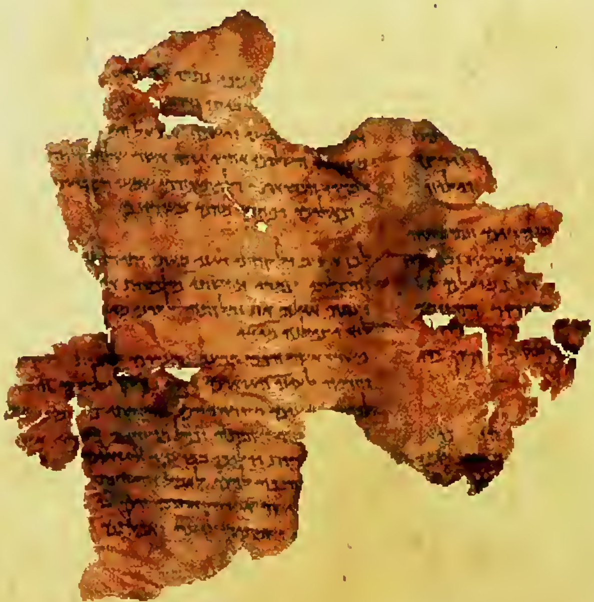
Natural History
P.O. Box 5000, Harlan, IA 51593-0257.

Natural History (ISSN 0028-0712) is published monthly, except for combined issues in July/August and December/January, by Natural History Magazine, Inc., in affiliation with the American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024. E-mail: nhmag@naturalhistorymag.com. Natural History Magazine, Inc., is solely responsible for editorial content and publishing practices. Subscriptions: $30.00 a year; for Canada and all other countries: $40.00 a year. Periodicals postage paid at New York, NY, and at additional mailing offices. Canada Publications Mail No. 40030827.

If you would like to contact us regarding your subscription or to enter a new subscription, please write to us at Natural History, P.O. Box 5000, Harlan, IA 51593-0257. Postmaster: Send address changes to *Natural History*, P.O. Box 5000, Harlan, IA 51537-5000. Printed in the U.S.A.

Hidden for over 2000 years.

You have 105 days to discover them.



DISCOVERING

THE DEAD SEA SCROLLS

SEPTEMBER 23, 2006 – JANUARY 7, 2007

DISCOVER

PACIFIC SCIENCE CENTER

ISRAEL ANTIQUITIES AUTHORITY רשות העתיקות

TRACING ANCIENT HISTORY THROUGH MODERN SCIENCE.

Advance tickets recommended, on sale now at pacificsciencecenter.org 877-DSS-1947

Discover the legendary Dead Sea Scrolls for yourself—including fragments never before displayed in public. Explore their history, spiritual impact and the science behind it all. Few in the world have this chance. You have 105 days. At Pacific Science Center in Seattle.

Curated by the Israel Antiquities Authority, this exhibit was developed in cooperation with Discovery Place and is presented in association with The Dead Sea Scrolls Foundation. This exhibition is supported by an indemnity from the Federal Council on the Arts and the Humanities; and is co-sponsored by the Mayor's Office of Arts & Cultural Affairs, City of Seattle; King County; the Washington State Department of Community, Trade and Economic Development; Ginger and Barry Ackerley; and Martin Selig. Photos courtesy of Israel Antiquities Authority.

KONG AM630 KCIS SPIRIT 105.3 Seattle Post-Intelligencer The Seattle Times

Crikey!

I thought of Steve Irwin, the legendary Australian "Crocodile Hunter" who was killed tragically this past September, when I saw the photograph of a crocodile snapping at a wildebeest ["Wildebeests of the Serengeti," by Richard D. Estes," 9/06].

Irwin had a strong passion for what he did, and he showed it. He was a superhero, performing feats above and beyond those of normal mortals. Because of him, those of us who watched his films and videos were able to get close and personal with dangerous animals. We learned about them through his adventures and his eyes. I used to think he was playing Russian roulette with the dangerous creatures he encountered, but I tried to think that nothing bad would ever happen to him. That was not to be.

But, Steve Irwin, you will always be remembered for your incredible legacy.

Paul Dale Roberts
Elk Grove, California

THE EDITORS REPLY: We too were shocked and saddened by the sudden loss. Whenever we meet up with a "gnarly little Sheila," we'll still wonder, What would Steve have done? He will be missed.

Do Biologists Count?

It seems that the success of a group of organisms is customarily measured by number of species—rather than individuals. Thus Laurie J. Vitt and Eric R. Pianka ["The Scaly Ones," 7/06–8/06] say: "In terms of extant species, scleroglossans outnumber iguanians 4.5 to 1." They give no population numbers.

Naively, one might think that if a species remains numerous for a long time without splitting, it must be well adapted to its niche. Could it be that biologists, at times, just cannot count individuals as readily as they can species?

Guy Ottewell
Uplyme, Dorset
United Kingdom

Drink up boys, before the Health Department closes the lid on this joint.

LAURIE J. VITT AND ERIC R. PIANKA REPLY: Guy Ottewell has posed an interesting question, and it has several answers, each equally valid. Evolutionary biologists often speak of "success" in terms of diversification, that is, the number of species ultimately generated. At a local level, however, such as a single place in a rainforest or desert, each species is "successful" ecologically to the extent that it has managed to survive through time within the assemblage of other species with which it competes and interacts.

Counting individuals can be extremely difficult. More to the point, perhaps, the densities of species (that is, the number of individuals per unit area) vary considerably from species to species, and the reasons for the variations are complex. For example, top-order predators (lions, white sharks, Komodo dragons) are less abundant than their prey. Large species (elephants, anacondas) are usually much less abundant (low density) than small species (rodents, side-blotched lizards). So "success" depends on one's perspective.

Mate Swap

The story by Robert B. Payne and Michael D. Sorenson ["Song Lines," 9/06] prompts me to write for clarification. Even before Konrad Lorenz's studies, bird breeders and falconers were aware of the role of imprinting in mate selection. In the case of birds, as I understand it, the early and persistent presence of a parental figure later becomes the chick's image of a suitable "mating partner." Hence birds raised by people (raptor chicks by falconers, for instance) may imprint on their keepers and later attempt to mate with them. Indeed, at least some bird species do just that—on hats worn by their custodians, specially designed to collect bird semen for artificial insemination.

In the case of surrogate parenting, such as the indigobirds raised by firefinches that Messrs. Payne and Sorenson describe, why don't the "parasitic" chicks fully imprint on the host species and, as adults, attempt to mate with its adult members? If they did so, of course, they would be equivalent to sterile individuals, which would put an evolutionary end to the "parasitic" behavior.

In his article about blackcaps in the same issue ["Change in the Air," 9/06], Stuart Bearhop suggests some level of imprinting, in the form of changed mating songs. Is imprinting in songbirds different from imprinting in other birds, so that it is expressed (mainly?) as songs in the former, and as visual cues in the latter?

Leo Salas
Roseburg, Oregon

ROBERT B. PAYNE REPLIES: Indigobirds do learn the songs of the species that act as their foster parents, and female indigobirds lay their eggs in the nests of the foster species on which they imprint. Those two behaviors are only part of the behavioral repertoire of recognition and mate selection in indigobirds. They are, however, the behaviors that count when indigobirds switch from an old host species to a new one.

Mate choice by female indigobirds in nature also depends on the responses of the males. In courtship, male indigobirds do a hovering display in the air, in front of a female. For their part, the males are not very choosy, and a male sometimes courts other species of indigobirds or even other kinds of birds that happen to visit the tree where the male is singing. Birds of other species ignore the displaying male, or fly away, rather than taking the next step that might lead to mating.

Female indigobirds are attracted to songs of their host species, typically a firefinch, no matter whether the singer is a firefinch or another indigobird that is mimicking the songs of the species of her foster parents. When a female indigobird is attracted by the singing of a male firefinch, she shows no sexual interest in him, nor he in her. She does watch the firefinch, though, and sometimes that is how she finds a firefinch nest where she can lay her egg. When she is attracted to a male indigobird that is mimicking a firefinch, she lets him strut his display, and then often flies to one or more other males with the same set of songs, comparing them as potential mates. Finally she chooses one male and returns to him to mate.

Because all male indigobirds make the same courtship displays, the female's choice is based largely on the differences in the males' songs. Although the songs that mimic the songs of her own foster species may be the most important factor in her choice, the male's performance of nonmimicking songs can also be attractive. In the field, my colleagues and I have even observed a few males (about 1 percent), probably raised by a host species other than the host species that parented the female, that were mimicking the songs of their own host species. Yet some females found them attractive.

In sum, a female picks her mate not only for his song mimicry, but also because she probably has some sense of what she is looking for in "Mr. Right"—good looks, good displays, and a good choice of tree to sing in.

Natural History *welcomes correspondence from readers. Letters should be sent via e-mail to* nhmag@naturalhistorymag.com *or by fax to 646-356-6511. All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

Sexy Necks

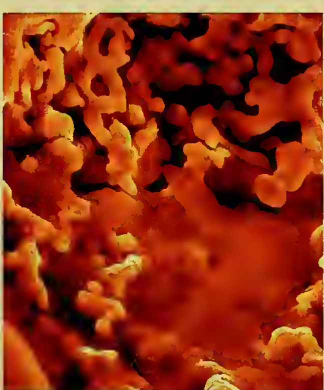
Museums around the world display fossil sauropod dinosaurs—*Diplodocus, Apatosaurus,* and others—with heads held proudly aloft on seemingly endless necks. It's easy to imagine the gigantic creatures reaching up to munch vegetation in the treetops. But according to Phil Senter, a paleobiologist at Lamar State College at Orange, in Texas, there's a problem with that image—and with the related hypothesis that competition for the highest browse drove the evolution of the sauropod's long neck. Skeletal evidence reported by others a few years ago, such as the shape of the neck vertebrae, suggests that sauropods held their necks at or below the horizontal.

If so, Senter notes, sauropods had two big problems. First, a long neck, stretched out to graze, would have offered an all-too-bitable target to hungry predators. What's more, just growing such a large body part would require a considerable investment of energy. Senter suggests an alternative explanation for the elongated neck of *Diplodocus,* which, at more than twenty feet, was among the longest necks of all known animals. Like the neck of the modern giraffe, he says, the *Diplodocus* neck—and those of the other sauropods—evolved through sexual selection. It was more likely a showy display to attract the opposite sex than a means of lifting the head higher to browse. Whoever thought teenagers invented necking? (*Journal of Zoology,* doi:10.1111/j.1469-7998.2006.00197.x, 2006)

—*Nick W. Atkinson*

Brachiosaurus skeleton was originally mounted with neck erect, a posture now known to be incorrect. The exhibit, at the Museum of Natural History at Humboldt University, in Berlin, is being revised.

Bacteria Strike Gold



Bacterial forms on the surface of gold, magnified 4,400X

More than a decade ago, geochemists studying how gold grains form encountered a mystery. On the surfaces of gold grains and nuggets collected at several sites in Australia and the Americas, they detected microscopic, gold-encrusted structures shaped suspiciously like mounds of bacteria. But were they really bacterial remnants? And if so, were bacteria somehow playing a role in the formation of gold?

To unravel the mystery, Frank Reith, a geomicrobiologist at the Cooperative Research Centre for Landscape Environments and Mineral Exploration in Kensington, Australia, and three colleagues collected gold grains from two Australian mines. Most of the grains bore the distinctive mounds, they discovered, and the mounds were covered with a thin layer of slime rich in bacteria. DNA analysis showed that each grain harbored as many as thirty species of bacteria that were distinct from the species in the surrounding soils. One species, almost certainly *Ralstonia metallidurans*, was present on all the grains.

Subsequent experiments showed that the ubiquitous *R. metallidurans* can pull dissolved gold—which is highly toxic to most life forms—out of solution and precipitate it as harmless particles of solid gold. The details of the process remain to be understood, but in nature it enables the bacteria to live in toxic soils and to contribute to the creation of solid gold. (*Science* 313:233–6, 2006)

—*Graciela Flores*

Ocean Commotion

A rise in global shipping is turning up the volume in the ocean. In the 1960s the U.S. Navy recorded ambient noise at several sites in the waters off the west coast of North America. Recently Mark A. McDonald, an acoustician at WhaleAcoustics in Bellvue, Colorado, and two colleagues revisited one of those sites, off southern California, and continuously recorded the sounds of the deep from November 2003 until March 2004.

Compared to the sounds the Navy recorded forty years earlier, the team discovered, low-frequency noise from ships has increased by at least ten decibels. That's ten times the former noise level, equivalent to the difference between the ambient noise in a library and that in a busy, big-box retail store, says McDonald. And the entire northeast Pacific Ocean is probably just as loud: the test-recording site is well away from shipping lanes, but sounds that originate throughout the region can be heard there.

Commercial ships doubled in number, quadrupled their cargo tonnage, and dramatically increased their speed and horsepower between 1965 and 2003. The mounting racket has unknown consequences for marine mammals, particularly whales and dolphins, which communicate with sound over long distances. But the animals will just have to get used to the din, says McDonald, because the volume is likely to continue rising. One possible note of optimism rises above the noise: dampening the engines and propellers of the largest 1 percent of the world's vessels would quiet the ocean down considerably. (*Journal of the Acoustical Society of America* 120:711–8, 2006)

—*Rebecca Kessler*

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST-CLASS MAIL PERMIT NO. 21 FREEPORT ME

POSTAGE WILL BE PAID BY ADDRESSEE

L.L.Bean, Inc.
95 Main St.
Freeport, ME 04032-9967

Mount Washington, New Hampshire: 5:30 a.m. The summit temperature is -9°F, wind chill 50 below, winds gusting at 80 mph. Overnight, two inches of solid ice have accumulated on sensitive weather instruments. Now someone has to go out there, shovel the huge snowdrifts and painstakingly chip off all that ice.

The Arctic Expedition Parka has a detachable hood for when winter days turn a little warmer. It's rare that Rick gets a chance to test this feature.

That lucky person is Rick Giard, intern for the Mount Washington Observatory. He's stationed here with a team of world-class meteorologists researching what has been called the "world's worst weather."

As the intern, Rick is assigned some of the toughest

IT TO THE GUY WITH THE WORST JOB EVER

jobs on the mountain. It's work that would be difficult anywhere, let alone in a place so windy even standing upright is a chore.

But don't feel too bad. Rick is thrilled to be here. Mount Washington might be the best place on Earth for someone who loves to study the weather. And it helps that he has us to keep him warm.

As Official Outfitter of the Observatory, L.L.Bean equips everyone on the mountain with high-performance cold weather gear. In return, the scientists put our products to the test in some of the harshest conditions imaginable. Everything from tents to long underwear to our new Arctic Expedition Parka gets a workout. Their feedback is crucial to making our products perform better year after year.

So if our gear can make the "world's worst weather" bearable, we're certain it'll work for you.

The L.L.Bean Arctic Expedition Parka. Breathable Gore-Tex℠ shell. Fully-taped seams. 14 pockets. And enough 775-fill goose down to keep you warm in temperatures as low as -50°F.

For a FREE catalog, call 800-504-2326 or shop now at llbean.com.

L.L.Bean

Mercury Rising

Fossil-fuel burning and certain industrial processes release toxic mercury into the atmosphere. In the Northern hemisphere, much of the contaminant travels northward with the winds, precipitates, and is stored in the soils of high-latitude wetlands. But intense wildfires, increasingly frequent because of global warming, have begun to release the gigantic toxic deposits back into the air.

To study the extent of the phenomenon, Merritt R. Turetsky, an ecologist now at Michigan State University in East Lansing, and six colleagues calculated the amount of mercury sequestered in forests and peatlands in western Canada and the amount released by fires. During severe fire years, they discovered, such emissions are reaching levels similar to industrial emissions from all of North America. Most of the wind-borne mercury will likely continue its journey northward and accumulate in arctic ecosystems, where high mercury levels are already poisoning people and wildlife. (*Geophysical Research Letters* 33: L16403, 2006) —*G.F.*

Spring Back

On Memorial Day, 1868, an old photograph (right) shows, the deciduous trees in Lowell Cemetery in Massachusetts had yet to leaf out. On Memorial Day, 2005 (far right), they stood in full verdure. Leafing or flowering dates each year depend on temperature, and global warming has been driving those events earlier in many places. Plants take part in many ecological interactions—with their pollinators, for instance—that are precisely timed. Changes in their seasonal development may therefore bring on broader ecological disruptions. Records of past plant development are scarce, though, so analyzing trends in timing has been difficult.

Now Abraham J. Miller-Rushing and Richard B. Primack, both ecologists at Boston University, and two colleagues have identified two fresh data troves. They compared dated historical photographs, as well as dated herbarium specimens, of plants in flower in eastern Massachusetts, with recent observations of the same species. The plants, they found, now flower about eleven days earlier than they did a hundred years ago, when the region was 4.5 Fahrenheit degrees cooler. Their findings echo independent estimates from other data, confirming that old photographs and herbarium specimens are reliable sources for climate-change research. (*American Journal of Botany*, in press, 2006)

—*R.K.*

Breakdown in the Desert

Here's a new way global warming may feed on itself. In most terrestrial ecosystems, microorganisms decompose the plant litter. In dry areas, however, sunlight is in charge, according to Amy T. Austin and Lucía Vivanco, ecologists at the University of Buenos Aires. They blocked sunlight from reaching grass litter in an arid Argentine steppe, and measured a 60 percent decline in the rate of decomposition over eighteen months.

When light breaks down organic matter, the greenhouse gases carbon monoxide and carbon dioxide are released into the atmosphere. But when microorganisms do the job, they bury much of the carbon that would otherwise form those gases. Dry habitats cover nearly 40 percent of Earth's surface. If global warming reduces cloud cover in dry areas, increased solar decomposition of plant litter may result in even more greenhouse gases. (*Nature* 442:555–8, 2006)

—*Stéphan Reebs*

Rain Stalls

Summers are getting longer in the Northern Hemisphere, thanks to global warming, and warmer springs aren't the only sign. According to Paul A. Dirmeyer, a climatologist at the Center for Ocean-Land-Atmosphere Studies in Calverton, Maryland, and Kaye L. Brubaker, a hydrologist at the University of Maryland in College Park, other changes are in the air—literally.

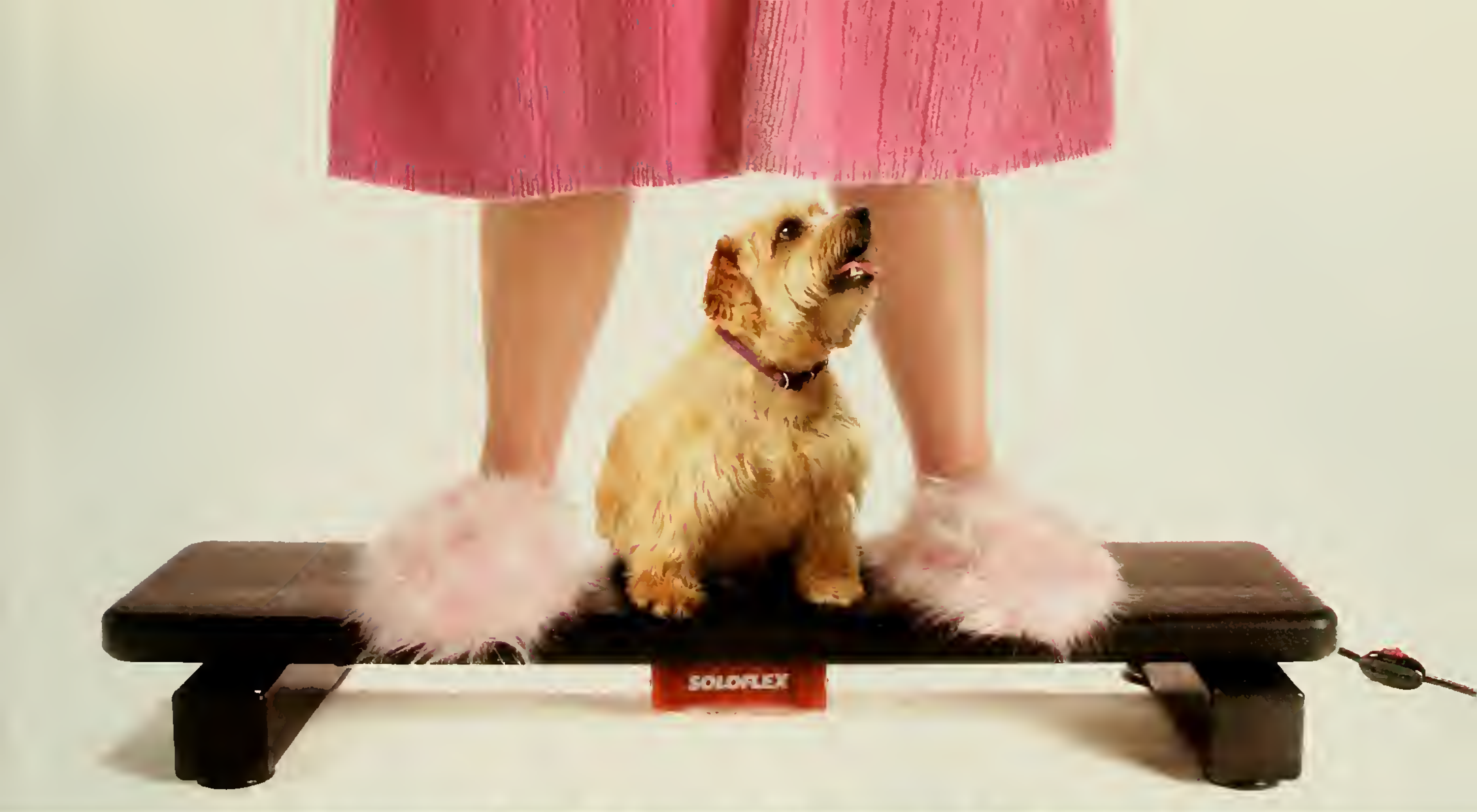
In summer, evaporation rates are higher and winds are weaker than they are in winter, so rainwater has a relatively high concentration of locally evaporated water; in other words, the recycling ratio is high. After analyzing data from 1979 through 2004, Dirmeyer and Brubaker observed a striking trend: in North America and Europe, high recycling ratios are appearing progressively earlier in the spring. The finding is consistent with other symptoms of global warming. (*Geophysical Research Letters* 33:L14712, 2006) —*S.R.*

Pipefish Baby Boom

Juvenile snake pipefish are suddenly on the rise in the northeastern Atlantic, and warming sea temperatures are the likely cause. Richard R. Kirby, a marine biologist at the University of Plymouth in England, and two colleagues studied samples collected by the Continuous Plankton Recorder, a kind of plankton trap that North Atlantic merchant ships regularly tow.

Juvenile snake pipefish were once rare, but they have appeared in increasing numbers since 2002. In just six months in 2005, more young pipefish were recorded than from 1958 until 1972. Female pipefish lay their eggs on males' abdomens. Warm waters reduce the time it takes the eggs to hatch, so the males can mate more often. Warmth speeds the juveniles' growth, too, so they escape their most vulnerable life stages quickly. Kirby says the pipefish baby boom belongs on a rapidly growing list: climate-change effects whose further consequences remain unknown. (*Biology Letters*, doi:10.1098/rsbl.2006.0530, 2006) —*N.W.A.*

Pipefish dad broods eggs.


SOLOFLEX

Field vole prepares to take a gritty bite.

True Grit

Gnashing your teeth against loose gravel in your salad is not considered the finest culinary experience—that's why most cooks wash the lettuce. But with many other plants, grasses in particular, washing isn't much help. The plants incorporate phytoliths, microscopic opals of silica (the main component of sand), in their leaves, which are thought to deter herbivores from eating the plants. Now two studies have updated the understanding of how phytoliths affect grazing animals.

Grazers often have minute grooves in their tooth enamel, and paleontologists have inferred the diets of ancient animals from such grooves on fossil teeth. The grooves are supposedly ground in by phytoliths, with minor assistance from dust and grit on plant surfaces. That assumption was apparently confirmed in 1959, when a study concluded that phytoliths are harder than enamel. But now, Gordon D. Sanson, a biologist at Monash University in Victoria, Australia, and two colleagues are warning scholars to take the old study with a grain of sand—sorry, salt. With technology unavailable fifty years ago, they showed that phytoliths are actually softer than sheep-tooth enamel. The dental grooves of modern grazers and fossil teeth probably come almost entirely from external grit—and that, coincidentally, is most common on low-growing plants, many of which bear phytoliths, says Sanson. (*Journal of Archaeological Science*, doi 10.1016/j.jas.2006.06.009, 2006)

In another study Fergus P. Massey and Sue E. Hartley, both ecologists at the University of Sussex in Brighton, England, report a different way phytoliths discourage herbivores. Phytolith-bearing grasses, they discovered, are relatively indigestible to field voles, and cause the voles to grow more slowly than usual. Furthermore, in response to repeated grazing by voles, grasses quadruple the silica in their leaves. Vole populations typically fluctuate in three- to five-year cycles, which ecologists have attributed to periodic changes in competition or predator populations. Massey and Hartley's discoveries suggest another mechanism. (*Proceedings of the Royal Society* B 273:2299–304, 2006) —*S.R.*

Neanderthals Get Smarter

The last of the Neanderthals disappeared from Europe around the same time the first modern humans arrived there, some 350 centuries ago. Just how similar the two groups were intellectually, and whether they overlapped or interacted has long puzzled archaeologists.

Decorated bone tools and body ornaments associated with the remains of Neanderthals have been found at a number of sites. If Neanderthals made the artifacts, they must have had a concept of decoration, and their behavior and cognition must have been surprisingly modern, even though their anatomy was not. Some investigators argue, however, that the Neanderthals got decorated tools and ornaments from early modern humans. They cite an alternation of dirt layers bearing Neanderthal and modern-human artifacts at Grotte des Fées, a site in central France, as proof that the two groups coexisted throughout the region.

João Zilhão, an archaeologist at the University of Bristol in England, and several colleagues have waded into the debate with a careful reassessment of the artifacts from Grotte des Fées. The team discovered that animals, natural disturbances, and careless digging by earlier fossil hunters caused the alternation of the two groups' layers. In fact, the Neanderthals entirely preceded modern humans at Grotte des Fées and thus, most likely, throughout the region. The Neanderthals must have made the ornaments and decorated tools on their own; intellectually, then, they were rather modern. (*PNAS* 103:12643–8, 2006) —S.R.

City Serenity

Traffic noise, bright lights, crowds of rushing people: urban life can sure be stressful. How do avian city dwellers keep all the disturbances from ruffling their feathers? According to Jesko Partecke and two other ornithologists from the Max-Planck Institute for Ornithology in Andechs, Germany, city life has mellowed the urban bird.

Partecke's team captured recently hatched European blackbirds from nests in Munich, as well as in a distant forest, then hand-raised both groups in equivalent conditions. Once the birds matured, the ornithologists periodically stressed each one by placing it in a cloth bag for an hour, all the while drawing blood samples. The results: the city-born birds secreted less corticosterone, a stress hormone, than their forest cousins.

The difference in stress response might have arisen in early nest experiences, before the birds were captured. A more plausible alternative, however, is that the city birds are inherently calmer than the forest birds. Chronic urban stress may be so detrimental that it selects against birds that too readily stress out. If so, within a relatively short period—European blackbirds started to colonize German cities only 200 years ago—evolution has molded the stress physiology of those birds to make city life more bearable. (*Ecology* 87:1945–52, 2006) —*S.R.*

David Welsh, Blackbird in the City *(detail)*

Delusions of Space Enthusiasts

Sometimes innovation gets interrupted.

By Neil deGrasse Tyson

Human ingenuity seldom fails to improve on the fruits of human invention. Whatever may have dazzled everyone on its debut is almost guaranteed to be superseded and, someday, to look quaint.

In 2000 B.C. a pair of ice skates made of polished animal bone and leather thongs was a transportation breakthrough. In 1610 Galileo's eight-power telescope was an astonishing tool of detection, capable of giving the senators of Venice a sneak peek at hostile ships before they could enter the lagoon. In 1887 the one-horsepower Benz Patent Motorwagen was the first commercially produced car powered by an internal combustion engine. In 1946 the thirty-ton, showroom-size ENIAC, with its 18,000 vacuum tubes and 6,000 manual switches, pioneered electronic computing. Today you can glide across roadways on in-line skates, gaze at images of faraway galaxies brought to you by the Hubble Space Telescope, cruise the autobahn in a 600-horsepower roadster, and carry your three-pound laptop to an outdoor café.

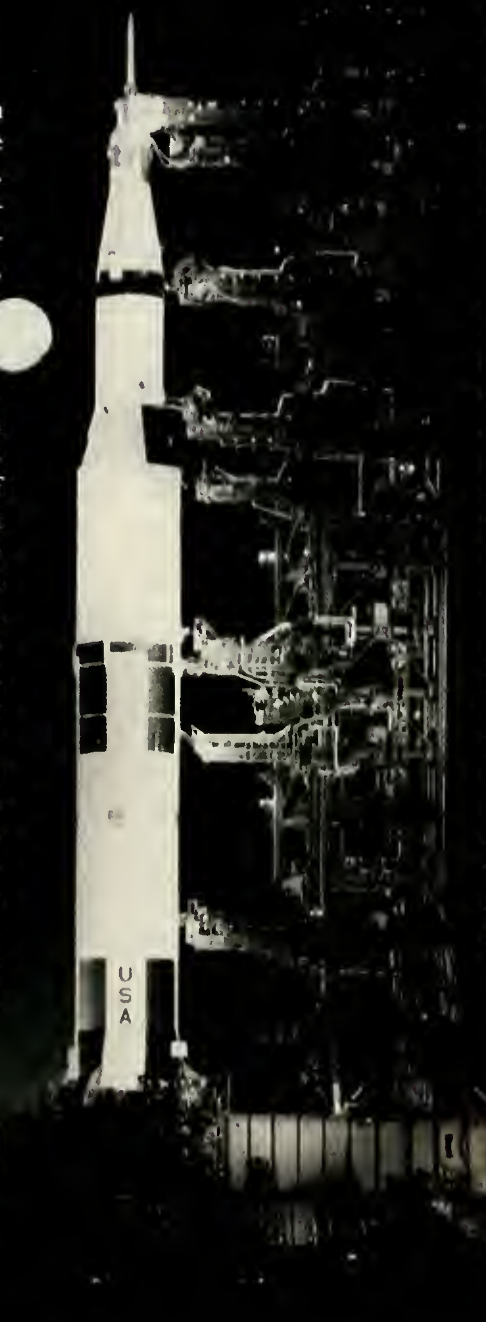
Of course, such advances don't just fall from the sky. Clever people think them up. Problem is, to turn a clever idea into reality, somebody has to write the check. And when market forces shift, those somebodies may lose interest and the checks may stop coming. If computer companies had stopped innovating in 1978, your desk might still sport a hundred-pound IBM 5110. If communications companies had stopped innovating in 1973, you might still be schlepping a two-pound, nine-inch-long cell phone. And if in 1968 the U.S. space industry had stopped developing bigger and better rockets to launch humans beyond the Moon, we'd never have surpassed the Saturn V rocket.

Oops!

Sorry about that. We haven't surpassed the Saturn V. The largest, most powerful rocket ever flown by anybody, ever, the thirty-six-story-tall Saturn V was the first and only rocket to launch people from Earth to someplace else in the universe. It enabled every Apollo mission to the Moon from 1969 through 1972, as well as the 1973 launch of Skylab 1, the first U.S. space station.

Inspired in part by the successes of the Saturn V and the momentum of the Apollo program, visionaries of the day foretold a future that never came to be: space habitats, Moon bases, and Mars colonies up and running by the 1990s. But funding for the Saturn V evaporated as the Moon missions wound down. Additional production runs were canceled, the manufacturers' specialized machine tools were destroyed, and skilled personnel had to find work on other projects. Today U.S. engineers can't even build a Saturn V clone.

What cultural forces froze the Saturn V rocket in time and space? What misconceptions led to the



Saturn V rocket, poised to launch Apollo 17 to the Moon, December 6, 1972 gap between expectation and reality?

Soothsaying tends to come in two flavors: doubt and delirium. It was doubt that led skeptics to declare that the atom would never be split, the sound barrier would never be broken, and people would never want or need computers in their homes. But in the case of the Saturn V rocket, it was delirium that misled futurists into assuming the Saturn V was an auspicious beginning—never considering that it could, instead, be an end.

On December 30, 1900, for its last Sunday paper of the nineteenth century, the *Brooklyn Daily Eagle* published a sixteen-page supplement headlined "THINGS WILL BE SO DIFFERENT A HUNDRED YEARS HENCE." The contributors—business leaders, military men, pastors, politicians, and experts of every persuasion—imagined what housework, poverty, religion, sanitation, and war would be like in the year 2000. They enthused about the potential of electricity and the automobile. There was even a map of the world-to-be, showing an American Federation comprising most of the Western Hemisphere from the lands above the Arctic Circle down to the archipelago of Tierra del Fuego—plus sub-Saharan Africa, the southern half of Australia, and all of New Zealand.

Football helmet, mid-1950s

Most of the writers portrayed an expansive future. But not all. George H. Daniels, a man of authority at the New York Central and Hudson River Railroad, peered into his crystal ball and boneheadedly predicted:

> It is scarcely possible that the twentieth century will witness improvements in transportation that will be as great as were those of the nineteenth century.

Elsewhere in his article, Daniels envisioned affordable global tourism and the diffusion of white bread to China and Japan. Yet he simply couldn't imagine what might replace steam as the power source for ground transportation, let alone a vehicle moving through the air. Even though he stood on the doorstep of the twentieth century, this manager of the world's biggest railroad system could not see beyond the automobile, the locomotive, and the steamship.

Rotary dial telephone, 1960s

Three years later, almost to the day, Wilbur and Orville Wright made the first-ever series of powered, controlled, heavier-than-air flights. By 1957 the U.S.S.R. launched the first satellite into Earth orbit. And in 1969 two Americans became the first human beings to walk on the Moon.

Daniels is hardly the only person to have misread the technological future. Even experts who aren't totally deluded can have tunnel vision. On page 13 of the *Eagle*'s Sunday supplement, the principal examiner at the U.S. Patent Office, W.W. Townsend, wrote, "The automobile may be the vehicle of the decade, but the air ship is the conveyance of the century." Sounds visionary, until you read further. What he was talking about were blimps and zeppelins. Both Daniels and Townsend, otherwise well-informed citizens of a changing world, were clueless about what tomorrow's technology would bring.

Even the Wrights were guilty of doubt about the future of aviation. In 1901, discouraged by a summer's worth of unsuccessful tests with a glider, Wilbur told Orville it would take another fifty years for someone to fly. Nope: the birth of aviation was just two years away. On the windy, chilly morning of December 17, 1903, starting from a North Carolina sand dune called Kill Devil Hill, Orville was the first to fly the brothers' 600-pound plane through the air. His epochal journey lasted twelve seconds and covered 120 feet—a distance just shy of the wingspan of a Boeing 757.

Portable typewriter, 1969

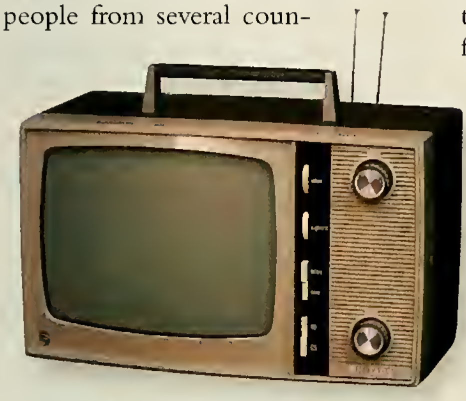
Judging by what the mathematician, astronomer, and Royal Society gold medalist Simon Newcomb had published just two months earlier, the flights from Kill Devil Hill should never have taken place when they did:

> Quite likely the twentieth century is destined to see the natural forces which will enable us to fly from continent to continent with a speed far exceeding that of the bird.
>
> But when we inquire whether aerial flight is possible in the present state of our knowledge; whether, with such materials as we possess, a combination of steel, cloth and wire can be made which, moved by the power of electricity or steam, shall form a successful flying machine, the outlook may be altogether different.

Some representatives of informed public opinion went even further. *The New York Times* was steeped in doubt just one week before the Wright brothers went aloft in the original *Wright Flyer*. Writing on December 10, 1903—not about the Wrights but about their illustrious and publicly funded competitor, Samuel P. Langley, an astronomer, physicist, and chief administrator of the Smithsonian Institution—the *Times* declared:

> We hope that Professor Langley will not put his substantial greatness as a scientist in further peril by continuing to waste his time, and the money involved, in further airship experiments. Life is short, and he is capable of services to humanity incomparably greater than can be expected to result from trying to fly.

You might think attitudes would have changed as soon as people from several coun-



Portable television, mid-1960s

tries had made their first flights. But no. Wilbur Wright wrote in 1909 that no flying machine would ever make the journey from New York to Paris. Richard Burdon Haldane, the British secretary of war, told Parliament in 1909 that even though the airplane might one day be capable of great things, "from the war point of view, it is not so at present." Ferdinand Foch, a highly regarded French military strategist and the supreme commander of the Allied forces near the end of the First World War, opined in 1911 that airplanes were interesting toys but had no military value. Late that same year, near Tripoli, an Italian plane became the first to drop a bomb.

Early attitudes about flight beyond Earth's atmosphere followed a similar trajectory. True, plenty of philosophers, scientists, and sci-fi writers had thought long and hard about outer space. The sixteenth-century philosopher-friar Giordano Bruno proposed that intelligent beings inhabited an infinitude of worlds. The seventeenth-century soldier-writer Savinien de Cyrano de Bergerac portrayed the Moon as a world with forests, violets, and people.

But those writings were fantasies, not blueprints for action. By the early twentieth century, electricity, telephones, automobiles, radios, airplanes, and countless other engineering marvels were all becoming basic features of modern life. So couldn't earthlings build machines capable of space travel? Many people who should have known better said it couldn't be done, even after the successful 1942 test launch of the world's first long-range ballistic missile: Germany's deadly V-2 rocket. Capable of punching through Earth's atmosphere, it was a crucial step toward reaching the Moon.

Richard van der Riet Woolley, the eleventh British Astronomer Royal, is the source of a particularly woolly remark. When he landed in London after a thirty-six-hour flight from Australia, some reporters asked him about space travel. "It's utter bilge," he answered. That was in early 1956. In early 1957 Lee De Forest, a prolific American inventor who helped birth the age of electronics, declared, "Man will never reach the moon, regardless of all future scientific advances." Remember what happened in late 1957? Not just one but two Soviet *Sputniks* entered Earth orbit. The space race had begun.

Whenever someone

says an idea is "bilge" (British for "baloney"), you must first ask whether it violates any well-tested laws of physics. If so, the idea is likely to be bilge. If not, the only challenge is to find a clever engineer—and, of course, a committed source of funding.

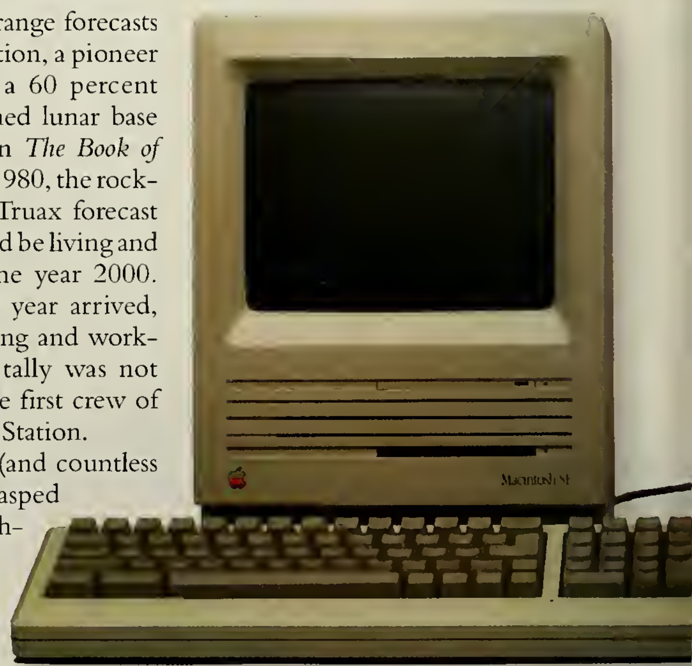
The day the Soviet Union launched *Sputnik 1*, a chapter of science fiction became science fact, and the future became the present. All of a sudden, futurists went overboard with their enthusiasm. The delusion that technology would advance at lightning speed replaced the delusion that it would barely advance at all. Experts went from having much too little confidence in the pace of technology to having much too much. And the guiltiest people of all were the space enthusiasts.

Commentators became fond of twenty-year intervals, within which some previously inconceivable goal would supposedly be accomplished. On January 6, 1967, in a front-page story, *The Wall Street Journal* announced: "The most ambitious U.S. space endeavor in the years ahead will be the campaign to land men on neighboring Mars. Most experts estimate the task can be accomplished by 1985." The very next month, in its debut issue, *The Futurist* magazine announced that according to long-range forecasts by the RAND Corporation, a pioneer think-tank, there was a 60 percent probability that a manned lunar base would exist by 1986. In *The Book of Predictions*, published in 1980, the rocket pioneer Robert C. Truax forecast that 50,000 people would be living and working in space by the year 2000. When that benchmark year arrived, people were indeed living and working in space. But the tally was not 50,000. It was three: the first crew of the International Space Station.

All those visionaries (and countless others) never really grasped the forces that drive technological progress. In Wilbur and Orville's day, you could tinker your way into major engineering advances. Their first airplane did not require a grant from the National Science Foundation: they funded it through their bicycle business. The brothers constructed the wings and fuselage themselves, with tools they already owned, and got their resourceful bicycle mechanic, Charles E. Taylor, to design and hand-build the engine. The operation was basically two guys and a garage.

Space exploration unfolds on an entirely different scale. The first moonwalkers were two guys, too—Neil Armstrong and Buzz Aldrin—but behind them loomed the force of a mandate from an assassinated president, 10,000 engineers, $100 billion, and a Saturn V rocket.

Notwithstanding the sanitized memories so many of us have of the Apollo era, Americans were not first on the Moon because we're explorers by nature or because our country is committed to the pursuit of knowledge. We got to the Moon first because the United States was out to beat the Soviet Union, to win the Cold War any way we could. John F. Kennedy made that clear when he complained to top NASA officials in November 1962:



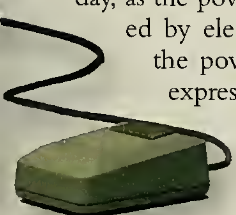
Macintosh home computer, 1984

Transistor radio, 1961

I'm not that interested in space. I think it's good, I think we ought to know about it, we're ready to spend reasonable amounts of money. But we're talking about these fantastic expenditures which wreck our budget and all these other domestic programs and the only justification for it in my opinion to do it in this time or fashion is because we hope to beat them [the Soviet Union] and demonstrate that starting behind, as we did by a couple of years, by God, we passed them.

Like it or not, war (cold or hot) is the most powerful funding driver in the public arsenal. When a country wages war, money flows like floodwaters. Lofty goals—such as curiosity, discovery, exploration, and science—can get you money for modest-size projects, provided they resonate with the political and cultural views of the moment. But big, expensive activities are inherently long term, and require sustained investment that must survive economic fluctuations and changes in the political winds.

In all eras, across time and culture, only three drivers have fulfilled that funding requirement: war, greed, and the celebration of royal or religious power. The Great Wall of China; the pyramids of Egypt; the Gothic cathedrals of Europe; the U.S. interstate highway system; the voyages of Columbus and Cook—nearly every major undertaking owes its existence to one or more of those three drivers. Today, as the power of kings is supplanted by elected governments, and the power of religion is often expressed in non-architectural undertakings, that third driver has lost much of its sway, leaving war and greed to run the show. Sometimes those two drivers work hand in hand, as in the art of profiteering from the art of war. But war itself remains the ultimate and most compelling rationale.



Having been born the same week NASA was founded, I was eleven years old during the voyage of *Apollo 11*, and had already identified the universe as my life's passion. Unlike so many other people who watched Neil Armstrong's first steps on the Moon, I wasn't jubilant. I was simply relieved that someone was finally exploring another world. To me, *Apollo 11* was clearly the beginning of an era.

But I, too, was delirious. The lunar landings continued for three and a half years. Then they stopped. The Apollo program became the end of an era, not the beginning. And as the Moon voyages receded in time and memory, they seemed ever more unreal in the history of human projects.

Unlike the first ice skates or the first airplane or the first desktop computer—artifacts that make us all chuckle when we see them today—the first rocket to the Moon, the 364-foot-tall Saturn V, elicites awe, even reverence. Three Saturn V relics lie in state at the Johnson Space Center in Texas, the Kennedy Space Center in Florida, and the U.S. Space and Rocket Center in Alabama. Streams of worshippers walk the length of each rocket. They touch the mighty rocket nozzles at the base and wonder how something so large could ever have bested Earth's gravity. To transform their awe into chuckles, our country will have to resume the effort to "boldly go where no man has gone before." Only then will the Saturn V look as quaint as every other invention that human ingenuity has paid the compliment of improving upon.

Astrophysicist NEIL DEGRASSE TYSON *is the director of the Hayden Planetarium at the American Museum of Natural History. Tyson's latest book,* Death by Black Hole: And Other Cosmic Quandaries—*an anthology of his favorite* Natural History *essays—has just been published by W.W. Norton.*

Times of Our Lives

Gravity, along with dark energy, plays a key role in the timing of our cosmic appearance and sets strict limits on the span of life anywhere in the universe.

By Robert L. Jaffe

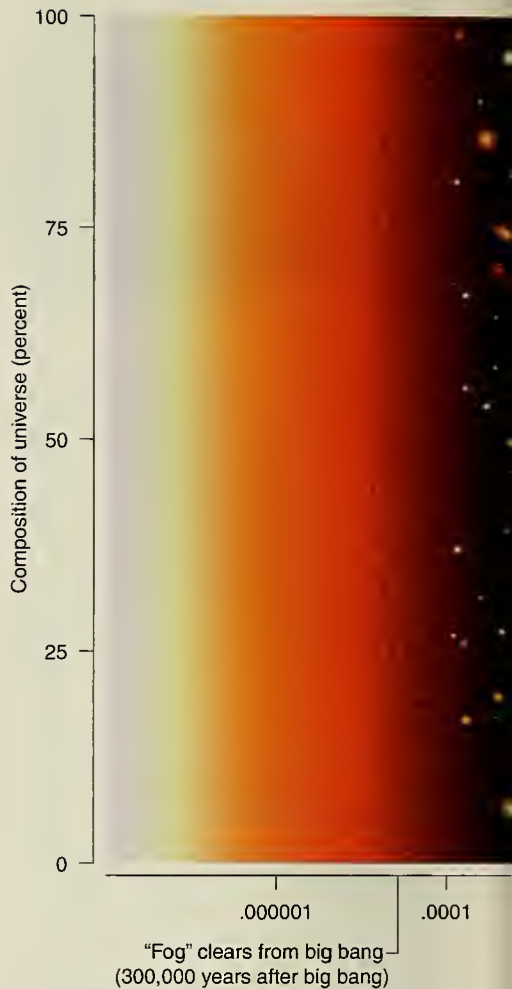
Behind Me—dips Eternity—
Before Me—Immortality—
Myself—the Term between
—Emily Dickinson

Time passes. We are all swept up in its flow. Human affairs are measured in seconds, days, and years—the times of our lives. But that perception of time is as myopic as the view of the universe was centuries ago, when people looked outward or inward with only the naked eye. Most people nowadays are accustomed to the idea that nature may work in the simplest or most dramatic ways in places too small or too far away to see. Physicists understand the need for giant particle accelerators to peer deep within the atom; astronomers recognize the need for exquisitely tuned telescopes to look at distant galaxies. Should anyone be surprised that the same is true of time? And just as the insights of physicists and astronomers have widened perspectives on space, so, too, can they help all of us explore the flow of time beyond the little eddy in which we live.

Aided by extraordinary instruments, physicists have discovered that nature tends toward two extremes. At one extreme are the hectic tempos inherent in the microworld of atoms, atomic nuclei, quarks, and the fundamental forces that drive them—electromagnetism, and the strong and weak nuclear forces. The time intervals corresponding to those forces are far faster than anything that people can perceive directly. At the other extreme is the great, slow waltz of cosmology, times over which the universe itself evolves. Given nature's preference for extremes, how is it that human beings inhabit a middle world of seconds, days, and years? After all, we are made of quarks and electrons, which swirl and vibrate at a fever pitch. The times of our lives seem arbitrary and irrelevant, compared with either fundamental or cosmological times. Where did they come from? What do they have to do with the laws of physics, or with the processes that enabled us to evolve and to observe the universe?

Last month I explained how each of nature's fundamental forces comes with its own internal clock, and how each runs exceedingly fast [*see "As Time Goes By," by Robert L. Jaffe, October 2006*]. But what about the vast timescales of cosmology? In that direction the terrain is still obscure, the crucial discovery was made just a few years ago, and the central questions are far from settled. What fixes the rhythm of cosmology? No one knows. But thanks to the recent discovery of the mysterious "dark energy" that dominates all the other forms of energy in the universe, cosmologists now know that the unit of cosmological time in the universe—the time over which the universe has changed in a fundamental way—is about 10 billion years.

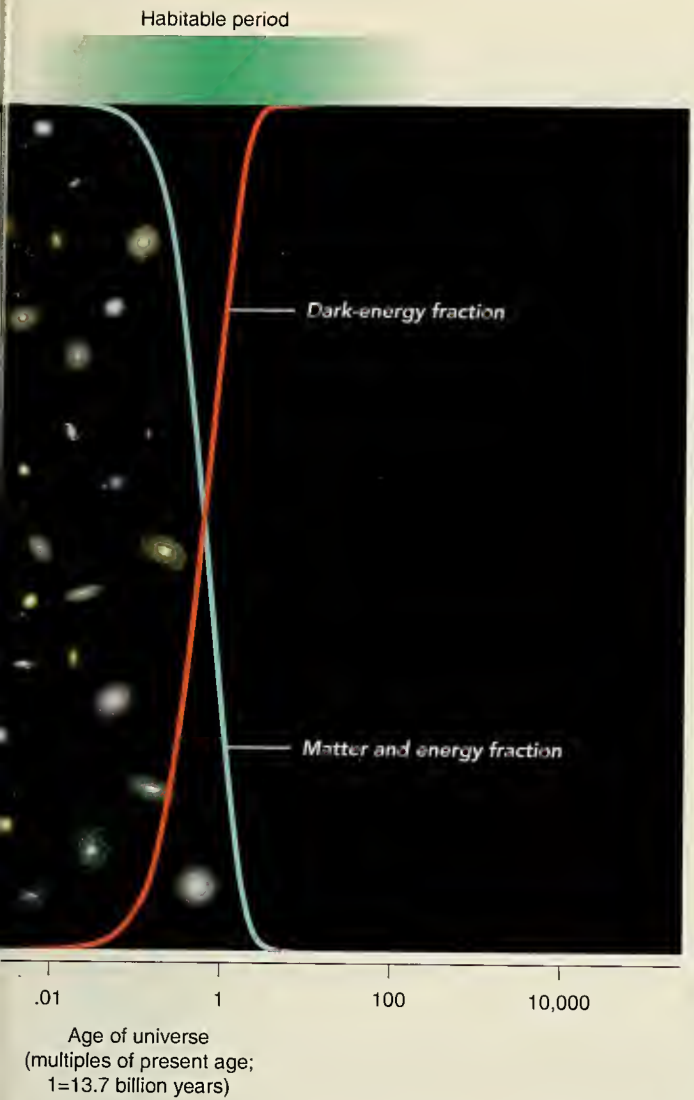
To appreciate the vastness of that interval, consider that 10 billion years is about 10^{39} beats of the clock of the strong force—the time it takes a quark to orbit once within a proton. Why is the scale of cosmological time so vastly



longer than the "heartbeat" of the fundamental forces of the universe? The question may well be the deepest mystery in modern physics.

And what of the times of our lives? Remarkably, if one looks carefully enough, the middle-size span of a human life seems to re-emerge with renewed significance. There is reason to think that the span of complex lifeforms may be roughly the same throughout the universe, a consequence of a delicate balance between the fundamental forces and the force of gravity, which express themselves most dramatically in the microworld and in the stars.

The modern era in cosmology began with Einstein's formulation of general relativity, his sweeping extension of Newton's theory of gravity. By embedding gravity in a geometrical pic-



Evolution of the universe is shown schematically from the big bang until 100 trillion years from now; time is plotted logarithmically on the horizontal scale. The blue curve shows that when the universe begins, it is made up almost entirely of matter and ordinary energy. Beginning about a billion years after the big bang, however, the percentage of dark energy (red curve) began growing rapidly and "soon" (at least on the logarithmic timescale) became dominant, about 4 billion years ago. In our era, 13.7 billion years after the big bang, we are still in transition from a universe dominated by matter and ordinary energy (the present composition is about 26 percent) to a universe dominated by dark energy (about 74 percent). The period in the history of the universe that is most favorable to life is plotted along the time axis as a green band at the top of the graph; the deeper the green, the more habitable the epoch. In the distant future, dark energy will overwhelm all other matter and energy, the stars will no longer shine, and life as we know it will cease to exist.

ture of space and time, Einstein was able to think in grand terms about the global structure of the universe. General relativity made it possible to ask, What sets the tempo of cosmological change? Einstein conjectured that the universe was static, and by inference, eternal. He had no evidence to the contrary.

Einstein also thought, correctly, that all bits of matter attract each other under gravity's irresistible force. But that posed a problem: how could a static universe resist collapsing under gravity's universal attraction? To avoid such a catastrophic outcome, Einstein postulated what he called the cosmological constant, which fills all space with energy and, most important, exerts a constant outward pressure that counterbalances gravity, suspending the universe in a delicate, static equilibrium.

In 1929, not long after Einstein introduced general relativity, the American astronomer Edwin P. Hubble discovered the first evidence that Einstein's initial picture was wrong: the universe is neither static nor eternal. Instead, Hubble showed, the universe is expanding. Distant galaxies are racing away from the Milky Way and from one another like spots inked on the surface of an inflating balloon. Long ago the universe was smaller, and it was expanding faster. Since then, gravity has been acting as a brake on the expansion. Most important, from Einstein's point of view, Hubble's universe had no need of an outward pressure to keep it from collapsing. When Einstein learned of Hubble's work, he discarded the cosmological constant, in later years calling it his "biggest blunder."

Hubble's concept of an expanding universe is the foundation of modern cosmology, according to which the universe was born in a great explosion, the big bang, some 13 or 14 billion years ago. Until quite recently, cosmologists generally thought the force of the big bang and the retarding effects of gravity were perfectly balanced, so that the expansion would exhaust itself only in the infinite future. Hubble's universe is almost as unchanging as Einstein's. After its violent birth, its uniform expansion continues without cosmological incident forever. Its present age has no significance except that it happens to be the moment that human beings have come along to make observations and debate cosmological questions.

All that changed in the 1990s, when astronomers tried to verify one of the central predictions of Hubble's cosmology, that the expansion of the universe should be slowing down. But how could astronomers measure such a universal deceleration? As the dots in the balloon analogy suggest, the more distant a galaxy, the faster it is receding. Yet when astronomers observe a distant galaxy, they are looking deep into the past, to the moment the light they observe was actually emitted. In that early epoch, the universe was smaller and, according to Hubble's standard cosmology, expanding more rapidly. So if the universe is decelerating, distant galaxies should be receding slightly faster than the present rate of expansion of the universe would suggest.

To almost everyone's surprise, the results of precise studies showed that distant galaxies are receding slightly slower, not faster, than expected from the present expansion rate. The universal expansion is no longer decelerating at all; in the past few billion years it has begun to accelerate. Nevertheless, all the other features of Hubble's standard cosmology appear, so far, to be correct. What to do? Although the answer is not certain, a consensus has emerged that Einstein's discarded cosmological constant fills the bill: space is, in fact, imbued with an energy density and an outward pressure that augments the expansion of the universe.

Remarkably, investigators pulling on another thread of the fabric of cosmology were reaching the same conclusion at just about the same time. They were auditing the relative contributions of various forms of matter and energy to the total energy of the universe. Cosmologists now know that visible matter and all the forms of light ("radiation") together account for only about 4 percent of the energy in the universe.

Another 22 percent or so is a mysterious, nonluminous, and ghostly stuff known as "dark matter," which does not interact appreciably with proton-neutron-electron stuff like us. Dark matter has never been observed directly and no one knows what it is—except that cosmologists are rather certain that like other matter, it has mass, carries momentum when it moves, and "feels" the force of gravity.

The rest of the universe, a whopping 74 percent, is "dark energy." Neither matter nor radiation, dark energy has energy, exerts pressure, and affects gravity, but unlike ordinary matter, it does not carry momentum. It is like nothing encountered before, but it is exactly like the substance Einstein postulated as the cosmological constant. And, to the delight of cosmologists, the pressure generated by dark energy is close to the value necessary to fuel the newly discovered acceleration of the universal expansion.

As the universe expands, new space is created, and with it, a minute amount of new dark energy. Like a sales tax, the dark energy is a fixed percentage of the newly created volume of space. Although ordinary matter and dark matter dwarf dark energy in familiar places such as the Milky Way, matter is concentrated only here and there. Beyond such clumps, dark energy is everywhere. When it is all added up, dark energy dominates.

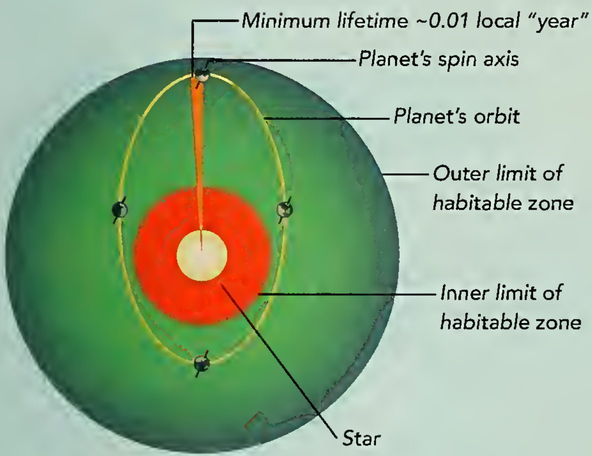
The discovery of dark energy has finally brought time into cosmology. Long ago, the universe was small. It included the same amount of matter and even more radiant energy than it does now. But because the universe was small, it included very little dark energy. By contrast, in the distant future, after the universe has expanded to many times its current size, matter and radiation will be further diluted and dark energy will dominate overwhelmingly.

Our epoch is special [*see illustration on two preceding pages*]. Now is when matter and radiation, on the one hand, and dark energy, on the other, are comparable fractions of the stuff of the universe. When the universe was about 70 percent of its present age, the fractions were equal. (Cosmologists measure time in orders of magnitude, and so the distinction between the present age of the universe and 70 percent of the present age is hardly significant.) But now the balance is shifting with what cosmologists consider breakneck speed. In the cosmologically recent past, when the universe was one-tenth its present age, matter accounted for more than 98 percent of the stuff in the universe. In the cosmologically not-too-distant future, when the universe is only five times its present age, matter will account for a mere fifteen parts per million of the stuff in the universe!

The implications for cosmology are fundamental. A benchmark timescale, independent of human observers, has finally emerged. The unit of cosmological time is the age of the universe at which the balance between matter and dark energy shifted in favor of dark energy: once again, about 10 billion years.

That number introduces a strange coincidence: the lifetime of a hospitable star like our Sun is also about 10 billion years. Why is the match so close? It is a mystery. Astrophysicists can calculate the lifetimes of stars from the laws of gravity, electromagnetism, and the weak and the strong forces. Massive stars burn fast and die young, but bright, stable, medium-size stars like our Sun live billions of years. Long ago the universe was hot, structureless, and uninhabited; stars had yet to form. Far in the future the universe will be cold, dark, and—once more—uninhabited; stars will no longer shine. Today is the epoch

LIFE SPANS IN THE HABITABLE ZONE



Earthlike planet whose orbit around a stable, sunlike star does not stray outside a zone hospitable to life (green) is shown schematically. If the planet's orbit crossed into the red zone, conditions would be too hot for life; if it crossed the outer boundary of the green zone, conditions would be too cold. The strength of the force of gravity confines the orbital period of such a planet to a range of between a tenth of an Earth-year and ten Earth-years. Two simplifying assumptions: life on the planet depends on the star for energy (the planet's internal heat is not a factor) and both the local "day" and the local "year" play important roles in the evolution of planetary life-forms. In particular, for the local year to play a role, the incoming energy from the star at the planet's surface must change periodically because of the orbital motion (for instance, because of an elliptical orbit, or because of a tilt of the planet's spin axis with respect to its orbital plane). The author estimates that the life span for any complex life on the planet (such as multicellular life) is likely to range between 0.01 and 1,000 local years, similar in order of magnitude to the range of life spans for complex life on Earth. Combining this with the estimate of the orbital period, the life span for complex life on the surface of a planet anywhere in the universe should range between 0.001 Earth-year (about nine hours) and 10,000 Earth-years.

of stars, and thus the epoch of life.

Our era is also the epoch of transition from a matter-dominated universe, whose expansion was, until fairly recently, decelerating, to a universe dominated by dark energy that will eventually cause everything to fly apart. This coincidence haunts modern cosmology. Is it an accident or is there some underlying connection between the dark energy, which no one understands, and the complex balance of fundamental forces that lead stars to shine for billions of years? Or is the only connection, as some speculate, that if the two timescales did not coincide, we would not be here to discuss it?

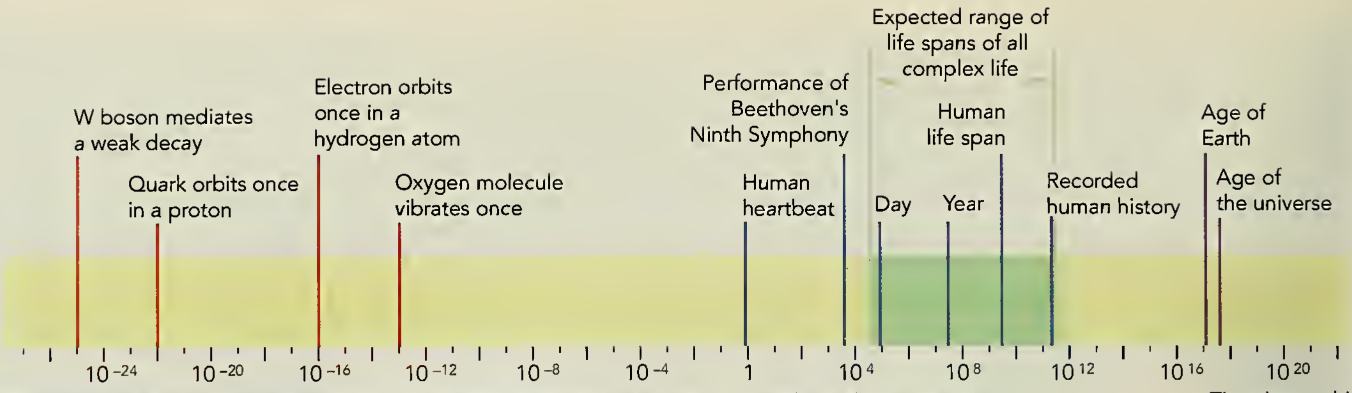
If the density of dark energy throughout space were too large, the universe would have blown apart long ago, before galaxies, stars, and observers like us could have appeared. If the pressure of dark energy pulled inward rather than pushing outward, which seems entirely possible, then the universe would have slammed shut in a "big crunch" long before stars had time to form. Perhaps only a universe in which the laws of physics enable the lifetimes of hospitable stars to match the clock of cosmological time would evolve observers who look at the night sky and ponder the mysteries of cosmology.

That "cosmic coincidence" has given new urgency to a question that has long lingered in the shadows between physics and metaphysics: could the laws of physics in our universe be determined, not by some wonderful unified theory, but instead, at least in part, because had they been otherwise, no observer could have evolved? Could there be a multitude of universes, each a different throw of the cosmic dice, each born with a different cosmological clock and a different set of physical laws? If so, most of them might be wasting away unobserved, and only a few, perhaps a very few, would turn out to be lucky enough to be noticed, to give rise to beings that could observe them. In this strange and speculative picture, we happen to live in a particularly hospitable universe, one blessed with a long, lazy, and calm cosmological tempo, compared to the helter-skelter time scales of fundamental processes.

What do we see if we try to tune the frame speed of the mind's eye to the tempo of cosmological time? Is our universe merely one event, one tick of the cosmological clock, part of a larger drama in which universes wink in and out of existence? "Tick": a universe with too much dark energy, which rips apart before stars can form; "tock": another universe, where the dark matter attracts rather than repels, so this universe collapses in on itself before any structure can form; "tick": a universe like ours, delicately balanced and long lived; "tock": something entirely different.

Trying to comprehend the universe by itself may be like trying to understand a single person alone, without ancestors or offspring or a society to put the person in some context. Perhaps the full story is a sequence or ensemble of universes—a "multiverse," as cosmologists are calling it—and the properties of our universe have to be understood in that larger context. Perhaps we need to grasp scales of time even longer and more alien than we attempt today. Perhaps we ought to be thinking about a theory of universes. If it seems ludicrous to regard the universe as so ephemeral, perhaps it is because our limited, human perspective on time has prevented us from perceiving the important rhythms of cosmology.

We seem lost in time. What set the pace of life on Earth? How did the day, on the order of 10^5 seconds, and the year, 10^7 seconds, emerge as the times of our lives? Are they characteristic times for life throughout the



Time intervals spanning more than forty-two orders of magnitude are plotted logarithmically. They range from the time it takes a W boson to mediate a weak nuclear interaction (10^{-25} second) to the present age of the universe (4.1×10^{17} seconds). Red lines mark durations on the microscale, which are governed by one of the three fundamental forces (excluding gravity); purple lines mark durations that take place on a cosmic scale, governed by gravity. Human-scale durations, marked in blue lines, unfold roughly in the middle of those two extremes on the logarithmic timescale. The expected range of life spans for life anywhere in the universe is the middle range shaded in green.

universe? If the search for extraterrestrial intelligence ever succeeds, will we humans find that the aliens live for a few billion seconds, as we do, or will their lifetimes be measured in milliseconds or aeons?

No one knows for sure, but modern physics paired with natural selection suggests an answer. Instead of arising directly out of the laws of physics or cosmology, the times of our lives seem to emerge from a fascinating and subtle interplay of the great forces that control the universe [*see "Matters of Size," by John Tyler Bonner, page 54*]. And there is reason to believe that the time of our lives may well be the timescale of all life in the universe.

Celestial mechanics is a piece of the puzzle. The day, the month, the year—those are the rhythms of light and dark, of the tides, of summer and winter, of the solar system. Our lives, it seems, are tuned to the music of the spheres. But it is not so simple: we are made of biological stuff, governed by laws of physics in which the day and the year do not appear. How did the chemistry of life become locked onto the rhythms of celestial mechanics? The answer seems to lie in natural selection, a law of nature different in kind from the physical laws I have invoked so far, but no less powerful.

Life arose on Earth, a planet circled by the Moon and circling the Sun. From the very beginning, the ooze that was to become us was cooked in a crucible by a flame that rose and fell with daily, monthly, and yearly rhythms. Through countless cycles of reproduction and predation, complex organisms adapted to the rhythms of the solar system.

To be sure, some organisms have evolved lifetimes as short as a few days or as long as a few millennia. But even those exceptions stray from celestial timescales by only a couple of orders of magnitude—not very significant on a timescale that ranges from 10^{-24} second to 10^{17} seconds. Could environmental pressure or scientific progress enable an organism to extend or compress its life span by factors of a million

(Continued on page 65)

DISTINCTIVE DESTINATIONS

As temperatures chill,
head south in pursuit of balmy breezes
and the warmth of the sun

This winter, rejuvenate yourself with a taste of the open-air lifestyle of **ARIZONA**, where you can enjoy both natural and culinary adventures

ESCAPE TO THE NATURAL BEAUTY AND vibrant cities of Arizona, whose uniquely inspired cuisine parallels its fusion of cultures. Experience the state's colonial heritage in the historic city of Tucson, where you can cap a day's adventure amid tall saguaro cacti in the Sonoran desert with a traditional Sonoran-style Mexican meal at El Charro Café. Opened in 1922, this café has always been operated by the same family. It attracts visitors with its authentic food including enormous chimichangas and delectable dishes, some made from marinated beef, dried on the roof and then shredded.

After a day exploring the museums of Phoenix, treat yourself to a creative meal at Lon's at the Hermosa, in nearby Scottsdale. Lon's takes you back in time to the days when cowboys roamed the vast Southwestern desert. This historic hand-built ranch house, influenced by Spanish and Mexican architecture,

Lon's at the Hermosa in Scottsdale

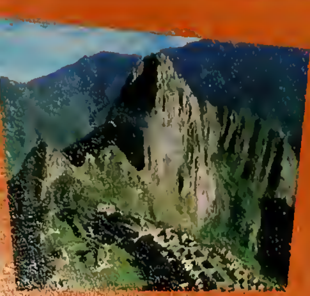
Todd Brenneman

is Arizona's only remaining authentic hacienda. The restaurant harvests many of its ingredients locally, and guests can enjoy outdoor seating October through May, with dramatic views of Camelback Mountain. In the art district of Old Town Scottsdale, you'll find a seventy-five-year-old adobe home that houses Old Town Tortilla Factory and an ubiquitous Southwestern atmosphere. The food here draws on Native American and Sonoran influences, and the house's special drink is made with Suaza tequila.

In northern Arizona, spend the day exploring the spectacular red rock formations of Sedona, perhaps with a hike at Red Rock State Park or at the Coconino National Forest. Then pamper yourself at the four-diamond L'Auberge Restaurant, newly renovated and overlooking beautiful Oak Creek. Relax with a cocktail at the restaurant's lounge before choosing from the award-winning menu, which includes a five-course tasting meal and an extensive wine list for the most discriminating diner.

Arizona offers a variety of restaurants that will satisfy a taste for change. From a casual relaxing atmosphere to a fine dining experience guests will not be disappointed. Take the opportunity to learn about Arizona's history or natural beauty, enjoy an incredible meal, and relax with a glass of wine or a slushy margarita. Arizona has it all.

For your free Arizona travel packet, visit arizona**guide**.com *or call 1-866-406-6728 toll-free.*



Magical Archaeology

Although the word Peru inevitably
founded by the Incas, the Inca t
inherited from older civilizations,


The Lord of Sipan
© Museo Tumbas Reales de Sipán

Heir to ancient cultures and a rich colonial tradition, PERU is a magical spot.

Top, colonial architecture in Lima; right, a view of the altiplano, or high plains of the Andes. Opposite, from top to bottom: the Amazon River; the ancient city of Machu Picchu; an ibis in the Uros Islands, one of nearly 1,800 bird species identified in Peru.

PERU IS HOME TO ONE OF THE MOST biodiverse countries on Earth and is a melting pot of different cultures. As home to 84 of the 104 life zones that exist on our planet, Peru is a privileged destination for nature lovers. And with 10,000 years of history, the country is covered with archeological sites and historical places as well as 180 museums.

While Peru inevitably evokes images of Machu Picchu and the Inca empire, its legacy dates from even more ancient times, when great civilizations bequeathed a legacy of their art, customs, and rituals. Caral, dating from 3000–1500 BC, is the oldest city in the Americas. Located just under 100 miles north of Lima, in the Supa valley, the city features a series of complexes such as the Great Pyramid, the Amphitheater Pyramid, and the Residential Quarters of the Elite. Caral is noted for its flutes made from condor and pelican bones, which some believe re-created the sounds of winds gusting powerfully over the sands of the city. It is just one of eighteen settlements identified in the valley.

A STUDY IN BIODIVERSITY

Peru is divided into three regions with an extraordinary variety of ecosystems sheltering a vast diversity of plants and animals. The coastline is paralleled by a long, slinking desert, hemmed in between the sea and the Andes Mountains. The highlands are dominated by the Andes, and the vast jungle surrounds the winding Amazon River. With such diversity, it's no wonder that the country is home to more than 400 species of mammals, 300 reptiles, 1,800 birds, and more than 50,000 plants.

Peru has some 3,000 species of orchids, most of which grow in the tropical jungle on the eastern slopes of the Andes: the cloud forest region. There, amid the exuberant vegetation produced by nearly 5,000 mm of rainfall a year, orchids multiply, forming veritable natural gardens. Even casual orchid fanciers might consider hiking the Inca Trail, which links Qorihuayrachina (on the outskirts of Ollantaytambo), with the Inca citadel of Machu Picchu. The Machu Picchu Historic Sanctuary is home to more than 200 orchid varieties, and the trail is a great way to study orchids and at the same time take in the spectacular countryside. Peru's cloud forests also shelter rare flowers, including the bromelia or giant begonia. There are several cloud forest regions, including the Chanchamayo Valley in the department of Junín.

FOR BIRDERS IN THE KNOW

Peru has the second highest number of bird species in the world, and counting only breeding species, it ranks first. More new species were described in Peru in the last 30 years than in any other country in the world, with about two new species on average described each year.

Northern Peru, once considered remote, is now gaining international attention as it focuses on promoting accessible birdwatching. This is one of the most biologically diverse areas on Earth, characterized by the Andes, the influence of two major oceanic currents, and the proximity of the Amazonian lowlands. It boasts an incredible diversity of habitats and nearly 1,400 bird species, including species representative of no less than eight endemic bird areas. The region supports 137 restricted-range bird species (defined by Birdlife International as confined to a range of less than 50,000 square kilometers), and some 65 that are considered globally threatened as well as 29 that are considered near-threatened.

The Northern Peru Birding Route, across the Andes from the Pacific coast to the Amazon, covers the complete range of habitats, affording sightings of some of the world's rare and most sought after birds amid spectacular scenery. Combine your birdwatching with a range of pre-Columbian archeological sites, such as Sipan, Sican, Kuelap, and Leymebamba, as well as museums. (Don't miss the Sipan museum in Lambayeque, which houses the Moche gold artifacts taken from the tomb of the lord of Sipan.)

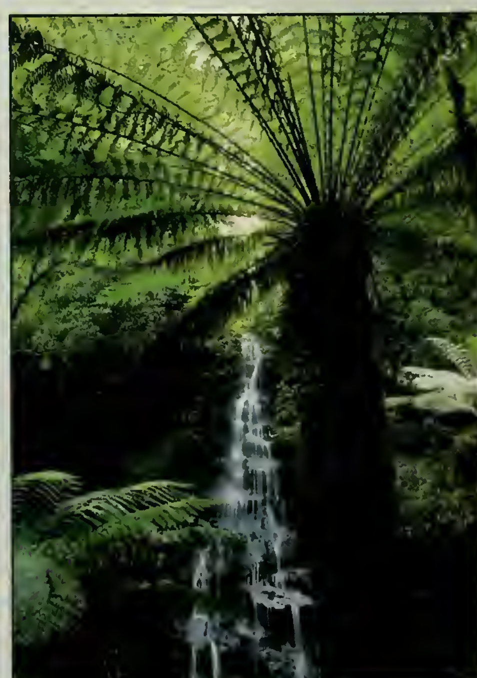
Three of the world's six species of flamingoes also can be found in Peru, the most flamingo species seen in any country on Earth. In some cases the most common of the three, the Chilean flamingo, can be seen in flocks of hundreds or even thousands quite close to cities and popular tourist sites.

For a wealth of information about birding in Peru, visit perubirdingroutes.com.

Off the southern coast of mainland Australia, **TASMANIA** boasts dramatic coastlines, rugged mountains, and pristine forests.

Top, Forester kangaroos, the largest marsupials in Tasmania, were introduced into Maria Island National Park; bottom right, Cryptic Falls in the Teepookana Forest Reserve.

WHEN EARLY WINTER BREEZES BLOW IN NORTH AMERICA, turn your eyes Down Under and visit Australia's smallest and most southerly state, just over 100 miles south of the mainland. It's summer in Tasmania, and temperatures are mild (the average maximum is 70 degrees), with warm afternoons and long twilights. In spite of its small size, the island's vegetation is diverse, comprising alpine heathlands, tall open eucalypt forests, and large areas of cool temperate rainforests and moorlands. More than a third of Tasmania is part of a network of national parks and the Tasmanian Wilderness World Heritage Area. Many of the plants are unique to Tasmania, and it is the only place to see such mammals as the Tasmanian devil, and the eastern and spotted-tail quolls (cat-sized carnivorous marsupials). Tasmania's isolation and ancient landscapes make it a haven for birds, with 12 endemics and nearly 200 other species of Australian birds. All but two of the endemics are widespread and relatively easy to find. Thanks to a progressive trail development program, Tasmania has numerous designated walking trails that allow travelers to safely access wilderness regions. These range from the 38-mile Overland Track through some of Tasmania's highest peaks, with cliff-side views of glacial lakes and waterfalls, to an easy, 20-minute circuit leading to Russell Falls. The Tahune Forest Airwalk is an anchored walkway in the treetops, 148 feet up in the air, which offers a bird's-eye view of old growth forests.



Sail with **ORIENT LINES**, and the world is yours to discover.

Iguazú Falls

ORIENT LINES, THE DESTINATION CRUISE SPECIALIST, TRAVELS TO all four corners of the world, offering unparalleled luxury voyages on its flagship, the *Marco Polo*. Classically designed like the grand liners of yesteryear, the *Marco Polo* is equipped with traditional teak decks and promenades for sunset gazing, star wishing, and invigorating walks in the salt sea air. Orient Lines is about to embark on several voyages of discovery to South America, with nine cruises to the continent available from November to February. The choices range from southern transatlantic tours from Cape Town to Rio de Janeiro or Buenos Aires to a 12-day exploration of the passionate spirit of cities like Rio, Montevideo, and Buenos Aires. Add on an overnight at South America's most extraordinary geological display, Iguazú Falls—more than four times the width of Niagara Falls—and visit both the Argentine and Brazilian sides of the national park.

Take a 12-day excursion through the magnificent landscapes and channels of the Chilean fjords, perhaps adding a stopover in Santiago. A 22-day tour highlights the best of Chile and Argentina, including stops at Robinson Crusoe Island and the Falklands; the 28-day South American Explorer adds Uruguay and Brazil. Whether you'd like a 9-day introduction to the Best of South America, or a three- to four-week cruise combining the best of the continent with a trans-Atlantic crossing to Rome, Orient Lines will remind you of the elegance and grandeur of cruises from days gone by.

NATURAL HISTORY
NOVEMBER 2006

The Ritual World of Pocahontas

As Jamestown celebrates its 400th anniversary, the dramatic rescue of John Smith turns out to have been part of an elaborate piece of statecraft, misunderstood by the English colonists.

By Frederic W. Gleach

In May 1607, during the reign of King James I of England, three small English ships sailed up what would soon be known as Virginia's James River and reached a small peninsula. A few more than a hundred passengers disembarked and established the first permanent English settlement in the New World: Jamestown. Although the site they selected was uninhabited, it was in the territory of the Paspahegh people, one of some thirty-odd Algonquian-speaking tribes that owed allegiance to a paramount chief best known as Powhatan. The Powhatan Indians (as the English called those tribes collectively, after their leader) soon struck back against the unauthorized incursion. The battle for control was to continue for most of the seventeenth century, though neither side properly recognized or understood the other's point of view.

Mussel-shell and silver earrings belonging to Pocahontas may have been given to her during her trip to London in 1616–17. She died in England, but the earrings were handed down through the family line of her only child, Thomas Rolfe.

It was during that struggle, in December 1607, that Pocahontas made her famous rescue of the English military captain John Smith. Smith described his experience of being brought before the paramount chief, writing of himself in the third person:

> Having feasted him after their best barbarous manner they could, a long consultation was held, but the conclusion was, two great stones were brought before Powhatan: then as many as could layd hands on him, dragged him to them, and thereon laid his head, and being ready with their clubs, to beate out his braines, Pocahontas the Kings dearest daughter, when no intreaty could prevaile, got his head in her armes, and laid her owne upon his to save him from death: whereat the Emperour was contented he should live to make him hatchets, and her bells, beads, and copper.

In the four centuries since that colorful episode took place, the story has been appropriated, mythologized, and often romanticized beyond recognition. Some scholars even doubt Smith's account, published seventeen years after the event, construing it as a self-serving fabrication. Unfortunately, no comparable early documents relate the Native American's side of the story. But given what is now known about Algonquian ritual forms and political philosophy, it is possible to reconstruct the true meaning of Smith's capture and "rescue." Today, on the eve of the 400th anniversary of the founding of Jamestown, it is long past time to replace the fictional account of this signal event in American history with what can be discerned through documentary and other evidence. The living descendants of Powhatan's people deserve no less.

The culture of the English colonists, of course, differed in many ways from twenty-first-century Anglo-American culture. Still, most people today find the English worldview more recognizable, hence much easier to grasp, than that of the Powhatans. The English were Christians—specifically, members of the Church of England—and their colony had been organized by the Virginia Company of London, chartered by the king. Accordingly, the colony was founded on both religious and mercantilist grounds, and both seemed to justify the taking of Indian lands.

For their part, the Powhatans were a confederation of tribes that, as local groups, appear to have inhabited eastern Virginia for several centuries. The confederation itself, however, probably came into being only a generation or two before the colonists' arrival. Although most scholars characterize the alliance as a confederation of tribes or as a paramount chiefdom, in fact membership in the alliance was not entirely voluntary. Many of the tribes had been brought in by conquest, and all of them paid tribute to Powhatan. Their combined territory, which encompassed most of Tidewater Virginia south of the Potomac River, including part of the Eastern Shore peninsula, was known as Tsenacommacah [*see map on page 43*]. (Other Native American groups lived to the north, south, and west of Tsenacommacah, but played relatively minor roles in the early history of the colony.)

Deerskin robe more than seven feet long belonged to Powhatan, the paramount chief of the confederation of tribes that the Jamestown colonists encountered in 1607. The robe is decorated with shell beads that may depict Powhatan at the center, flanked by a deer (right) and a wolf or mountain lion (left), and surrounded with circles that represent the various tribes in his confederation. In the background of these two pages is an engraved map of Virginia's Chesapeake region, originally published in 1612; Powhatan is detailed at the top left of the map, which is oriented with north toward the right.

In the English worldview, the universe was a "great chain of being," with a fixed set of relationships. God headed both the spiritual and natural realms; within that larger structure was human society, also organized hierarchically, with the king as its head. Power flowed down from those special individuals, and respect flowed up.

The Powhatans, in contrast, understood the universe to be a dynamic system of relationships, always with the potential for radical change. The exercise of power tended to be less coercive and more persuasive than it was among the English, and it was based more typically on the respect personally earned by a powerful individual than on an abstract right of position or privilege. Individual authority flowed from one's relationships with supernatural beings and forces (supernatural, that is, in Western terms; from an Algonquian perspective they were perfectly natural). Some Algonquian positions were inherited, but the powers of the people holding them depended on their individual qualities, which could change if they gained or lost connections with spiritual forces.

In addition to a chief, each tribe, as well as the confederation as a whole, had a council, and each chief's authority derived from the respect accorded him by that council and, ultimately, by the people. In Powhatan, the confederation had a powerful and highly respected chief. He wielded economic, political, and religious authority that was both achieved and inherited, epitomizing the ideal Algonquian leader.

In spite of his power, Powhatan was not the only leader of his confederation. Just as the English political structure followed the religious structure of Western monotheism, the political structure of the Powhatans reflected the Indians' dualistic religious system, which had two important creator beings. Two chiefs held power, each ruling in his own distinct domain. In anthropological literature, the terms peace-chief and war-chief have been applied to such figures; in practice, the division of leadership was based on the distinction between internal, domestic matters and foreign affairs—in this case, matters dealing with non-Powhatans. Although that structure was common among Algonquian groups as well as among other native peoples of what became the southeastern United States, it was never really understood by the English—or by most scholars—partly because it was so alien to Anglo-American culture.

The English colonists always sought to deal directly with Powhatan, whom they understood to be an emperor over the chiefs (or "kings") of the tribes. But Powhatan was actually the peace-chief, and so it was not his role to meet with outsiders. At least at the outset of contact, he wanted Opechancanough, the confederation's war-chief, to deal with the colony.

For their part, as the Powhatans learned more about the colony, they took Smith, who appeared to be the leader of the first group of settlers, to be the colony's war-chief. The colony's peace-chief, they concluded, was the unseen Captain Christopher Newport, who actually had charge of the ships and had sailed back to England for more supplies and settlers. Hence the Indians deemed it inappropriate that Smith, a war-chief, should meet with Powhatan.

Pamunkey Indians at the 1907 Jamestown Exposition re-enact how Pocahontas intervened to save Captain John Smith from execution. The Pamunkeys were one of the tribes that formed the Powhatan Confederation at the time of the founding of Jamestown. They are accorded official recognition by the state of Virginia, and retain a small reservation.

Given the subsequent history of European dominance in the New World, and the widespread assumption that superior arms gave the English an inescapable advantage, it is easy to forget that in Virginia in the early 1600s, the Powhatans were in control. The colonists themselves could not conceive that fact, so convinced they were of their superiority over the "savages." Yet, if it had been their intent, the Powhatans could readily have exterminated the English with a sustained campaign. Apparently, however, Powhatan saw advantages in having the colony remain. The greatest, perhaps, so long as the English could learn to behave as proper (Powhatan) people, was the access the colony afforded to English trade goods: having come from beyond the everyday world, they were imbued with spiritual power.

A settlement of outsiders on the outskirts of their territory need not have presented any special difficulties for the Powhatans, but Jamestown was planted firmly within Tsenacommacah. Some way of bringing the colony fully into the Powhatan world eventually had to be found. Had the colonists mastered the proper etiquette of chiefly relations, the means might have evolved on its own. But Smith's constant prodding to meet the Indians' "emperor" only demonstrated the urgency of normalizing what was an irregular situation. The solution was extremely creative: to conduct a ritual that redefined the English as Powhatan, and their settlement as a village of Tsenacommacah.

In December 1607, seven months after the English reached Virginia's shores, Smith was captured while exploring near the headwaters of the

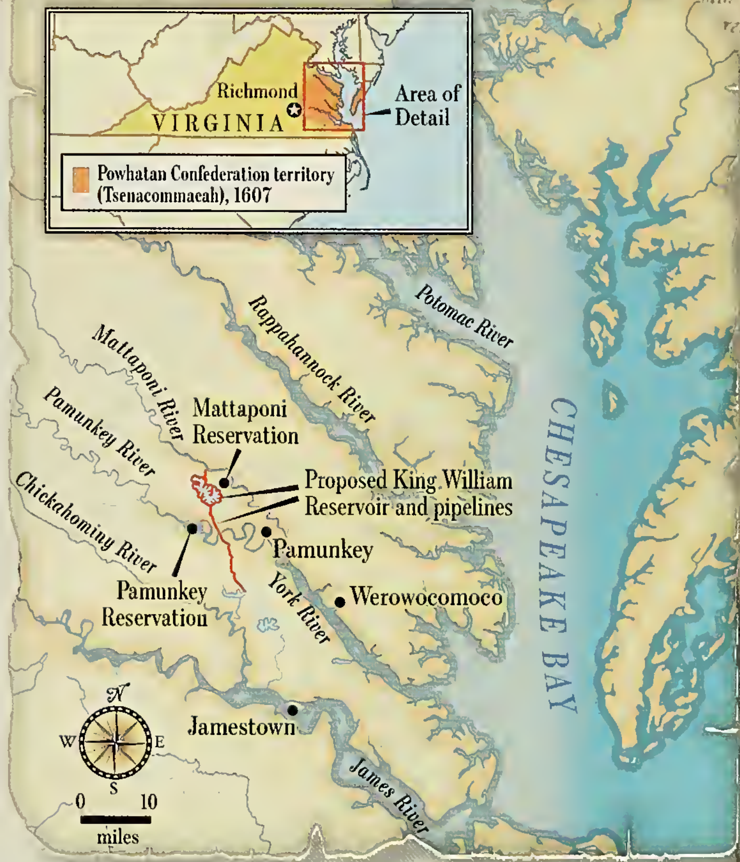
Chickahominy River. According to his account, he was taken before Opechancanough, who, as war-chief, would have been the appropriate person to oversee affairs with outsiders. There, Smith was subjected to the first of what would be three apparent threats on his life during this captivity. He was tied to a tree, facing a body of archers, but Opechancanough held up the compass Smith had given him and spared his life. Then, surrounded by armed, three-man escorts, he was led to a hunting camp, where he witnessed (or, more properly, participated in, though he didn't see it that way) an extended ritual, including a sequence of three dances. Smith was kept there for several days, and he talked often with Opechancanough, until another Indian—a man whose son Smith was accused of killing—threatened to kill him.

The Indians then marched Smith to several different villages, ending at Opechancanough's home in Pamunkey. There he was subjected to three consecutive days of rituals, in which groups of three and threefold repetitions were prominent, and maps of the Powhatan world were created. As I interpret them, the rituals were intended to redefine the world with a place for the English colony, which in effect was to join the Powhatan Confederation.

With Powhatan's brother Kekataugh taking over from the war-chief, Opechancanough, Smith was next marched to the periphery of Tsenacommacah. From there he was brought before Powhatan himself in his ruling town of Werowocomoco, on the York River. It was then that Smith underwent the ordeal at the hands of the chief that he famously described.

In the end, the dramatic events amounted to a symbolic death and rebirth, though from Smith's point of view, the renewed threat on his life must have seemed quite real, and the intervention by Pocahontas, the chief's playful daughter, then about twelve years old, a spontaneous act. But most likely it was all an elaborate drama. Two days later Smith was taken to a house in the woods, where Powhatan and 200 other tribesmen, all painted black, came to him and said they were now friends; that Smith should return to Jamestown and send presents—that is, tribute—to Powhatan; that Smith would be forever esteemed as Powhatan's son; and that the colony would be left in peace.

Intriguingly, it is after those events that Powhatan first expressed a wish to meet with Captain Newport. His shift accords with the transformation of the colony's status, and was one of the details that helped me to recognize the model of dual chieftaincy in the Powhatans. Now that dealing with the colony was an internal matter, it was appropriate from the Powhatan perspective to reach out to the colony's supposed peace-chief, instead of dealing with the war-chief, Smith.



If the colonists had kept to their allotted territory around Jamestown, if they had not constantly encroached into fresh Indian lands, and if they had sent tribute to Powhatan as did the other tribes of Tsenacommacah, good relations might have endured in perpetuity. But that was not to be. The English understanding of their relations with the Native Americans, their view of themselves as superior, their drive to increase their economic base, and their goals of converting the "heathen" Indians to Christianity all worked against an amicable relationship with the indigenous groups. Instead, the colonial territory continued expanding for years, triggering violent responses that were intended to remind the colonists of their place, but were perceived as irrational and barbaric attacks.

As for our protagonists, Smith himself was forced to return to England in 1609, following an injury. And Pocahontas, while visiting the Potomac Indians in 1613, was taken prisoner by the English. Housed in the colony with a devout minister, she soon converted to Christianity and, in 1614, with her father's blessing, married one of the colonists, John Rolfe. In 1616 she and Rolfe sailed to England, where she became a court favorite. Unfortunately, as she and Rolfe were setting out on the return voyage to


Images of Pocahontas, with the exception of the leftmost portrait, portray artistic inventions and idealizations without any claim to authenticity. Shown left to right are: an engraving made in early 1617, apparently from life, when she was visiting England (the name Matoaka, inscribed on the oval, was another of her Native American names; as a married Christian she was called Rebecca); a lithograph (ca. 1836–44) based on an earlier painting; an engraving from the book World Noted Women, *published in 1858; an image from a late-nineteenth-century cigar box; an illustration by Elmer Boyd Smith for* The Story of Pocahontas and Captain John Smith *(1906); a still of the heroine from the movie* The New World *(2005), as played by Q'Orianka Kilcher.*

Virginia in early 1617, she died of causes left unrecorded. She was buried at Gravesend. Deeply grieving for his daughter, Powhatan left the government of the confederation to his brother Itoyatan and to Opechancanough, and died not long thereafter.

By then, the balance of power was beginning to shift. The Powhatan population was declining from disease and stress, and the ranks of the colonists were steadily growing. In March 1622 and again in April 1644, Opechancanough led massive assaults against the colonists, killing hundreds. I believe those attacks were not intended to destroy the colony, but to impress upon them yet again that they were supposed to be living as Powhatans, keeping to their territory—rules they had never understood in the first place. In 1622 the Powhatans could still have destroyed the colony, had that been their desire, but by 1644 the tide had changed; destruction was no longer an option. By the second attack, according to the account published in 1705 by the Virginia historian Robert Beverley, Opechancanough "was now grown so decrepit, that he was not able to walk alone."

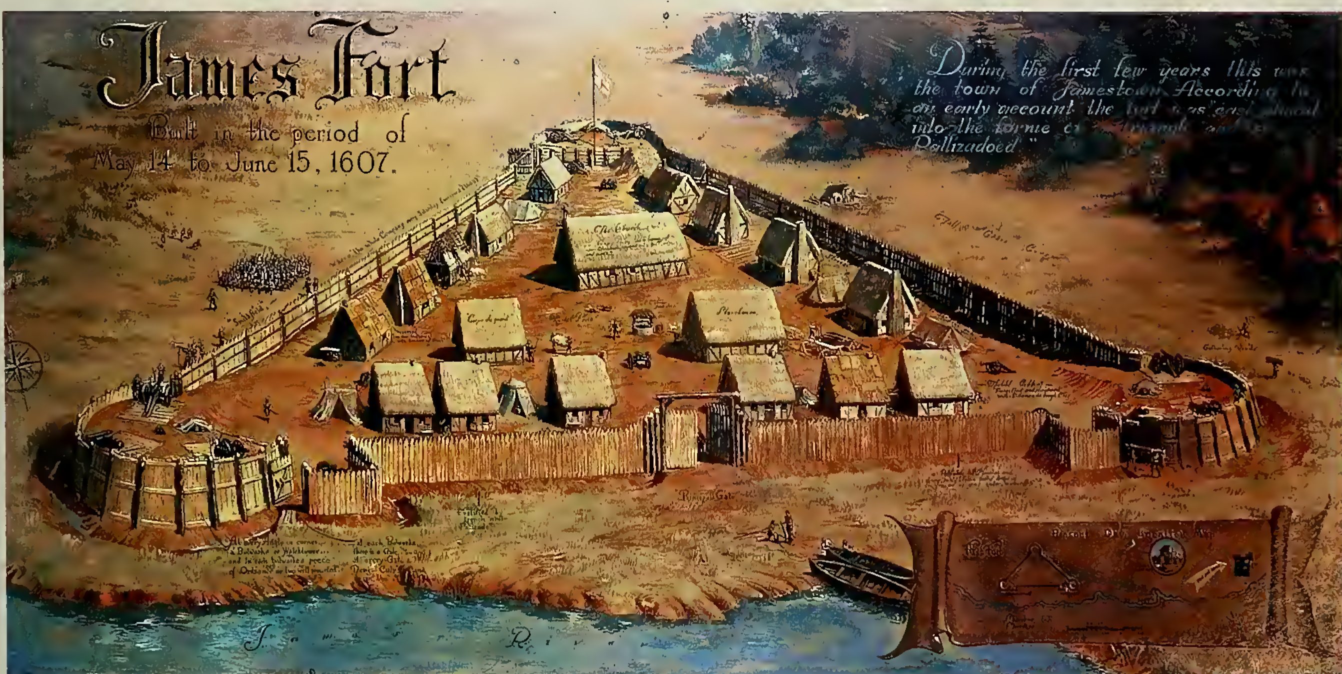
Taken prisoner in 1646, Opechancanough was killed by a soldier who "basely shot him thro' the Back." A peace treaty was signed the same year, officially establishing the remaining Powhatan Indians as a subject people and setting territories aside for them. But the colonists hardly paused in their expansions, and they repeatedly violated the 1646 treaty and its 1677 successor. The set-aside territories were reduced and in many cases eliminated. Only two small reserved areas have survived to the present, at Pamunkey and Mattaponi, Virginia; several other recognizable descendant communities remain, though without reservation lands.

For much of the three centuries after the founding of Jamestown, the Powhatans and other Virginia Indians remained largely invisible in the broader sweep of colonial and U.S. history. They farmed, fished, hunted, made pots, traded with their neighbors, worked as hunting and fishing guides, and regularly paid their annual tribute to the governor, typically in deer and turkeys. Disregarded by most Virginians, they gradually abandoned many of the old ways and incorporated many aspects of the surrounding culture. But they never forgot their part in history or lost their desire to be treated as equals.

Following the American Revolutionary War and throughout the nineteenth century, European Americans put considerable effort into rediscovering the roots of the nation's history. Scholars in elite northern institutions, however, emphasized Plymouth and the Puritans rather than the earlier southern colonies, and challenged the accounts from Virginia. The tale of Pocahontas was one episode, however, that seems never to have been forgotten. The story of the rescue was retold in plays and epic poems throughout the nineteenth century. In the late nineteenth century the Powhatan Indians themselves began to perform recreations for public gatherings.

When Jamestown planned its tercentennial celebrations, the Indians hoped to use that stage to reclaim their heritage. The original intent of the 1907 Jamestown Exposition was to return the Jamestown colony and Virginia to their place of historical precedence. Had the exposition retained that emphasis, the Powhatans' participation might have enhanced their public recognition. But as the exposition was developed, financed, and marketed, it became more of a celebration of American military and naval might. Not part of the official attractions, the Virginia Indians were obliged to perform Pocahontas's rescue of Captain John Smith in "The Warpath," a large area of the fair grounds devoted to amusements. There they had to compete with the image of Indians presented by the "101 Ranch Wild West Show," whose Native American participants came from Oklahoma and the Plains. The one contemporary account that mentions the Virginia Indians' performance is derisive.

The Powhatans' circumstances soon got even worse. In 1924, Virginia's Racial Integrity Act was passed, defining and separating "white" and "colored" persons. Walter A. Plecker, the state registrar, made it his



James Fort, built in 1607 almost immediately after the Jamestown colony was founded, is shown in an artist's reconstruction based on documentary evidence and recent archaeological discoveries. For the past two centuries, many people believed the remains of the fort had been washed away by the James River, but the Jamestown Rediscovery project of the Association for the Preservation of Virginia Antiquities, which launched excavations in 1994, has demonstrated that most of the foundations have been preserved.

Postcard from the Jamestown tercentennial prominently depicted Native Americans. Nevertheless, descendants of the Powhatan Indians were not invited to participate in any of the official attractions, but were relegated to the amusement area.

mission to have all Indians defined as "colored." He even went so far as to hunt out families identified as Indian and alter their birth certificates. The Virginia Indians had intermarried, as had most eastern tribes, with other peoples regardless of race, and Plecker set out to convince the public and to establish legally that no "pure," "true" Indians remained in Virginia. (The law was less scrupulous about "purity" in declaring that Virginians were "white" if they had no more than one-sixteenth Indian ancestry and no other racial mixing—a loophole to accommodate those who were proud to claim descent from Pocahontas through her son Thomas Rolfe.)

Only well after Plecker's retirement in 1946, and with the rise of Native American activism in the 1960s and 1970s, did conditions begin to improve. In the 1980s the state began to recognize nonreservation communities of Indians as tribes; added to the two reservation communities that had already long been recognized, the total number has reached eight. Yet none of the tribes has gained federal status. Like most other eastern tribes, the Powhatans and the other Virginia tribes made treaties with seventeenth-century entities that predated the federal government. Those treaties have never been recognized at the federal level—though several times in the past century various groups of Virginia Indians have explored the possibility.

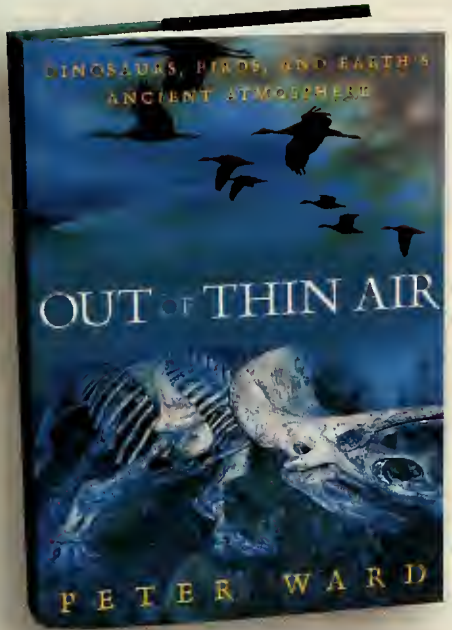
Today six of the eight state-recognized tribes have renewed their efforts to get federal recognition. Their aim is to reverse their marginalization and improve their access to high-quality education. The proposed King William Reservoir, which would divert water from the Mattaponi River and threaten both the natural environment and the Mattaponi Indians' fisheries and way of life, has helped galvanize their determination. The tribes feel they might have more negotiating power if they had federal recognition. But some Virginians oppose recognition for fear that the tribes might then develop casino gambling. And some Virginians still seem to accept Plecker's view that no real Native Americans are left in Virginia, anyway.

With the approaching 400th anniversary, there has been another renewal of interest in the Indians of Virginia, and particularly in the Powhatan peoples whose ancestors met the Jamestown colony. Archaeologists are excavating not only at the site of Jamestown but also at Werowocomoco, Powhatan's chiefly seat. Historians and anthropologists are revisiting the old accounts. Perhaps most important, the Indians themselves are still striving to regain some recognition and appreciation.

This past July, a delegation of Virginia Indians traveled to England. They met with school groups and government officials, conducted a dance and drum exhibition, led a seminar on "Culture and Identity Today," and held a private ceremony for Pocahontas at the church where she was buried, in Gravesend. Their English hosts received the group warmly, and, for their part, the visitors found the experience deeply moving and rewarding. It was the first time an official delegation of Virginia Indians had made such a journey. □

IT'S ELEMENTARY

AIR



October • Science • 0-309-10061-5
$27.95 • 276 pages

For 65 million years dinosaurs ruled the Earth–until a deadly asteroid forced their extinction. But what accounts for the incredible longevity of dinosaurs? A renowned scientist now provides a startling explanation that is rewriting the history of the Age of Dinosaurs.

"So much more than another book about dinosaurs *Out of Thin Air* is an authoritative, yet very readable, treatment of the history of oxygen levels and their affects on diversity and extinction from deep time to the modern world. In addition to those who consider themselves evolutionary biologists and geobiologists, this book is for those in the public who are concerned with the state of present atmosphere and what it means to our health. This important book is to be read, digested, and discussed."

–Professor David B. Weishampel, palaeontologist, department of cell biology and anatomy, Johns Hopkins University School of Medicine, and co-author of *The Evolution and Extinction of the Dinosaurs*

"Ward's ideas deserve careful scrutiny and are likely to be discussed broadly." –*Publishers Weekly*

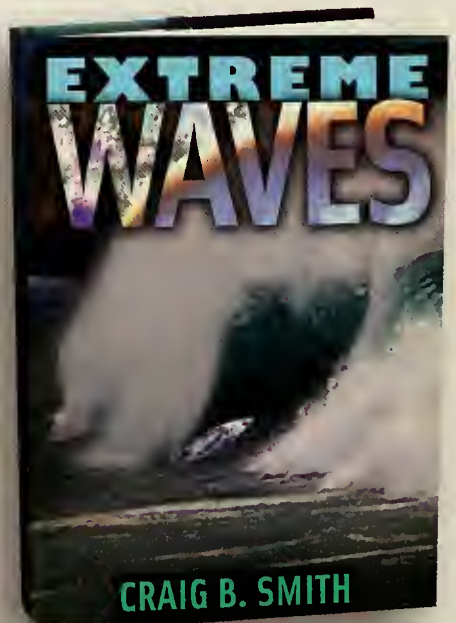
WATER

Science is our best tool for analyzing and predicting the most extreme waves. Eyewitness accounts may be our best tool for understanding why we need to. Author and amateur sailor Craig B. Smith combines these elements into a fascinating account of where extreme waves come from and why they matter.

"Rough seas, rogue waves, and tsunamis are fascinating but dangerous. In this excellent and readable overview, Craig Smith provides a splendid blend of descriptions of historical incidents, recent personal accounts, and scientific underpinnings. Mariners, armchair enthusiasts, and those concerned with the safety of ships at sea and of coastal communities will enjoy the book and learn a lot from it."

– Chris Garret, Lansdowne Professor of Ocean Physics, University of Victoria

"The complexity of waves staggers the imagination. In modern times, Smith says, with the importance of shipping and the growth of off-shore drilling platforms, understanding waves is more vital than ever–we must especially understand extreme, or rogue, waves that can appear out of nowhere and tower over a hundred feet high . . . Science is only beginning to understand tsunamis, hurricanes and rogue waves, and Smith's book is for readers who want a serious scientific look at what we're learning." –*Publishers Weekly*



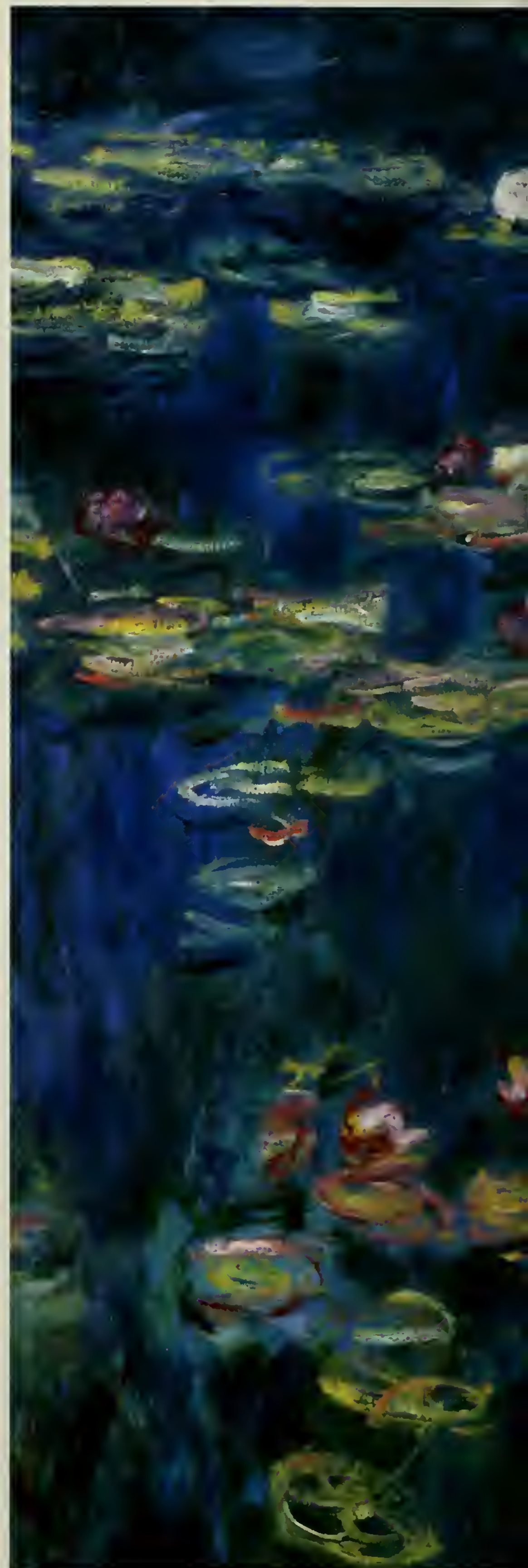
November • Science • 0-309-10062-3
$27.95 • 336 pages

JOSEPH HENRY PRESS
an imprint of The National Academies Press
888-624-7651 • www.jhpress.org

Sex among the Flowers

A bouquet of botanical breakthroughs is shedding light on the exuberant evolution of the earliest flowering plants and their mysterious sexual history.

By William E. Friedman



In an oft-quoted letter written in 1879, Charles Darwin confessed, with his usual candor, that the "rapid development as far as we can judge of [flowering plants] within recent geological times is an abominable mystery." In fact, through much of Darwin's later life, he was keenly interested in and vexed by the evolutionary origin of flowering plants, or angiosperms. In 1875, for instance, Darwin confided to a colleague that the "sudden appearance of so many [angiosperms] in the [Cretaceous period] appears to me a most perplexing phenomenon to all who believe in any form of evolution, especially to those who believe in extremely gradual evolution." Even just months before his death in 1882, Darwin continued to maintain that "nothing is more extraordinary in the history of the Vegetable Kingdom . . . than the *apparently* very sudden or abrupt development of the [flowering plants]."

Darwin's frustration stemmed, in large part, from the remarkably rapid origin and diversification (as shown by the fossil record) of flowering plants within a brief period of earth's history—and his own strong views that evolutionary change was typically a slow and gradual process. Darwin was convinced that the origin of angiosperms was one of the great challenges in the effort to decipher the evolutionary history of life.

What so impressed him remains impressive today: how some 250,000 species of flowering plants have come to dominate the earth's vegetation. They flourish in the tropics and in the arctic, in alpine terrain, as well as in deserts and lakes. They range from mighty oak trees to woody and herbaceous vines, from underground parasites to carnivores that prey on insects, from floating aquatics to epi-

Claude Monet, Water Lilies: Green Reflections *(detail), ca. 1914–26. The painting celebrates one of the world's most familiar flowers. Water lilies are also among the most ancient flowering plant lineages on earth, having thrived since the age of the dinosaurs.*

phytes (plants that live on other plants), such as orchids and bromeliads. Darwin was also astute enough to recognize the importance of a question that intrigues evolutionary biologists today: how to square such diversity with the fact that flowering plants are far and away the youngest major lineage of plants. Their evolutionary origin can be traced in the fossil record to the Early Cretaceous, some 130 million years ago. In contrast, conifers had a head start of more than 170 million years. By all measures, angiosperms have diversified to a greater extent and in a shorter time than any other group of plants.

What were the progenitors of angiosperms? What did the first ones look like? How did their many unique biological features evolve? Why did the origin and early diversification of flowering plants proceed so rapidly? To shed light on such questions, I have studied extant plant species belonging to the same ancient flowering plant lineages that flourished in the days of dinosaurs. My findings, together with the recent work of other botanists, indicate that many of the century-old assumptions about the biological features of the first flowering plants and the subsequent diversification of early angiosperms are fundamentally wrong.

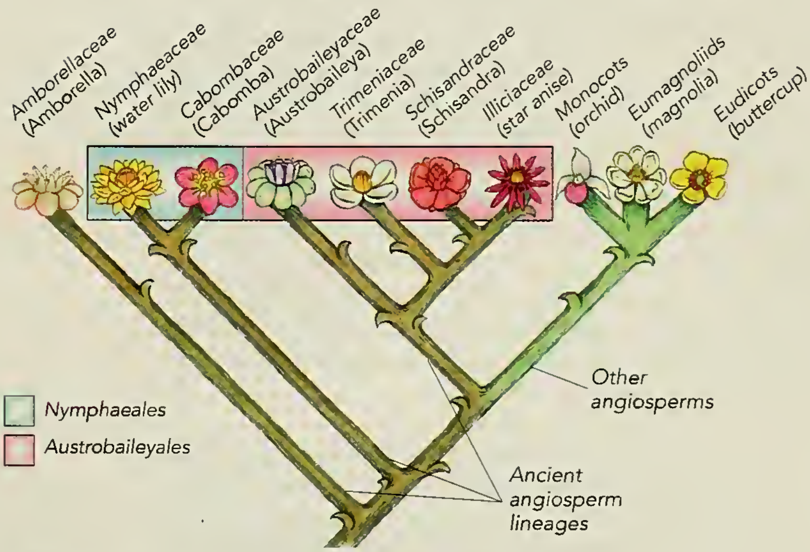
Like gymnosperms, angiosperms propagate via seeds, which house and nourish the developing embryo. But unlike gymnosperms, whose seeds are exposed to the environment (in cones, for instance) angiosperms envelop their future seeds in one or more protective structures called carpels. The word "angiosperm," the botanical name for flowering plant, comes from the Greek words for "vessel" and "seed."

The recent breakthroughs in reconstructing early angiosperm evolution and diversification have come from work in three interconnected fields of evolutionary biology: paleontology, phylogenetics (the analysis of the genealogical relationships of life), and morphology (the study of the development and structure of organisms).

The fossil record remains silent about the ancestors of flowering plants, just as it was in Darwin's day. Such a lack of data has been an important obstacle to understanding the origins of flowering plants. Fortunately, in the past decade, paleontologists—by digging, hammering, and sifting through layers of Early Cretaceous fossils—have radically expanded knowledge of how the earliest flowering plants diversified. Armed with soil sieves and microscopes (or hand lenses), paleobotanists have discovered thousands of fossil flowers, seeds, and fruits, exquisitely preserved in all three dimensions at sites around the world. Those primeval forms were fossilized nearly instantaneously through a process of charcoalification. In essence, they were toasted to a hard consistency by proximity to a fire and dropped into sediments that still cling to the banks of rivers.

It is now evident that within just a few million years of their origin, an astonishing array of floral and vegetative morphologies had evolved among flowering plants. Paleobotanists have discovered early flowers resembling those of water lilies, star anise, members of the Chloranthaceae, the magnolia order, the buttercup order, monocots and more. Other early angiosperm flowers are sufficiently different from those of extant lineages to represent groups now long extinct.

Most people think of a flower as having four basic parts or organs: sepals and petals (the sterile parts of the flower that together make up the "perianth"), stamens (the pollen-producing "male" organs), and carpels (the seed-producing "female" organs). Although we tend to be drawn to flowers because of their often showy petals, the earliest fossil flowers either lacked a perianth or had an inconspicuous perianth made up of morphologically similar parts called tepals. All of the earliest fossil flowers were small, on the order of a few millimeters, and rather undistinguished. Those fossil discoveries confirm the recent hypothesis made by the floral morphologist Peter K. Endress of the University of Zurich: that sepals and petals evolved after angiosperms began to diversify.



Evolutionary "family tree" depicts the relations among the lineages of flowering plants, reconstructed on the basis of recent DNA analysis. Amborella and its ancestors have now supplanted a magnolia-like group as the lineage thought to be the most ancient among flowering plants.

Although most Early Cretaceous flowers were hermaphroditic (with both stamens and carpels), some species had individual flowers that included only stamens (male function) or only carpels (female function). In some cases a single stamen constituted the entire flower—definitely not corsage material!

All in all, those paleontological findings are remarkable, particularly in light of the assumption, which prevailed through most of the twentieth century, that the first flowering plants had moderately large, multipart flowers with a conspicuous perianth—the one morphology consistently absent from the earliest fossil record of flowers.

Following on the heels of that wealth of newfound fossil data, advances in phylogenetic theory and data analysis have opened a second major front in the effort to decipher the early evolution of angiosperms. Throughout most of the twentieth century, a broad consensus emerged that angiosperms evolved from magnolia-like plants. Then in the late 1990s, DNA analyses dethroned them, and crowned two other lineages as the most ancient living exemplars of angiosperms: the amborella family (with a single species of small trees endemic to New Caledonia, *Amborella trichopoda)* and the Nymphaeales (water lilies, numbering about seventy species). Both of those lineages began to evolve before the origin of the three groups of flowering plants that dominate today: the monocots, the eudicots, and the eumagnoliids.

Once botanists realized their studies of the earliest flowering plants had been focusing on the wrong groups, plant morphologists intensified their studies of the poorly known biological features of *A. trichopoda* and the water lilies. But in interpreting their findings, a note of caution must be sounded. Can one make valid inferences about the flowering plants of the distant past from studies of extant members of ancient flowering plant lineages? Can the modern plants really be regarded as "living fossils?" The answer to both questions is yes, and no. All organisms, ourselves included, are an amalgam of ancient and more recently evolved biology. So only some of the biological features of *Amborella* and water lilies can help clarify the early evolutionary history of flowering plants. The *A. trichopoda* plants growing in New Caledonia today are 130 million years removed from the earliest angiosperms, as are the water lilies that grace lakes worldwide. The key to the study of so-called "ancient lineages" of flowering plants is to identify those biological features of the extant members of the lineage that have been inherited from the earliest flowering plants themselves.

Even the two most ancient lineages of flowering plants have undergone substantial changes in their evolutionary history. The best current evidence is that the earliest angiosperms were small, tropical understory trees that produced small hermaphroditic flowers. In other words, although today's water lilies are aquatic, their ancestors were not. And although today's *A. trichopoda* are dioecious, that is, their male and female parts are borne on different plants, their precursor plants have parts of both sexes.

In particular, in the case of the amborella lineage, unisexual plants evolved at some point between its divergence from all other flowering plants 130 million years ago and the origin of the sole extant species, *A. trichopoda* (which may even be a relatively young species). Despite that change, *A. trichopoda* retains "primitive" characteristics in that it lacks differentiated petals and sepals (it has tepals).

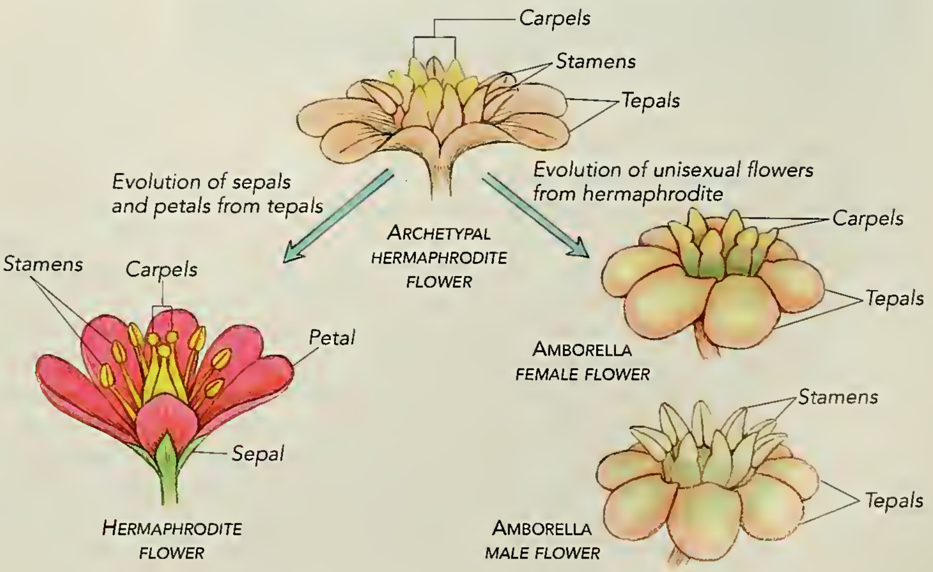
In my laboratory in the late 1990s—practically before the ink was dry on the new phylogenies—my colleagues and I began to investigate the reproductive features of *Amborella,* water lilies, and members of other extant ancient angiosperm lineages. One of the biggest questions about the origin and early evolution of flowering plants arises from the unique way they nourish their progeny. Inside the seed of every flowering plant are two closely integrated partners in the reproductive process: an embryo that will develop into the next generation of plant, and an entity called the endosperm. Endosperm is a tissue that forms alongside the embryo, acquires nutrients from the maternal plant, and subsequently passes the nutrients along to the developing embryo.

Although endosperm may seem far removed from people's day-to-day lives, nothing could be further from the truth. Two-thirds of human caloric intake worldwide is endosperm. Endosperm accounts for most of what is the edible grain of rice and wheat, most of the kernel of corn, even the milk and meat of a coconut.

It is no wonder that many kinds of endosperm taste good and are nutritious; endosperm is filled with nutrients that, barring human intervention, would have nourished a plant embryo. Without endosperm, human evolution might have proceeded very differently—or not at all. The diet of early humans on the savannas of Africa probably included many kinds of grains that were, essentially, endosperm. The initial cultivations of maize in the New World and wheat in Eurasia were central to the development of human agricultural practices thousands of years ago.

Angiosperms are the only plants to nourish their embryos with endosperm. What makes endosperm so unusual and distinct from the embryo-nourishing tissues of any other plants is that it, like the embryo, develops only after being fertilized [*see illustration on page 53*]. The fertilization event takes place at the same time as the egg is fertilized. Hence the process is known as "double fertilization," and it is unique to flowering plants. Typically, endosperm begins growing when one of the two sperm carried by a pollen grain fuses with two "polar nuclei" within the future seed. The other sperm fertilizes the egg. The result is that each endosperm nucleus typically carries three sets of chromosomes (hence it is "triploid") and is genetically biparental.

By contrast, in all other plants the tissue that nourishes the embryo carries only one set of chromosomes (hence it is "haploid") and is derived solely from the maternal plant. Evolutionary biologists regard the biparental genetic endowment of endosperm nuclei as a potential major advantage because an extra set of genes from a second parent confers hybrid vigor on the tissue. That hybrid vigor may have been a critical factor in enabling flowering plants to reproduce more quickly than their ancestors, which in turn may have enabled angiosperms



Hypothetical flower of the ancestral angiosperm (at right, top) looked quite different from the flowers most people think of today. It lacked petals and was just a few millimeters across. Its coloring is unknown. The distinction between sepals and petals characteristic of most modern flowers evolved after angiosperms began to diversify (near right). Like most modern flowers, the archetypal flower was probably a hermaphrodite: it possessed both female parts (carpels) and male parts (stamens). Yet the flowers of modern Amborella, the only living member of the most ancient extant lineage of angiosperms, are unisexual (far right). The flowers are not all drawn to the same scale.

to move into ecological niches not already occupied by other plants.

But how did plants shift from embryo-nourishing tissue that was haploid and genetically maternal to the more vigorous tissue that is triploid and genetically biparental? For more than a century, that question has remained unanswered. About twenty-five years ago, a few geneticists suggested that the endosperm of flowering plants had evolved through a diploid stage. But there was no evidence: almost all flowering plants have triploid endosperms. Of course, it was possible that an ancient lineage of flowering plants bearing a diploid intermediary stage had gone extinct.

Armed with the new phylogenies, Joseph H. Williams, a botanist now at the University of Tennessee in Knoxville, several of my students, and I began an intensive study of fertilization and endosperm in Nymphaeales (water lilies) and members of other ancient angiosperm lineages such as *Illicium* (star anise) and Austrobaileyales. To our surprise, we found that endosperm begins to form after the fusion of a sperm with a single haploid female nucleus in members of the Nymphaeales and Austrobaileyales. The result is diploid, genetically biparental endosperm. It looked as though we had discovered a missing link—a diploid intermediate step—between the haploid, genetically maternal, embryo-nourishing tissues in the ancestors of flowering plants and the triploid, genetically biparental endosperms of most flowering plants.

Amborella plants living in New Caledonia today may bear the closest resemblance among modern plants to the first angiosperms—though which features of the modern plant are ancient and which developed more recently is often hard to tell. The flowers are just a few millimeters across; the ones in the photograph are magnified 20X.

If only we had left well enough alone!

Two years ago I finally began to explore the reproductive biology of *Amborella*. There had been hints in the past that its endosperm might be triploid, like that of most other flowering plants. My work confirmed that it was, in contrast with the diploid star anise. Because *Amborella* represents a lineage more ancient than Nymphaeales or the Austrobaileyales, the conceptually satisfying identification of a potential missing link in the two younger groups was called into question. Two equally plausible scenarios emerged from that research. Perhaps endosperm was originally diploid, and the amborella lineage and most other angiosperms separately became triploid. Or perhaps endosperm started off triploid, at least in the common ancestor of all extant angiosperms. If the latter was the case, the diploid endosperms of water lilies and the relatives of star anise evolved by eliminating one of the two sets of chromosomes from the mother plant. Sometimes, more data lead from a clear-cut hypothesis to several alternative evolutionary explanations, none of which is provably better than the others. Such is the life of an evolutionary biologist.

Another line of investigations has led to similarly intriguing complications. As I was examining the reproductive process in *A. trichopoda,* I discovered that the species differs from all other flowering plants in the way it forms an egg cell. The feature was extremely subtle, and it took nearly two years of data collection and analysis to become certain of the details.

The way gametes (egg cells and sperm cells) form in plants is highly conservative; evolutionary innovation is rare. In all plants except the angiosperms the formation of an egg cell is "indirect": the egg is one of the daughter cells from a cell division of the so-called egg-mother cell. (For unknown reasons the other daughter cell eventually degenerates.) In contrast, all flowering plants form egg cells directly. There is no egg-mother cell or final cell division.

All flowering plants, that is, except *A. trichopoda.* When it comes to making an egg cell, *A. trichopoda* behaves like all nonflowering plants: it first forms an egg-mother cell that divides to produce an egg and a sister cell that eventually degenerates. Here, then, is a potential missing link between flowering plants and their nonflowering ancestors.

Or is it? It is also possible that the first flowering plants formed their egg cells directly, and that sometime along the 130-million-year-long path to *A. trichopoda,* this lineage reverted to (or convergently evolved) indirect egg-cell formation.

Each explanation is a good fit with the known data. For now, there is nothing to rule out any of these hypotheses.

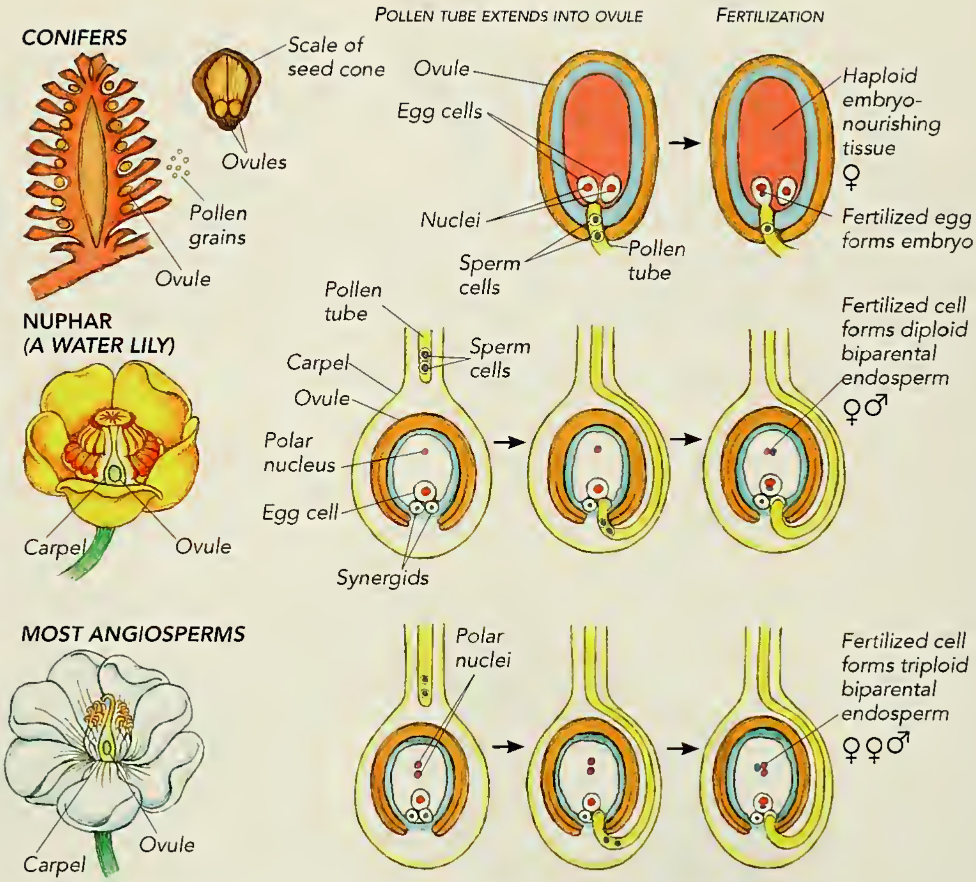
The two recent embryological discoveries—diploid endosperm in Nymphaeales and Austrobaileyales, and indirect egg-cell formation in *Amborella*—may one day gain satisfactory evolutionary explanations. Yet, no matter what the explanations, one thing is certain: these findings demonstrate that the reproductive biology of ancient angiosperm lineages is far more diverse than botanists had ever dreamed.

Taken together, the discoveries strongly suggest that within the first 15 million years of angiosperm history more structural and developmental innovations evolved than during the preceding 230 million years of seed-plant evolution. In essence, angiosperms broke the mold.

And so, to return to the question I asked at the beginning of this article, what accounts for this biological revolution? Why, nearly 230 million years after the establishment of slowly evolving seed-bearing plants, did so many biological innovations appear among angiosperms in such a brief period of time?

Many ideas have been put forward over the years. The French paleobotanist Gaston de Saporta, in his correspondence with Darwin, first suggested that the rapid pace of angiosperm diversification was a result of the co-evolution of showy flowers and insect pollinators. Many biologists have pointed to the potential advantages of a genetically biparental endosperm, as I mentioned earlier.

Recently botanists have discovered evidence of a "whole-genome duplication" among the immediate ancestors of flowering plants. If the first angiosperms had an extra, redundant genome, it would have provided an entire set of genes that were no longer constrained to perform their previously necessary biological roles. Instead, they could have served as raw materials for evolutionary experimentation at the molecular level, significantly enhancing the potential for biochemical and structural innovations.



Shifts in fertilization among three plant groups may hold a key to understanding the evolution of flowering plants. In nonflowering seed plants such as the conifers (top row), one of two sperm released by a pollen tube fertilizes an egg cell in what will become the seed and forms an embryo. The conifer's embryo-nourishing tissue is haploid, that is, each of its cells has one set of chromosomes. What makes most angiosperms unique in the plant world is double fertilization (bottom row). Once the tip of the pollen tube reaches a helper cell called a synergid, one sperm from the tube fertilizes an egg cell, and a second sperm fertilizes two female "polar nuclei" near the egg cell. That second fertilization initiates the growth of the embryo-nourishing tissue, known as endosperm. Endosperm in most angiosperms is triploid, that is, each of its nuclei has three sets of chromosomes. Nuphar (middle row), a member of the ancient angiosperm lineage of water lilies, may be a missing link between seed plants such as conifers and most angiosperms. Its endosperm is diploid (each of its nuclei has two sets of chromosomes), the result of the fusion of a sperm with one rather than two female polar nuclei.

In the final analysis, modern biologists must still live with Darwin's assessment: the rapid and extraordinary diversification of flowering plants within recent geological times is "perplexing" and "mysterious." In spite of recent breakthroughs, it remains difficult, if not impossible, to fathom the myriad causes for such rare periods of rapid evolutionary diversification and innovation during the history of life.

Is that a problem? Hardly. It is a fair reminder that reconstructing evolutionary history is not always simple or straightforward. It is, however, always enjoyable—a statement with which Darwin, vexed as he was by the angiosperms, would surely agree. □

Matters of Size

From bacteria to blue whales, organisms live in worlds defined by their size. The implications for movement, metabolism, and even life span are surprisingly diverse.

By John Tyler Bonner

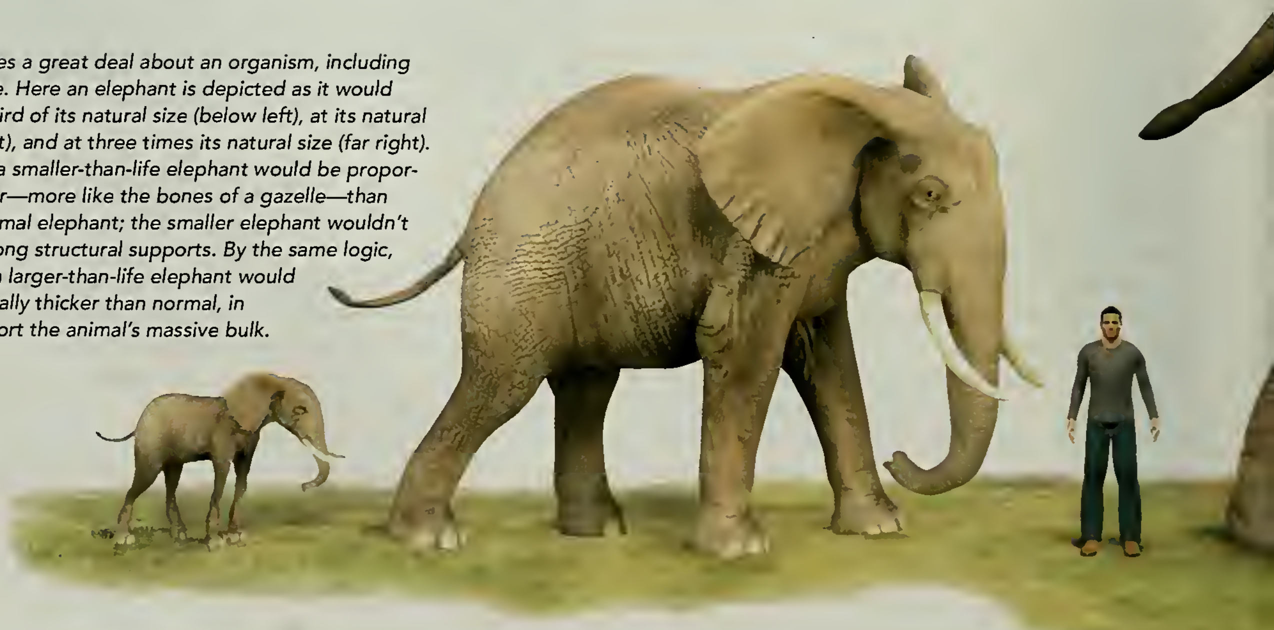
When I was a student and first saw, through a microscope, one-cell protozoa moving across my field of vision, I marveled at how fast they traveled. Later I realized that they were in fact moving very slowly and that the magnification of the microscope had fooled me. After all, speed is distance divided by time, and the high power of the microscope made the minute distance appear quite large. The image of those microscopic protozoa zipping around at an incredible rate was an optical illusion. It was rather disappointing to learn that the microworld was not dazzlingly fast but rather sedate.

I suppose it was only natural that I perceived my first protozoa from my own frame of reference. I judged them not on their terms—taking account of how their small size might affect how they interacted with their environment, how they moved in space and through time—but on my own terms. Yet as a comparatively large creature, I live in a world almost inconceivably different from the one that protozoa inhabit. Among living organisms, size is everything. It is the supreme regulator of all matters biological, and thus a prime mover in evolution. Size governs the shape and activities of all organisms, from the smallest bacteria to the largest whale—which, remarkably, differ in mass by some twenty-one orders of magnitude. Size is the universal determinant of what any organism can be and can do.

Size matters most because of its direct effects on various physical properties. An organism of any given size must have enough strength to support itself and to move. It must have a surface that allows enough oxygen and food to reach its inner tissues. It must have a proper division of labor among the structures of its body, and an appropriate rate of metabolism for those structures to function. Ultimately, an organism's size determines everything about it, including its abundance, rate of locomotion, generation time, longevity, and anything else to do with time.

Consider the relation between weight and strength. The weight of a body is directly related to its volume. If the body shrinks or grows by some factor in its linear dimensions without changing shape, its volume shrinks or grows by the cube

Size determines a great deal about an organism, including its basic shape. Here an elephant is depicted as it would appear at a third of its natural size (below left), at its natural size (near right), and at three times its natural size (far right). The bones of a smaller-than-life elephant would be proportionally thinner—more like the bones of a gazelle—than those of a normal elephant; the smaller elephant wouldn't need such strong structural supports. By the same logic, the bones of a larger-than-life elephant would be proportionally thicker than normal, in order to support the animal's massive bulk.

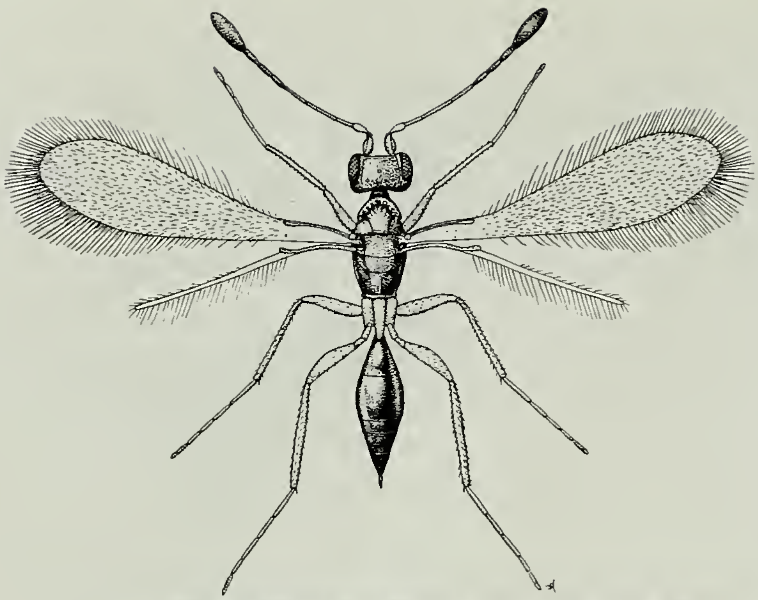


of that factor. For example, double the edge length of an ordinary cube, and your new, enlarged cube will be 2^3, or eight, times its original volume. Structural strength, by contrast, depends on the cross-sectional area of the support—a leg bone, say. Growth or shrinkage in a linear factor changes area by the square of that factor. Any cross section of the same cube whose volume grows eightfold will enlarge by only a factor of 2^2, or four. So as the size, and thus the weight, of an organism increases, the relative strength of its skeleton or other supporting structures actually decreases.

Galileo Galilei, the revolutionary Italian astronomer, first demonstrated the principle in his book *Dialogues Concerning Two New Sciences,* published in 1638. Trees cannot grow to extraordinary size, he writes,

> because the branches would break down under their own weight; so also it would be impossible to build up the bony structures of men, horses, or other animals so as to hold together and perform their normal functions if these animals were to be increased enormously in height; for this increase in height can be accomplished only by employing a material which is harder and stronger than usual, or by enlarging the size of the bones, thus changing their shape until the form and appearance of the animals suggest a monstrosity.

In the animal world, the fact that a small gazelle has slender, graceful legs, and an elephant is endowed with great stumps, is precisely what Galileo would have expected. If gravity on Earth were what it is on the Moon—a sixth of its usual strength—one could imagine that elephants would have evolved into gigantic gazellelike beasts. As



Fairy fly (Alaptus magnanimus) *is shown fifty times its natural size. Small organisms, particularly those less than a millimeter long, exert such small inertial forces that they experience the air (or water) they live in as a highly viscous substance. The hairs on the wing margins of the fairy fly are adaptations that help it "swim" through the air.*

Galileo makes clear, the shape of trees is equally affected by size. A giant sequoia has, like the elephant's foot, a wide, solid base compared with the base of a smaller tree.

Surfaces that permit oxygen, food, and heat to diffuse into or out of the body also vary with size, and those variations can have a powerful effect on shape. Diffusion is the random movement of molecules from regions of high concentration to low, so that at equilibrium the molecules are evenly spread out. The process takes place through an animal's surface. Since the area of the surface varies with the square of the animal's linear dimensions, and the weight varies with the cube of those dimensions, the rate of diffusion through the animal's surface decreases proportionally as the animal grows.

Consider two hypothetical spherical organisms, one the size of a sand grain a millimeter in diameter and the other the size of a Ping-Pong ball. Oxygen is a small molecule that diffuses rapidly; in a matter of seconds it can penetrate a living body to a depth of one millimeter. The middle of the sand grain-size sphere is close enough to the surface that its oxygen is continuously replenished by steady diffusion. But in the Ping-Pong ball-size beast, a molecule of oxygen would take an hour or so to reach the interior, and that would not do. The only way an organism larger than a millimeter in diameter can survive is to bring its interior within a millimeter of its surface—everywhere. That can be managed by radically increasing the amount of surface, making many convolutions and folds so that every interior point is close to the surface. In practical terms, as the organism enlarges to the size of a Ping-Pong ball, it must grow more skin. In doing so, it keeps the ratio of its surface area to its volume from decreasing as fast as would be the case if there had been no change in the shape of its surface. The result is a radical change in shape.

Shape changes brought about by diffusion problems can be far more extreme than simply the making of more skin. To get oxygen to inner cells, animals have a marvelously complex set of devices. They have lungs or gills that bring the oxygen close to the blood vessels; blood that picks up the oxygen; a heart, a most ingenious and durable pump that pushes the oxygen-bearing blood into a system of branching blood vessels; and minute capillaries, which permeate the body and lie close—well within the one millimeter limit—to each cell. The lungs (or gills) and blood vessels have vast surfaces; as in a wrinkled Ping-Pong ball, they keep the surface-to-volume ratio of large animals roughly the same size as it is in smaller creatures. More than that, motion—the lungs moving air in and out, the heart beating to circulate the blood—supplements diffusion to deliver fresh oxygen rapidly to the cells.

To keep going, an animal also needs to take in food that it can burn for energy. The food canal, from mouth to anus, is a tube, a surface through which the broken-down, dissolved food must pass. The greater the surface of the gut, the greater the ability to absorb food; the larger the animal, the greater must be the surface area of its gut to keep a constant ratio of gut area to the animal's weight. Thus the gut of a nematode worm, which is little bigger than an eyelash, is a straight tube. The human gut is a tortuous, convoluted tube many times our length. Furthermore, our small intestine has a forest of minute papillae lining its interior that greatly increase the gut surface. We also have salivary glands, a pancreas, and a liver, all producing batteries of enzymes that break down our food into small molecules, so that it can diffuse more readily through the gut wall. Size thus has a profound effect on an organism's complexity: the greater the size, the more division of labor is required to keep the body supplied with what it needs from the outside world.

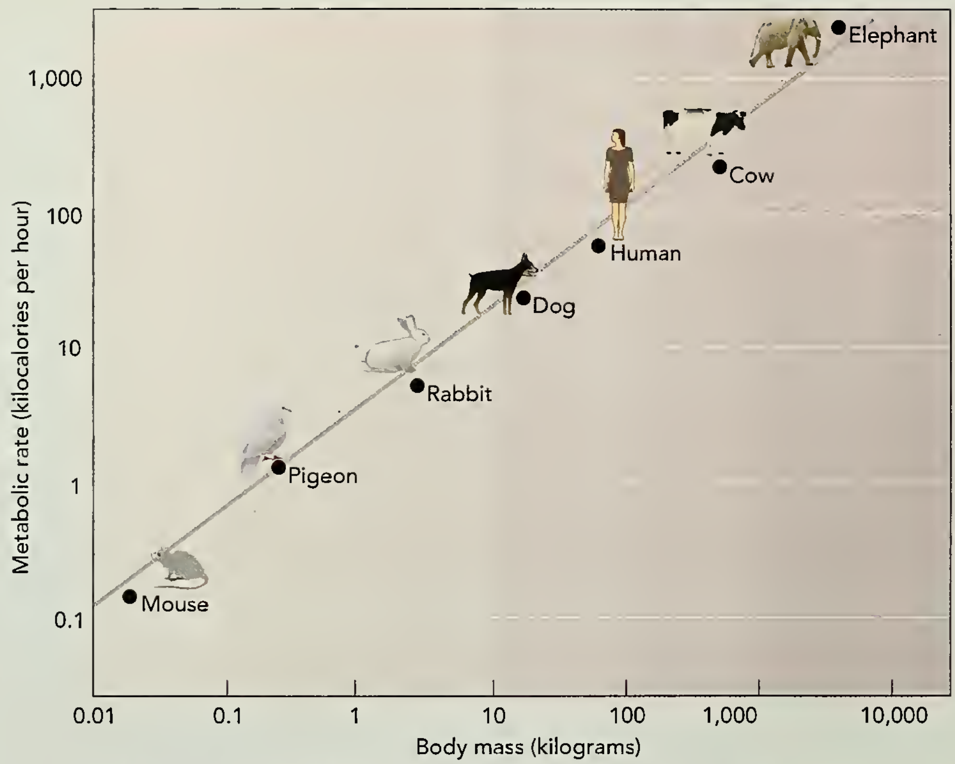
Just as an organism's basic body plan varies with size, so does the speed of its movements. Large animals do everything at a slower pace than small animals. A hummingbird's wings move so fast that one cannot see them, whereas a great blue heron gracefully waves its wings in what, by comparison, appears to be slow motion. Such a relation between size and movement is apparent in the human body.

In the eyelids, the small muscles responsible for blinking can contract in a split second. By comparison, our legs move slowly.

In 1950 the Nobel Prize–winning English physiologist Archibald V. Hill published an important paper concluding that animals of the same proportions should run at the same speed. A mouse and a more or less similarly constructed large mammal ten times taller would tie in a race. The mouse's legs would make a step one-tenth the length of the larger animal's stride, Hill maintained, but it would move ten times faster, so they should run at the same speed.

Actually, even though large animals move their body parts more slowly than small animals do, their overall pace of locomotion is faster. Some years ago, I prepared a graph of the speeds and sizes of various animals. I found that, in general, bigger implies faster, whether the animals run, swim, or fly. Double the length of a running animal, and it runs roughly twice as fast—and that holds true for runners of vastly different construction, from eight-legged mites to two-legged ostriches. Swimmers follow the same general rule, with the exception of (for reasons unknown) the blue whale. Larger-bodied flyers, too, can move faster, but the advantage is less pronounced because of the extra horsepower needed for flying compared with swimming or running.

In locomotion there is a fundamental distinction between the large and the very small. The dominant physical forces that a large organism must contend with are quite different from the ones that dominate life for the small. In terrestrial organisms, the effect of gravity varies with weight, and so with the cube of the organism's linear dimensions. By contrast, the force of attraction between surface molecules varies roughly with the organism's linear dimensions. Minute beasts—particularly those smaller than about a millimeter in diameter—hardly feel the effects of gravity at all, because for them the force of molecular attraction overwhelms the effect of gravity. In fact, molecular attraction affects every aspect of their existence, enabling them to defy gravity by clinging to vertical or overhanging surfaces.



"Mouse-to-elephant curve," in which both the vertical and horizontal scales are logarithmic, shows how the metabolic rates of several warm-blooded animals vary with their body masses. The slope of the line, that is, its vertical rise divided by its horizontal run, is 3/4; that the slope is less than one reflects the fact that large animals have proportionally less surface area for their size than small animals do. Surface area includes not only skin but also all the membranes of an animal's respiratory and digestive systems, through which oxygen and food pass and heat (the product of metabolism) escapes. Because increases in surface area do not keep pace with increases in volume, the metabolisms of large animals are slower than those of small ones.

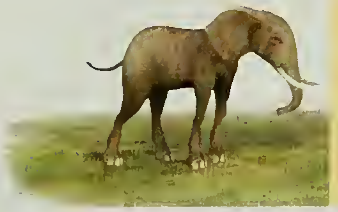
A fly, for instance, can readily walk up a wall, something we humans cannot even begin to manage. The weight of the insect is negligible, and the bottoms of its feet have many hairs that make intimate contact with all the nooks and crannies of the wall's surface. The molecules in the feet and those in the wall press close together; the closer they get, and the greater the surface area of the contact, the stronger the force of molecular attraction is between them.

In addition to having the force of molecular attraction dominate their lives, small organisms live in a world of low Reynolds numbers. The Reynolds number, named for the nineteenth-century British engineer Osborne Reynolds, is a convenient way of describing the immediate environment of a body moving in a fluid. The way Reynolds defined it, his number is small when the inertial forces on the moving body are negligible, and increases as the inertial forces become more important. For example, a swimming whale experiences a much higher Reynolds number than does a bacterium swimming in the same water. The reason is that the inertia of the whale is huge compared with the viscous forces acting on it: if the whale suddenly stops swimming, it will keep gliding for some time. By contrast, when a bacterium stops swimming, it comes to a stop in a split second. Microscopic organisms live in a world of low Reynolds numbers.

To give readers a feel for the conditions in that world, the physicist Edward M. Purcell once painted the following picture: Imagine a man swimming at the same low Reynolds number as would exist for his own sperm. It would be as if he were trying to swim in molasses so thick that he could not move his arms or legs any faster than the minute hand of a wall clock. If the man were able to move several feet in a couple of weeks, he would qualify as a low-Reynolds-number swimmer. As Purcell says, "Motion at low Reynolds numbers is very majestic, slow, and regular."

To be able to move at all under such conditions, bacteria have evolved an ingenious means of locomotion: long, thin appendages called flagella, which rotate like ships' propellers. Their flagella enable bacteria to travel at a rate, in body lengths per second, that is proportional to our own.

Small flying insects also inhabit a low-Reynolds-number environment. Their inertia is insignificant compared with the viscous forces acting on them; to them, even air is like molasses. As a consequence, the wings of more than one group of insects have evolved into what look like minute feather dusters. For example, fairy flies—which are actually minute parasitic wasps—essentially swim through the air with their wings [*see illustration on page 56*].



Amazingly, the number of heartbeats in the life of an elephant is approximately the same as the number of heartbeats in the life of a shrew.

The tempo at which an organism lives is also markedly affected by its size [*see "Times of Our Lives," by Robert L. Jaffe, page 26*]. An elephant's heart, for instance, makes about twenty beats a minute, but a shrew's heart makes more than 600. The tiny shrew lives only a year or two, but the huge elephant lives, on average, between forty and fifty years. Yet amazingly, the two creatures have approximately the same total number of heartbeats in their lifetimes. Life for the shrew goes faster because its engine is racing along compared with the elephant's engine, and the total budget for the activity of both is the same. An increase in size slows down all the processes of life, and therefore life as a whole takes longer to unfold.

The relation between time and size—at least for animals—is based on the way size affects metabolism. Large animals obviously need more total energy than small animals do. But large animals burn less fuel per ounce of flesh than small animals; in other words, they have lower metabolisms. If the relation between metabolism and size is plotted on a graph in which both axes are ruled off logarithmically, the result is a straight line [*see graph on preceding page*]. The slope of the line, the so-called mouse-to-elephant curve, was discovered in the 1930s by the biologist Max Kleiber. The slope is about 3/4—that is, the ratio of its vertical rise (which corresponds to increasing metabolic rate) to its horizontal run (which corresponds to increasing size) is three to four. The fact that the slope is less than one shows that as animals become larger, the increase in the surface area across which food and oxygen must pass lags behind the increase in the volume of the animals' bodies.

But how does an animal manage to keep its motor going under such seemingly imbalanced conditions? To begin with, any means by which an animal can use less food and oxygen and still function effectively is presumably advantageous. If an elephant's cells burned food with the same intensity as the cells of a mouse, they would require vastly more food than the elephant consumes. Furthermore, combusting food generates heat. To keep its temperature at a reasonable level, an elephant whose cells ran as hot as a mouse's would need a far greater surface area for dissipating heat than an ordinary elephant has. Of course, one way to keep cool would be to maintain the same ratio of surface area to volume as the mouse has, but in that case the animal would no longer look like an elephant. Instead, it would have great convolutions of skin and internal organs, rather like some kind of monstrous walnut. The alternate, evolutionary solution has been for the metabolism to slow down just enough so that the animal can exist and also look like an elephant. If its metabolism were faster, the elephant would either starve or burst into flames, or both.

By the same token, small, warm-blooded animals must eat constantly to keep their intense internal fires burning. If a shrew cannot find enough food, it suffers irreversible internal damage after a few hours and dies of starvation, whereas we humans can go on a hunger strike and survive many days without perishing. Presumably elephants can go even longer without food—though how long is a bit less reliably known, because they are wise enough not to go on hunger strikes.

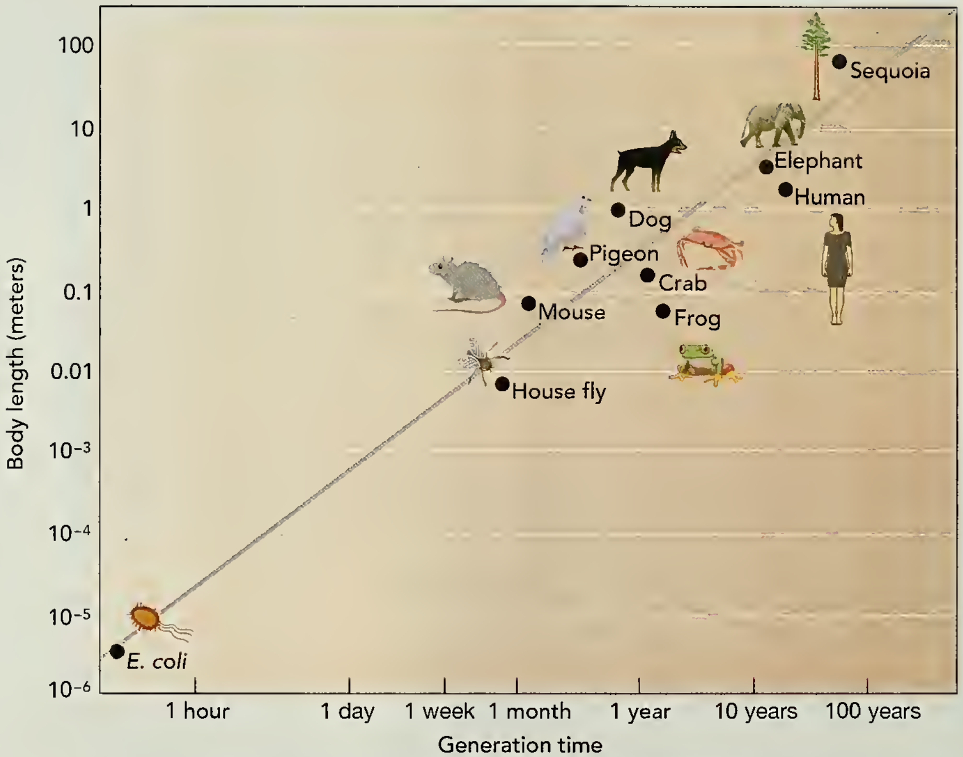
Obviously, it takes longer to build a big organism than it does a small one; in that way, too, size dictates the pace of an organism's life. Organisms grow in size as they develop from a single cell to reproductive maturity. That period is known as their generation time. (It goes almost without saying that many organisms, including trees, fish, and some reptiles, continue growing even after they start reproducing.)

The generation time of people is about twenty years, so a century brings five generations. By contrast, bacteria—which are single cells—may divide every half hour. An enormous number of their generations can be packed into just one of ours. Giant sequoias, on the other hand, need sixty years for a generation, because that's how long it takes them to produce cones with seeds. In a general way, for every doubling in the length of an organism, the generation time doubles as well [*see graph on this page*].

Because each generation results in more individuals, size affects the abundance of an organism in nature, too: the bigger the organism, the less frequently it reproduces and the more space it needs. The number of bacteria per square mile in the African veldt is unimaginably larger than the number of elephants there.

Big-bodied animals and plants also live longer than their small counterparts. Intriguingly, though, brain size is an even better predictor of life span than body size is. Perhaps the reason is that body size can be greatly affected by environmental conditions, such as food supply. But brain size is relatively immune from such effects, because the brain is permanently encased in a bone prison. People live unusually long lives for our body size—and our brain size.

Exactly how size relates to longevity remains a puzzle for biologists, but there is some experimental evidence that life span relates directly to metabolism. Large animals live longer than small animals, and their internal fires burn at a slower, less frenetic rate. Keeping an animal on a minimal diet, thereby artificially reducing its metabolic activity, results in longer life. Genetic mutations that lengthen or shorten life span have been discovered in yeast, nematode worms, and fruit flies. Mutant nematodes bred in the laboratory have survived to twice the age of ordinary nematodes—and their metabolisms slowed to half the normal rate.



Body length is plotted against generation time for various organisms. Both the vertical and horizontal scales are logarithmic. Generation time is the time it takes an organism to grow from an embryo to reproductive maturity. Large organisms have longer generation times, as well as longer lives, than small organisms.

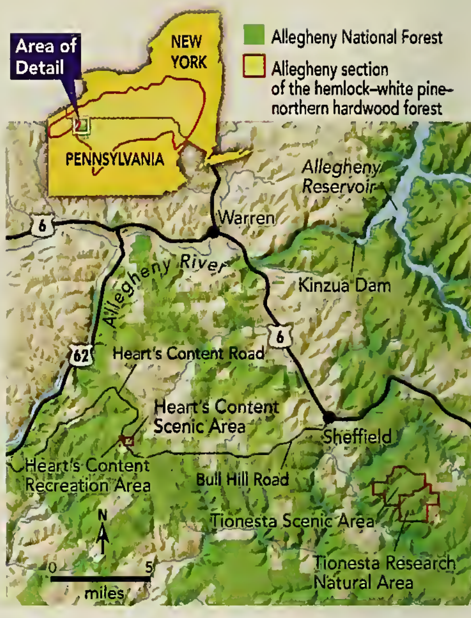
Needless to say, our great interest in longevity comes from our permanent fascination with extending human life, and our endless quest for a fountain of youth. It is doubtful that altering our genes could extend human life. Even if it could, we might end up with people who were extremely slow and lethargic. To me, that sounds like too high a price to pay for becoming a Methuselah. □

This article is adapted from John Tyler Bonner's forthcoming book Why Size Matters: From Bacteria to Blue Whales, *which is being published this month by Princeton University Press.*

Last Stands

Pristine patches of a northeastern forest are threatened by insects and disease.

By Robert H. Mohlenbrock



VISITOR INFORMATION
Allegheny National Forest
P.O. Box 847
Warren, PA 16365
814-723-5150
www.fs.fed.us/r9/forests/allegheny

A large forested zone extends from central Minnesota eastward through Maine, reaching northward into bordering areas of Canada and, at its southernmost extent, into Pennsylvania. The zone is generally referred to as the hemlock–white pine–northern hardwood region, for its dominant trees. But a domain so vast was hardly undifferentiated wilderness even before the coming of Europeans to North America. In the middle of the twentieth century, the noted botanist and ecologist E. Lucy Braun crisscrossed the forest, and she is credited with delineating its regional variations.

One of them is the Allegheny section, which extends roughly across northern Pennsylvania and southern New York. The only two known tracts of forest that exemplify that section in relatively pristine condition—in that their trees were never logged in historic times—are preserved in Pennsylvania's Allegheny National Forest. Both, however, are subject to native and nonnative biotic threats.

I described one of the two, comprising the Tionesta Scenic and Research Natural areas, in a column for this magazine exactly two decades ago [*see "This Land: Tionesta Forest, Pennsylvania," November 1986*]. There I reported the effects of a tornado that had swept through the forest just the year before. The second tract comprises the 122-acre Heart's Content Scenic Area and an adjacent campground, the Heart's Content Recreation Area.

The forest at Heart's Content is home to a rich variety of plant species, but it is made up principally of eastern hemlock and white pine, with an intermingling of sugar maple and other trees. Some of the trees are estimated to be more than 300 years old, and some hemlocks and white pines are more than 150 feet tall. American beech, once a common component, has largely succumbed to beech bark disease, the result of bark damage by the scale insect *Cryptococ-*

Southeastern arm of the Allegheny Reservoir, looking southeast

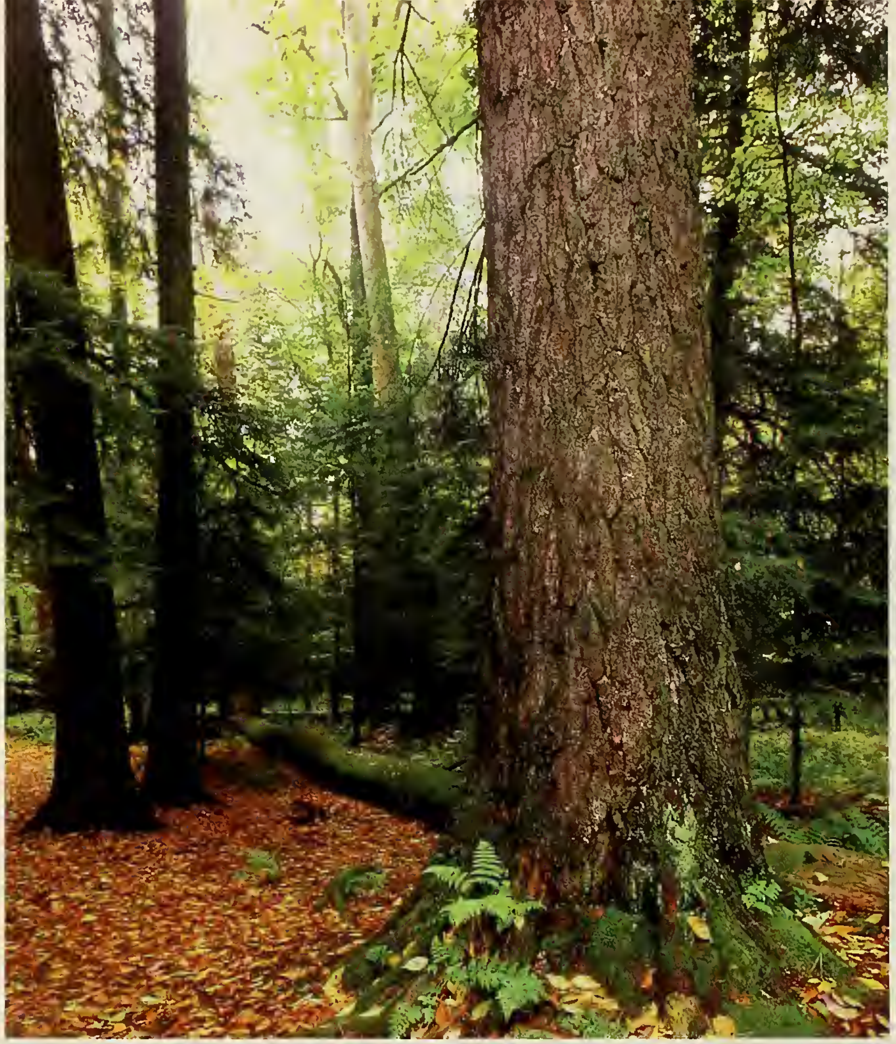
HABITATS

Rich forest Because they grow so densely, eastern hemlock and white pine can seem to be the only tree species around. But many others can be found, including American beech, American elm, basswood, cucumber tree, hop hornbeam, mountain ash, mountain maple, musclewood, northern red oak, red maple, striped maple, sugar maple, sweet birch, tulip tree, white ash, white oak, wild black cherry, witch hazel, and yellow birch. Among the trees that appear where the dense canopy has been slightly interrupted are big-toothed aspen, bitternut hickory, chokecherry, pin cherry, quaking aspen, and slippery elm.

Shrubs and woody vines include arrowwood, blackberry, black elderberry, bush honeysuckle, dogberry, eastern black currant, flowering maple, hobblebush, mountain holly, multiflora rose, pagoda dogwood, poison ivy, pussy willow, red-berried elder, red raspberry, riverbank grape, Virginia creeper, and yellow honeysuckle.

Ferns and their relatives The understory has an abundant *cus fagisuga,* which opens the trees to fungal infections. The insect was introduced into North America in the late nineteenth century.

Where the canopy is intact, the forest floor is uniformly shaded and moist, conditions that favor germination of the seeds of the major tree species, particularly the shade-tolerant ones. In times past, whenever one of the mature trees died, the seedlings were ready to replace it, thereby maintaining what some ecologists consider a climax forest. Even if a larger area opened up, the shade-tolerant seedlings overtook and shaded out the faster-growing, sun-loving species such as red maple, tulip tree, white ash, wild black cherry, and yellow birch.



Virgin white pine in Heart's Content Scenic Area (foreground) is about three feet in diameter and more than 150 feet tall. Virgin eastern hemlocks are in the background.

According to Robert L. White, a principal forester at the Allegheny National Forest, however, the overgrowth of some plants is now interfering with the development of tree seedlings, jeopardizing the natural replacement of the mature trees that die. Where beech-root suckers concentrate, for instance, they typically grow into small trees between three and eight inches in diameter, then die of beech bark disease. Their presence poses an obstacle to the usual cycle.

Elsewhere, dense growths of ferns, grasses, and striped maples, combined with browsing by deer, are limiting the emergence of hemlock and white-pine seedlings. Intriguingly, sweet birch is by far the dominant tree species in the swath made by the 1985 tornado in the Tionesta Scenic and Research Natural areas; much of it germinated from seed after the blowdown.

Foresters are also alert to the dangers posed by nonnative insects such as the hemlock woolly adelgid, an aphidlike insect introduced from Japan in the 1920s, and the emerald ash borer, an Asian beetle detected in Michigan in 2002. Although neither one has turned up in surveys of the Allegheny National Forest, the adelgid has been reported in Pennsylvania not far to the southeast, and the borer has already spread to Ohio. Even climax forests lack defenses against such invasive species.

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

population of ferns, including hay-scented fern and ostrich fern, both huge species, as well as the generously proportioned Goldie's wood fern, lady fern, and toothed wood fern. Among the smaller ferns are lowland bladder fern, New York fern, and sensitive fern. At least four kinds of clubmosses, which are spore-producing species that are related to ferns, also grow on the forest floor.

Wildflowers and grasses Late-flowering species that, in early November, are still in bloom or just past flowering include big-leaved aster, cespitose smartweed, eastern lined aster, flat-topped white aster, heart-leaved aster, partridge berry, sweet-scented bedstraw, Virginia knotweed, Virginia water horehound, white snakeroot, and wrinkle-leaved goldenrod. Among the flowers that bloom in spring are American spikenard, big white trillium, Canada columbine, false Solomon's seal, foamflower, goldthread, heart-leaved ragwort, hooked buttercup, rough fleabane, round-leaved yellow violet, self-heal, smooth blue violet, white avens, and yellow wood sorrel.

By Laurence A. Marschall

Generation: The Seventeenth-Century Scientists Who Unraveled the Secrets of Sex, Life, and Growth
by Matthew Cobb,
Bloomsbury Publishing; $24.95

Ovid and Virgil, two of ancient Rome's greatest poets, both gave the same cockamamy recipe for creating bees: Dig a very large hole; insert one dead bull; cover with earth, leaving nothing but the horns sticking out of the ground; wait several weeks; cut off the horns near the ground. Swarms of bees should now emerge from the holes in the buried carcass.

Kiki Smith, Untitled (Ovum and Sperm), 1992

That intelligent men could agree on such preposterous stuff is mind-boggling. But as late as the 1600s, biological ignorance was so deep that most people accepted the idea that animals such as insects and worms were "generated" spontaneously from decaying matter. Everyone recognized that higher animals and humans *did* reproduce in kind, and that copulation surely had something to do with it. But there were profound misunderstandings. Medical scholars debated furiously whether babies came from a man's semen, from a woman's menstrual blood, or from some other emanation.

None of that confusion is surprising, given the sorry state of anatomy at the time. Leonardo da Vinci, in a strikingly explicit cross-sectional rendering of human lovemaking, drew a duct connecting the woman's nipples and her uterus, and another connecting the man's penis and his brain (the latter connection, some wag is sure to point out, still seems plausible). Nor, in retrospect, does it seem strange that physicians might have failed to recognize the role of the sperm and egg in the process. Both are far too small to be seen with the naked eye. Understanding reproduction, in short, demanded a closer look than anyone had yet thought to take.

According to Matthew Cobb, a lecturer in Life Sciences at the University of Manchester, England, physicians took that closer look during the latter half of the seventeenth century, with startling results. In the late 1660s an Italian physician and savant, Francesco Redi, published the results of a series of elegant experiments with rotting meat, which showed that baby insects actually hatched from eggs laid by other insects of the same species. It was a short jump from Redi's work to the conclusion that *Ex ovo omnia:* "Everything comes from an egg."

But were there human eggs? There were indeed, as three anatomists, the Dane Niels Stensen (Nicholas Steno) and two Dutchmen, Reinier de Graaf and Jan Swammerdam, discovered. Their collective skill in dissection and biological illustration enabled them to give the first reliable descriptions of the human reproductive system.

Cobb's scholarship is as meticulous as the work of his protagonists, and it crackles with lively anecdotes from their scientific reports. In December 1672, we learn, a shipment of representative specimens sent by Swammerdam arrived at the Royal Society in London, among them a preserved female uterus, a dissected penis, and a clitoris. All have since disappeared, though, according to Cobb, "the uterus may still be lurking somewhere in Bloomsbury." Equally memorable is the tale of Theodore Kerckring, who, to prove that the small, liquid-bearing structures in the ovaries of a woman's cadaver were indeed eggs, cooked and ate them. They hardened on heating, just like hen's eggs, but tasted "flat and unpleasant." Evidently, more work remained to be done.

The final chapters in Cobb's history belong to the early microscopists, notably the famous Dutchman Antoni van Leeuwenhoek. Looking through his lens, Leeuwenhoek was the first to report seeing hordes of "little animals" (sperm) in semen. By the eighteenth century, the idea that buried cattle gave birth to bees was beginning to sound as crazy as the notion that storks brought babies. Of course, the full story of reproduction, still emerging in this age of molecular genetics, in vitro fertilization, and cloning, is far stranger than anything our forebears could have imagined.

Jane Goodall: The Woman Who Redefined Man
by Dale Peterson
Houghton Mifflin Company; $35.00

Books about celebrities are a peculiar subspecies of biography, presenting a distinct literary challenge even to the most expert writers. The general contours of their subject's lives are well-known, but readers want more than a simple recital of dates and accomplishments. Everyone knows that Jane Goodall is the "chimp lady" who spent years crouched in the African jungle recording the doings of primates at Tanzania's Gombe Stream Chimpanzee Reserve. Those of us who grew up in the 1960s and 1970s may recall her as a lanky, khaki-clad figure whose articles in *National Geographic* revealed the hidden complexities of ape society, and made us envious of her adventures. Over the years, like other celebrity naturalists (E.O. Wilson comes to mind), she mellowed into an eloquent elder spokesperson for the conservation movement, establishing preserves for endangered apes in Africa and traveling the world with an urgent message of environmental stewardship.

Those are the bullet points in the life now addressed by Dale Peterson, author of several books about wild primates (one in collaboration with Goodall) and editor of Goodall's letters. Those connections have given him unparalleled access to his subject, who is still very much alive and kicking. And Peterson uses it to good advantage to convey how a young woman with little higher education could come to Africa, establish herself as one of the foremost experts in animal behavior, and rise to prominence as an environmental guru.

Gumption and genius clearly played major roles. Goodall took it on herself to save up her secretarial pay so she could hop a boat to Kenya in 1957. She took charge of every situation, impressing people everywhere with her intensity and her wit. She also seemed to have a natural ability to blend into the scenery and sit motionless for hours, a talent that enabled her to get closer to her ape "informants" than any previous observer.

It also did not hurt to have a smart and powerful mentor, Louis S.B. Leakey, whom Goodall met on her very first trip to Africa. Leakey, an eminent naturalist and anthropologist who was hot on the trail of human origins, gave Goodall the idea of studying chimps as a way of understanding how primate behavior might have evolved. It was Leakey who sent Goodall to Gombe, raised the funding for her early work, acted as an adviser and publicist, and even sponsored her doctoral studies at Cambridge.

Others have also played big roles in her success: her lively and supportive mother, two husbands—the photogra-

Jane Goodall and friend

pher and cinematographer Hugo von Lawick and the conservationist Derek Bryceson—and numerous students and colleagues at Stanford University.

Peterson is an expert guide to the territory. He leavens his narrative with well-chosen descriptions of Goodall's work (which she has written about at much greater length herself, notably in her 1986 book, *The Chimpanzees of Gombe*). He includes an informative discussion of her paradigm-breaking discoveries of chimpanzees as sophisticated tool makers and meat eaters.

But perhaps because of his closeness to his subject, one senses in Peterson a bit more reserve about the back story of Goodall's career, the stuff readers really want to know about her celebrity life. There are some revealing passages on Goodall's relations with her husbands, but a good deal less about the kidnapping of four students by rebels from Zaire (now Congo) in 1975—which seems to have put an end to the carefree atmosphere of research at Gombe. Peterson covers the succeeding three decades in a scant 120 pages.

Yet if one leaves this book feeling full while oddly hungering for more, that's not entirely the fault of the author. A life this large cannot be encapsulated in a single book or described from a single vantage point. Peterson's take on Goodall may not be the definitive life history, but it is surely the informative first of many.

The Demon Under the Microscope: From Battlefield Hospitals to Nazi Labs, One Doctor's Heroic Search for the World's First Miracle Drug
by Thomas Hager
Harmony Books; $24.95

Harry, the sad protagonist of Hemingway's 1936 short story *The Snows of Kilimanjaro,* lies in an African campsite dying of gangrene, "because he had not used iodine two weeks ago when a thorn had scratched his knee as they moved forward trying to photograph a herd of waterbuck." How strange that sounds to modern ears! What's the big deal about a thorn? Didn't Harry have a first-aid kit? Couldn't he have taken a shot or swallowed a pill, even if the wound was infected?

At the time, though, readers were well aware that Harry's fate was sealed. Hemingway saw that firsthand, as a young ambulance driver in the First World War, when wound infections among injured soldiers were as deadly as bullets to the heart. One in five of the nearly 2 million British troops hospitalized in the Great War either lived on as permanent invalids or never made it home at all. A large number of them died not from the direct trauma of battle but from the ghastly effects of infection. It was no better for the other side; between 100,000 and 200,000 German soldiers perished the same way, as *Gasbrand* ("gas gangrene") ate away at their flesh and sent poison through their veins. Doctors were powerless, even though they understood the bacterial nature of the infections. There simply were no drugs that could kill invasive microorganisms once they entered the body.

There were few drugs of any sort, for that matter. One physician of the 1920s reckoned that only a dozen substances were effective in treating disease, among them aspirin, insulin, quinine, plus a few other palliatives and sedatives. The best a "healer" could do before the mid-1930s was diagnose, comfort the patient, and let nature run its course.

Science writer Thomas Hager's absorbing account of the discovery of sulfa, the first antibiotic wonder drug, sheds light not only on the history of medicine, but also on the present age—innocent of so many of the infectious scourges of the past. Hager's book focuses on Gerhard Domagk, a German chemist who won the 1939 Nobel Prize in Physiology or Medicine for his work on antibiotics. Domagk, like Hemingway, served as a medic in the Great War—an experience that, understandably, gave him an abiding interest in pathology and the treatment of infection. By the late 1920s he was an established medical researcher, working for the German drug company Bayer AG and looking for the "magic bullet" that would cure infectious diseases.

Domagk relied on a method still much in use in searching for new drugs—trial and error. He and his staff, including experts in chemical synthesis, would try one compound after another, meticulously testing each for its capability to kill bacteria in Petri dishes and cure animals infected with a particular bacterium.

In fact, the work was not as haphaz-

Prontosil, the first widely sold sulfa antibiotic

 (Continued from page 30)

ard as it sounds. The investigators would start with molecules that might conceivably have an affect on a microbe—say a molecule that readily attaches itself to a particular bacterium. Then they would vary its chemical structure a bit here and a bit there to see whether the variation would prove lethal. Most of the time it did not. But Domagk, tireless, relentlessly systematic, and an excellent team leader, persisted, eventually finding a molecule called sulfanilamide that did the trick. During the 1930s many other antibiotics were identified, patented, and marketed.

By the start of the Second World War the prognosis for wounded soldiers was no longer so grim. Severe wound infections, though still seen, were treatable, and deaths from other infectious diseases became treatable as well. Today, with a panoply of antibiotics down at the pharmacy, most people no longer fear death by common infection. Yet as investigators race against drug-resistant strains, it's worth recalling the desperate state of pre-antibiotic medicine and the heroic work of Domagk and his fellow microbe-fighters.

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

PICTURE CREDITS Cover: The Granger Collection, New York; pp.6-7: Staffan Widstrand; pp.12 and 78: illustrations by Dolly Setton; p.14(top): Louie Psihoyos/Getty Images; p.14(bottom): ©Copyright CSIRO Australia; p.18(top): Courtesy Richard B. Primack; p.18(bottom): Courtesy Richard R. Kirby; p. 20(top): ©O.S.F./Animals Animals; p.20(bottom): David Welsh; p.21: NASA-KSC; p.22(top right): *Natural History* Staff; p.22(left): www.helmethut.com; pp.22, 23, and 24(bottom): Digital Image ©The Museum of Modern Srt/Licensed by SCALA/Art Resource, NY; pp. 23 and 25: Jon Evans/thevalvepage.com; pp.26,27, 29 and 30: illustrations by Advanced Illustrations Ltd; pp.40–46(background): Map Library of Congress; p.40: APVA Preservation Virginia; p.41: Ashmolean Museum, University of Oxford; pp.42 and 46: courtesy the author; pp.43 and 60: maps by Joe LeMonnier; pp.44–45(top, left to right, 1-6): The Granger Collecrion, New York (1,2,4,5), ©Classic Image/Alamy (3), The Kobal Collection (6); p.45(bottom): APVA Preservation Virginia; pp.48-49:Art Resources/Monet, Claude (1840-1926) Waterlilies, study of water: Green Reflecrions, ca. 1914–1926. Room 1, East wall. INV20102. Photo: Herve Lewandowski. Musee de l'Orangerie, Paris, France; pp.49, 50, and 51: illustrations by Patricia Wynne; p.53: courtesy the author; pp.54-55: illustration by Steve Kingston/Apple Agency Ltd.; pp.57 and 59: illustrations by Ian Worpole; p.56 © The Natural History Museum, London; p.60: Janeal Hedman; p.61: ©Blair Seitz; p.62: ©Kiki Smith, Courtesy PaceWildenstein, New York; p. 64(bottom): AP Photo/Bela Szandelszky; p.64(top): Bayer Industry Services GmbH & Co. OHG; pp.68-69: NRAO/AUI/NSF

or a billion? Although nothing is impossible, it seems highly unlikely.

So suppose human life spans are linked to celestial clocks by natural selection; still, that does not explain why the day and the year are so long compared to the timescales of fundamental physics. Why does it take so long for the Earth to circle the Sun? If that seems a foolish question, recall that the timescales of the strong interactions that fuel the Sun and the electromagnetic forces that make it shine are tiny fractions of a second. How do they manage to produce a solar system that moves to such a leisurely rhythm? The answer comes from a surprising direction: the weakness of gravity compared to the strength of the strong force. Simply stated, the year—and therefore our lives—are so long because gravity is so weak!

The evolution of life appears to require a warm, stable environment: not so hot that complex structures are destroyed, nor so cold that chemistry grinds to a halt. It also must be stable enough to preserve delicate structure while evolution works its slow and steady magic. The neighborhoods of quiescent, long-lived stars seem the preferred real estate for such processes to unfold. Stars are made when atoms are squeezed and heated so much that their nuclei begin to fuse and emit the energy that makes them shine. Gravity is what squeezes matter together and heats it up.

So why doesn't a baseball or our Earth become a star? Because gravity is too weak. If gravity were much stronger, it would pull all the atoms in a baseball hard enough, create enough pressure, and generate enough heat to initiate fusion, leading to miniature, short-lived stars orbited by planets smaller still. Back to reality—with gravity as weak as it is, it takes about 10^{57} hydrogen atoms packed by gravity into a sphere to ignite fusion at the core of the sphere.

Not surprisingly, 10^{57} atoms is roughly the mass of our Sun. Astrophysicists estimate that stars a tenth the mass of the Sun do not ignite, whereas giants ten times its mass burn too quickly for life to evolve in their vicinity. The orbital period of a planet placed at a comfortable distance from a long-lived, stable star ranges between about a tenth of and ten times our year: quite a narrow band [*see sidebar on page 29*]. If gravity were stronger, stars and planetary orbits would be smaller, orbital periods shorter, and life everywhere in the universe, tuned to those periods by natural selection, briefer.

So the time of our lives may well be the universal tempo for complex life, give or take a factor of ten. It is not carved directly into the laws of fundamental physics or written into the script of cosmology. It emerges instead in an interplay of physics and natural selection: the weakness of gravity compared to the strong force is what makes stars large and planetary periods long, when measured by the rhythm of the strong interactions. Then natural selection binds the time of our lives to celestial mechanics. There is every reason to think that those forces are active everywhere in the universe, and that all life marches to the same beat.

Since the advent of modern science, the universe has seemed a mostly cold and empty place. People have known for centuries that our place in it is nothing special. Now, it seems, the flow of time as we perceive it is far removed from the times of fundamental physics and cosmology that make the universe tick. And yet the times of our lives are likely the times of all life in the universe. The heartbeats we call seconds, the hours that pass as winter shadows move across yesterday's snow, the years gone by since Emily Dickinson wrestled with time and eternity, these may well be universal experiences in any universe filled with life.

Robert L. Jaffe is a professor of physics at M.I.T., where he has also served as chair of the M.I.T. faculty and director of the Center for Theoretical Physics. His research has focused on the properties of quarks, the way they bind together to form particles such as protons and neutrons, and the role of quarks in the structure of the universe. This article is the second of a two-part essay.

Earthly Treasure

By Robert Anderson

Panning for gold used to be one of my long-standing desires. My own personal gold "rush" came this past year when I chaperoned my son's school trip to Sutter's Mill in Coloma, California. There, in 1848, James W. Marshall discovered a few gleaming yellow flecks, and in less time than it takes to holler a claim, the news was out that there was gold "in them thar hills." Today, even novices like my son and his friends can still, with a bit of patience, wash away the worthless material in some troughs of local river sand to reveal a few flakes of the precious metal. The Marshall Gold Discovery State Historic Park (find it at parks.ca.gov/?page_id=484) has information on visiting the site.

If you'd like to learn how it's done, go to video.google.com and type in *panning gold;* among the unrelated offerings, you'll find a video of a demonstration in Alaska, the site of the state's big gold rush of 1898.

The influence of geology on human affairs is often not appreciated, but in the quest for gold, it is manifest. The find at Sutter's Mill triggered one of the greatest migrations in the Western Hemisphere. Go to the Virtual Museum of the City of San Francisco (www.sfmuseum.org) and click on "The Gold Rush" to learn about the boom time from those who lived it. I particularly enjoyed Sutter's own account, "The Discovery of Gold in California," in which he laments, "Instead of being rich, I am ruined."

Many of the forty-niners were similarly disenchanted. Real prospecting is backbreaking work, often leaving people with little to show for it. Those foolish enough to pursue the dream might start by reading the U.S. Geological Survey's primer on gold prospecting (pubs.usgs.gov/gip/prospect2/prospectgip.html), which discusses different kinds of gold deposits and where they are most likely to be found.

Although jewelry consumes nearly 75 percent of the production, gold (both as coins and as jewelry) has long been the investor's hedge against bad times. Since early 2001 its price has more than doubled, leading some to speculate that it will go much higher (go to goldprice.org for the latest prices and charts in a variety of currencies). The upward trend has also increased worries about the environmental damage associated with revved-up mining operations. A report by National Public Radio (npr.org/templates/story/story.php?storyid=5518157) examines the controversy as it relates to one California town in the foothills of the Sierra Nevada Mountains. In part to allay environmentalists' fears, the mining lobby has set up at least two Web sites (responsiblegold.org and gold.org).

Iconic gold: King Tut's funerary mask

Given recently renewed interest in the value of this precious metal, the new exhibition on gold at the American Museum of Natural History is well timed. It will give New Yorkers and visitors to the Big Apple the chance to see a room, twelve feet square by eight feet high, entirely lined in a layer of gold leaf whose total weight is only three ounces. Go to amnh.org/exhibitions/gold for more information on the exhibition, which opens November 18 and runs until August 19, 2007.

At the southern tip of Manhattan lies another exhibition of gold—the largest concentration of bullion in the world, stored in the Federal Reserve Bank of New York's subterranean vault. Surprisingly, tours are available, including a glimpse of more than $100 billion in gold bars, each weighing a little more than twenty-seven pounds. Go to newyorkfed.org/aboutthefed/visiting.html and click on "The Key to the Gold Vault" for fascinating details on the Fed's operation.

On the West Coast, the Natural History Museum of Los Angeles County has one of the largest collections of natural gold in the world, with more than 300 pounds of gold objects. The largest nugget weighs in at 156 troy ounces, or slightly more than ten and a half pounds (nhm.org/research/minsci/exgold.htm). The real mother lode, however, lies elsewhere.

Nearly 40 percent of all gold mined to date has come from a single geologic formation: South Africa's Witwatersrand Basin, an ancient lake or seabed that extends 9 million acres below ground. Viewed from space, the formation is outlined by mine tailings dumped in an arc across the southern edges of Johannesburg (see www.jsc.nasa.gov/images/eol/2003/johannesburg.html). To follow the debate about the origins of this mammoth ore deposit, go to John L. Muntean's article in *Geotimes,* the magazine of the American Geological Institute (www.agiweb.org/geotimes/apr06/feature_GoldOrigins.html).

But there's an even bigger gold bonanza in the Earth's oceans. By some estimates, more than 10 million tons of gold is dissolved therein, though no one can hope to get rich quick. Many a scientist has tried to devise a scheme for extracting gold from seawater. Unfortunately, at an average concentration of ten parts per trillion, that gold isn't worth the cost of pumping the water that carries it. Even Midas wouldn't touch it.

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

By Joe Rao

Two unusual and exciting events reward starry-eyed sky watchers this month: a glimmering shower of falling stars and the stately passage of Mercury across the face of the Sun.

Mercury reaches inferior conjunction, passing between Earth and the Sun, on November 8th. But unlike most conjunctions, in which the planet simply appears to move close enough to the Sun to get lost in the glare, this conjunction is a striking celestial phenomenon, in which the silhouette of the planet actually passes in front of the Sun's disk. The event is known as a "transit" of Mercury.

Transits are relatively rare: this one is only the second of fourteen transits of Mercury that will take place during the twenty-first century. From start to finish the entire event takes just under five hours; this one is visible in its entirety from the west coast of North America (including central and southern Alaska), Hawai'i, New Zealand, and the east coast of Australia.

From the contiguous United States, observers east of a line running roughly from Bonners Ferry, Idaho, to El Paso, Texas, can see the beginning stages of the transit. But sunset intervenes before Mercury moves off the Sun's disk. Mercury reaches the Sun's eastern edge at 11:12 A.M. PST (2:12 P.M. EST) and takes about two minutes to move completely onto the Sun's disk. The planet should be recognizable near the Sun's lower left edge as a black, sharp-edged dot only 1/194 the Sun's diameter. As you watch, the Winged Messenger gradually crosses to the Sun's right, or western, edge, then takes about two minutes to move completely off the solar disk. The transit ends at 4:10 P.M. PST.

To see the transit you'll need a telescope with at least fifty-power magnification. Eye safety is always a prime concern when viewing the Sun. You can permanently burn the retina of your eye by looking directly at the Sun through a telescope! Instead, hold a white card or screen behind the eyepiece, where you would ordinarily put your eye, and look at the enlarged image of the Sun projected onto the card or screen. During the transit, you'll see the black dot of Mercury in the projected solar image. If, from your position on Earth, the Sun sets before the transit ends, you'll want to check that your observing site has a low horizon, unobscured by trees or buildings, to the south of due west.

After the transit, Mercury emerges into the morning sky for the start of its most favorable apparition of 2006. Start watching for it on the 20th, when it rises with the morning twilight, more than an hour and a half before sunrise. Scan low along the east-southeast horizon about forty-five minutes before sunrise. Mercury is a yellowish-orange "star" shining at magnitude –0.1. In the mornings that follow, Mercury grows brighter and rises earlier, as much as an hour and forty-five minutes before the Sun, before the break of dawn, in a completely dark sky. The planet reaches its greatest western elongation on the 25th, when it appears twenty degrees from the Sun. By month's end, Mercury has brightened to magnitude –0.6 and should be relatively easy to find, low in the east-southeast sky between forty-five minutes and an hour before sunrise.

Venus is an evening "star" this month, but it sets less than half an hour after the Sun all month long. The Sun's glare keeps it out of sight, probably until sometime in early to mid-December.

Mars, like Venus, is masked by the glare of the Sun. It passed through solar conjunction on October 23rd and will not become visible in the morning until December.

Jupiter is also pretty much out of sight throughout November. It starts the month invisibly in the evening sky, setting less than forty-five minutes after the Sun. It reaches solar conjunction on the 21st, then enters the morning sky. But like Venus and Mars, we'll have to wait until December to see Jupiter once again.

Saturn, in the constellation Leo, the lion, appears as a yellowish-white "star" of magnitude +0.5, rising in the east-northeast shortly after midnight at the start of the month. By month's end it is rising two hours earlier and reaching its highest point in the southern sky just as morning twilight begins. Through a telescope at midmonth, the ring system appears to be tipped roughly twelve degrees toward Earth. On the morning of the 13th, the Moon, just past last quarter, moves between the bluish star Regulus, to its lower right, and Saturn, to its upper right.

The Moon is full on the 5th at 7:58 A.M. Our satellite wanes to last quarter on the 12th at 12:45 P.M. and to new on the 20th at 5:18 P.M. The Moon waxes to first quarter on the 28th at 1:29 A.M.

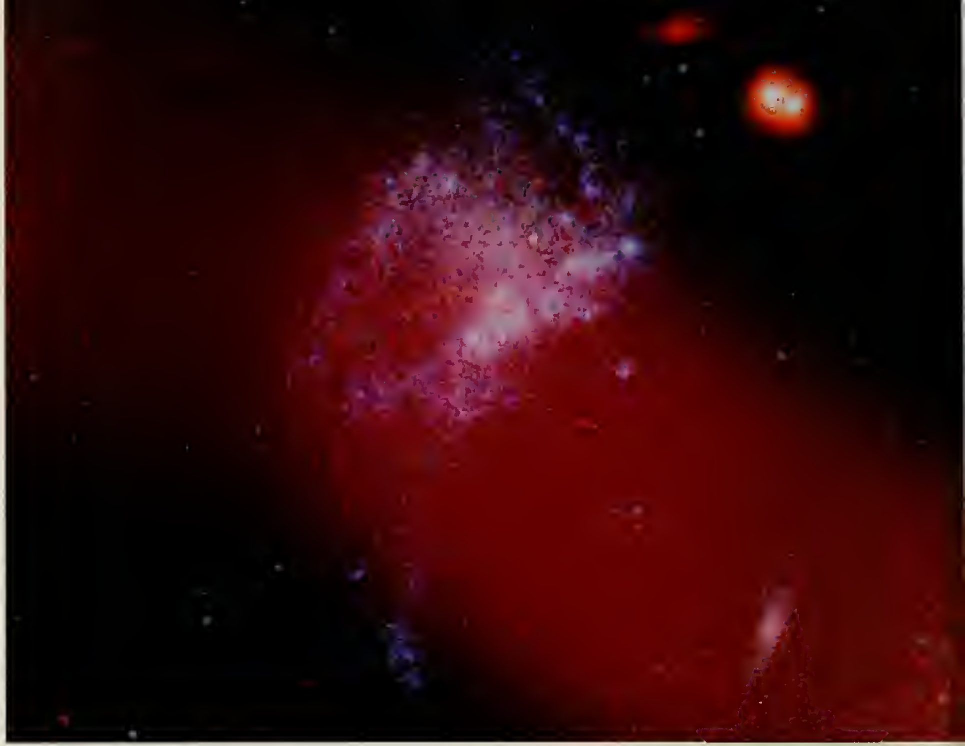
The Leonid meteor shower is forecast to produce a short burst of strong activity this month. Peak activity should take place around 4:45 A.M. Greenwich mean time on the 19th. Viewers in Africa and Europe have the best views, because at the peak hour, Leo (the constellation from which the meteors appear to radiate) reaches its highest point in the sky. That corresponds to 11:45 P.M. EST on the 18th in eastern North America, just as Leo is beginning to rise. Even at their best, the Leonids typically yield only about ten meteors an hour. Around the time of this year's maximum, however, the rate could briefly climb to 100 to 150 shooting stars an hour! For the best views, try to find a clear, dark place where you can see as much of the sky as possible. Don't stare at any one place but keep your eyes moving over the entire sky. Keep alert for brilliant fireballs and bolides (exploding meteors).

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

Name Games

Getting the family surname on that special object in the sky is a toss of the dice—unless your name is Minkowski.

By Charles Liu



False-color composite (above) of optical, infrared, and radio images of Minkowski's Object (MO, the bluish-white object at the center of image) also gives a close-up view of the jet of energized particles (attenuated reddish band) bombarding the object. The jet originates from matter redirected by intense magnetic fields surrounding a black hole at the center of a galaxy known as NGC 541. As the clouds of energized particles condense, MO's stars are formed. A second composite image (opposite page) gives a broader overview of MO's galactic neighborhood. In the overview image MO is deep blue, NGC 541 is the bright white blob near the center, and the jet is dark red.

Across Planet Earth this past summer, headlines repeated the verdict of the International Astronomical Union (IAU), the major professional organization for astronomers worldwide. Pluto was officially demoted to the status of "dwarf planet," down a notch from the more glorified rank of "planet." (Don't blame me; like many of my colleagues, I was not there for the vote.) One of the small objects that triggered the new designation—2003 UB 313, formerly (and informally) called Xena—was reclassified as a dwarf planet and officially named Eris. The IAU's naming committee also approved monikers for the erstwhile planet's two small, newly discovered moons: Nix and Hydra.

Historically, classifying and naming are among the IAU's most important roles in astronomy. By professional consensus, only the IAU may grant official names to astronomical bodies. Even the discoverers of comets and asteroids, who have naming rights to the celestial objects they find, must submit the names to the IAU for approval.

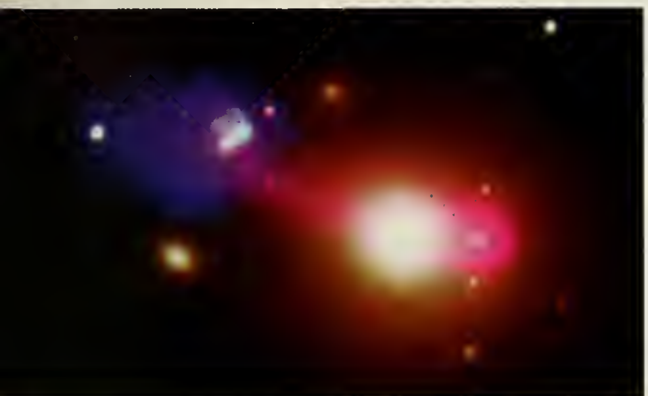
Of course, the IAU's solemn protocol doesn't do away with unofficial names. For a modest fee, many commercial outfits will "name" a star after you, even though you could just as legitimately name one after yourself without paying a penny. Occasionally we astronomers, too, unofficially name a celestial object after someone, for convenience or to give due credit to the discoverer. And once in a while the name sticks: Barnard's Star, for instance, or Hubble's Variable Nebula.

So it is with Minkowski's Object, or MO. The object itself is a funny-looking, galaxy-like thing some 220 million light-years from Earth, in the direction of the constellation Cetus, the whale. Two decades ago Wil van Breugel, a Dutch-born astronomer at Lawrence Livermore National Laboratory and the University of California, Merced, hypothesized that the object is being blasted by a powerful jet of matter spewed across intergalactic space by a supermassive black hole in a nearby elliptical galaxy. Now van Breugel has revisited his idea, as a member of a research team led by the astronomer Steve Croft, his colleague at both institutions. Their question: Could MO be an active example of how primordial galaxies formed some 13 billion years ago?

As for the "Minkowski" in the object's name, that is a nod to a famous family in the history of science. The first of the family to be charted on astronomical records is the nineteenth-century German mathematician Hermann Minkowski, renowned for his work on the so-called geometry of numbers, which led him to discover the space-time continuum. Moreover, during his years as a mathematics professor in Zurich, he taught a young visionary named Albert Einstein, who adapted Minkowski's ideas to create the general theory of relativity.

Hermann's older brother Oskar was no star in the astronomical firmament, but he was a leading medical internist, who discovered that the pancreas plays a major role in diabetes. Oskar's son Rudolph, born in 1895, became a physicist who specialized in what was, in the 1930s, the fledgling field of radio astronomy.

Rudolph Minkowski excelled in identifying celestial objects that emitted radio waves, and in analyzing how the objects produced those emissions. In the early days of radio astronomy, it was next to impossible to identify radio sources. The problem was one of basic optics: The power of any telescope—radio or otherwise—to resolve, or distinguish, two objects in the sky depends on the wavelength of the incoming radiation. Astronomical radio waves tend to range in length from about a tenth of an inch to about ten yards—a minimum of 100,000 times the length of visible light waves! So even though radio telescopes were, and are, much bigger than optical ones, their ability to pinpoint the positions of the radio sources they detect was, and is, far inferior to their visible-light counterparts. (A single radio telescope today would need to be many miles across to have the same resolving power as a modern optical telescope. For that reason, large arrays of modest-size radio antennas are now aligned on grids to capture the radiation and then combine the data electronically so as to yield a detailed image.)



In 1958, at a symposium on astronomical radio sources outside our own galaxy, Rudolph Minkowski presented a picture of a patch of sky where a radio source had been detected. Back then, no specific visible object in the patch could be identified as the source. In subsequent years, though, astronomers determined that the radio waves were coming from the center of a large "central dominant" elliptical galaxy known as NGC 541. Situated at the center of a rich cluster of galaxies, it has swelled in size by cannibalizing smaller galaxies in the cluster. Curiously, about 50,000 light-years from its core, among many other small galaxies within NGC 541's gravitational sway, there is a small blob of stars and gas, perhaps a dwarf galaxy, that looks peculiarly "wind-blown."

That galaxy is Minkowski's Object. It looks as if it has arms that are being blown outward from NGC 541—and that's pretty much what's happening. Reviewing images made by the Hubble Space Telescope, Croft's team showed that the biggest arm in MO has a sharp crook in it, suggesting that something is pushing the gas-and-star–laden arm away in a straight line [*see image on opposite page*]. The push is apparently coming from a glowing jet of material, shooting outward from the core of NGC 541 at just the right frequency to create radio waves. And throughout the regions where MO meets the jet—regions that form a swath cutting nearly clear through MO—are chains of what appear to be stellar nurseries and newly formed star clusters.

Croft's team has concluded that MO isn't just a galaxy that wandered into the path of a powerful radio jet. Rather, MO is a galaxy that formed *because* of the jet. Intense magnetic fields near the black hole at the center of NGC 541 redirected some of the infalling material into streams of charged particles that slammed into nearby clouds of warm, clumpy hydrogen gas. That produced a powerful shock wave that compressed the gas clouds, causing them to cool. The density of the clumps further increased and, subsequently, the clumps formed the stars shining in MO today. In fact, most of MO's light seems to be coming from a batch of stars that formed less than 10 million years ago—a blink of an eye, cosmologically speaking—so the process of gravitational condensation may have started recently and happened quickly.

Galaxy formation triggered by energetic jets of matter may have been highly common some 12 to 13 billion years ago. In that era, newly minted supermassive black holes throughout the cosmos were spraying radio jets like the one from NGC 541 through many clumps of unprocessed interstellar gas. So MO may be a nearby glimpse into the far distant past—an astronomer's ringside seat for a process that may have formed many of the oldest galaxies in the universe today.

As fascinating as MO is, it's not the only, or even the most celebrated, celestial structure named after a Minkowski. Asteroid 12493 Minkowski was named after Rudolph's uncle Hermann; Crater Minkowski, on the far side of the Moon, was named after both Rudolph and Hermann. What is probably Rudolph Minkowski's most significant contribution to astronomy, however, does not bear his name at all: the National Geographic Society–Palomar Observatory Sky Survey (POSS). That survey covered every patch of the sky that could be observed from Mount Palomar, California. Begun in 1948, it took more than ten years to complete, and Rudolph oversaw its creation, production, and dissemination.

Not only did the survey lay the groundwork for much of the astronomical research of an entire generation of astronomers, but its systematic gathering of high-quality data and its unselfish distribution of those data to the entire astronomical community established the paradigm for all subsequent major astronomical surveys. Celestial immortality is usually reserved for those who make great discoveries. But it can also come from leaving a legacy that gives others the tools to make those discoveries, thereby shaping the future of the field of astronomy.

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

EXPLORER GUIDE

EXPLORER GUIDE

FYi READER SERVICE

ADVENTURE TRAVEL/ TOURS

1. ADVENTURE LIFE JOURNEYS
Small group travel in the Andes, Amazon, Galapagos, Patagonia, Antarctica, and Central America. Expert local guides lead our cultural and ecological explorations and naturalist cruises.

2. ADVENTURESMITH EXPLORATIONS
Small ship cruise and adventure travel experts. Explore nature up close and in style aboard luxury yachts, small ships and wilderness lodges.

3. AMAZONIA EXPEDITIONS
Award-winning Jungle Lodge in the Tamshiyacu-Tahuayo Reserve, shown to have the greatest diversity of mammals in all of the Amazon.

4. AMERICAN MUSEUM OF NATURAL HISTORY EXPEDITIONS
Join an AMNH Expedition and experience first hand the world's greatest wildlife areas, archeological sites and cultural treasures in the company of AMNH scientists and researchers.

5. AUSTRALIAN NATURAL ADVENTURES
Custom nature and soft adventure travel to Tasmania and Australia. Personal and small group touring based on your own interests and timetable. Accredited Tasmanian specialists.

6. CANODROS
Canodros offers up-scale services in Ecuador with the Galapagos Explorer II and Kapawi. We are committed to providing a memorable and enriching experience of the culture, and natural history.

7. CHEESEMANS ECOLOGY SAFARIS
Wildlife, birding and photography nature tours to the world's most pristine habitats. With 30 years experience, let us take you to the world's richest ecosystems. Non-smokers only.

8. CROW CANYON ARCHAEOLOGICAL CENTER
Small-group cultural adventures led by world-renowned scholars explore some of the world's most interesting locations.

9. GALAPAGOS TRAVEL
Specializing in comprehensive, educationally-oriented, professionally-led natural history tours of the Galapagos Islands. Spend 11 or 15 days touring all the significant outer islands.

10. SERIOUS TRAVELER
Cultural Tours. Small Groups. Exotic destinations. Craft Tours. Libya, Iran, India, Faroes, Apulia, Tibet, Myanmar, Silk Road, Kenya and much more! Travel Concepts International.

11. SOL INTERNATIONAL
We specialize in South America, offering exceptional nature and cultural programs to areas where wildlife abounds and indigenous communities are unspoiled. Small groups, customized itineraries, personalized service.

12. TARA TOURS
Tara Tours specialize in travel to Central and South America since 1980. Free brochures and quotes.

13. TERRA INCOGNITA ECOTOURS
For trips that make a difference to you and to the places we visit. Trek Mountain Gorillas, snorkel on Barrier Reefs, rainforest hikes, whitewater rafting, and more.

14. ZEGRAHM EXPEDITIONS
Offers small-group expeditions to remote locations around the world. Expertly led and staffed, our programs provide the finest adventure travel experience imaginable.

BOOKS

15. ISLAND PRESS
Island Press is a leading publisher of books about the environment for professionals, students, and general readers—from solutions oriented books for working professionals to books on ideas that inform and inspire.

16. JOHNS HOPKINS UNIVERSITY PRESS
Celebrating 150 years of publishing for the world. Books about nature and science.

CANADA

17. NEW BRUNSWICK, CANADA
From the world's highest tides in the Bay of Fundy to rivers that reverse their flow. . . there are no small wonders in New Brunswick, Canada!

18. NEWFOUNDLAND & LABRADOR
Newfoundland and Labrador. We offer our visitors the natural wonders of whales, icebergs and seabirds framed by our dramatic seascape and landscape and unique culture.

19. QUEBEC CITY
Discover the magic of North America's most European City! Only 40 minutes from the Old City, go birdwatching, hiking and enjoy yourself. Our waterfalls and our colorful region will charm you!

20. PRINCE EDWARD ISLAND, CANADA
Come experience our unique red cliffs and parabolic sand dunes and hike or bike the Confederation Trail across our Island.

CRUISES

21. NORWEGIAN COASTAL VOYAGE ANTARCTICA CRUISES
Our 19-day voyage to Antarctica gets you closer to the wildlife and spectacular scenery of "The White Continent." Noted lecturers, expedition guides, and PolarCirkel shore excursions make this the journey of a lifetime.

22. NORWEGIAN COASTAL VOYAGE NEW WINTER CRUISES
These cruises feature watercolor painting and photography lessons, a whale-watching "safari", Arctic Spitsbergen, and other unforgettable experiences. Prices start under $1,999.

23. ORIENT LINES
Unique CruiseTours℠ combine a luxury cruise aboard the elegant *Marco Polo* with included hotel stays and city tours before and/or after your cruise. Enjoy the best of land and sea with the Destination Cruise Specialists!

INTERNATIONAL TRAVEL

24. BELIZE
Catch the Adventure! From rainforest resort to Barrier Reef. Belize is only 2 hours from the USA. Belize. Mother Nature's best kept secret.

25. GUATEMALA
From our archeological skyscrapers to our quaint colonial cities; our Mayan culture to our vast natural resources..Come "Discover" our Mayan Spirit.

26. ICELAND
Where else can you experience an ancient heritage, pristine nature, and modern lifestyle that coexist in harmony? Enjoy yourself in a pure, natural, and unspoiled place—Iceland: The Way Life Should Be.

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST-CLASS MAIL PERMIT NO.14 MAPLE SHADE, NJ

Postage will be paid by Addressee

NATURAL HISTORY

PO Box 9000
Maple Shade NJ 08052-9600

For free information from the advertisers listed below, circle the corresponding numbers on the attached postage-paid card. Mail card, fax it to 856-380-4101, or visit us at www.naturalhistorymag.com. If the card is missing, mail your request to: P.O. Box 9000, Maple Shade, NJ 08052.

27. INDIA
India offers incredible experiences for travelers on journeys of self-discovery! Come visit India for an experience that is truly incredible.

28. PROMPERU
Peru has it all. Fascinating history, as the land of the Incas, incredible nature with more than 1,800 species of birds and colorful traditional culture. Come to Peru.

29. YUCATAN
You will be mystified, captivated and delighted by Yucatan. From prehistoric temples to indigenous theater, from colonial cities to mangroves, from convents to superb cuisine. . .come and visit Yucatan.

INVESTMENT MANAGEMENT

30. CALVERT—INVESTMENTS THAT MAKE A DIFFERENCE®
The nation's largest family of mutual funds that integrate rigorous financial analysis with a thorough assessment of corporate integrity including environmental impact.

MARYLAND

31. DORCHESTER COUNTY, MD
Home to world-renowned Blackwater National Wildlife Refuge, excellent paddling, cycling, fishing and hunting; explore the heart of Chesapeake Country on Maryland's Eastern Shore.

32. FREDERICK COUNTY, MD
Maryland's Crossroads of History. Antiques, battlefields, covered bridges, parks, wineries and more close to Gettysburg and DC.

33. KENT COUNTY, MD
A scenic peninsula on the Chesapeake Bay, offering fishing, boating, kayaking, small beaches, awesome sunsets, museums, the "Arts," farmers' markets, and great shopping.

34. MARYLAND VACATIONS
Beaches, mountains, big cities, small towns. Maryland has so many things to do, so close together.

35. QUEEN ANNE'S COUNTY, MD
Historic Sites from the 1600's, waterfront dining on Kent Narrows, cycle the Cross Island Trail, antiquing in Historic Stevensville.

36. TALBOT COUNTY, MD
Five beautiful rivers, 602 miles of shoreline, unique charming hamlets St. Michaels, Oxford, Tilghman Island and Historic Easton offer a timeless treasury of natural beauty and history.

37. WORCESTER COUNTY, MD
Maryland's only seaside county. Visit Assateague Island National Seashore. Kayak, canoe, bird watch or golf. Stay in one of our many bed & breakfast inns.

MISCELLANEOUS

38. ATHENA PUBLICATIONS, INC.
Athena Review, journal of archeology, history and exploration, invites you to send for more information on a free issue.

39. BBC AMERICA SHOP
Bringing you the very best in British entertainment: award-winning DVDs and videos from your favorite television shows as well as movies, books, audio books and other British gifts.

40. GEVALIA KAFFE
Experience the pleasure of Gevalia® Kaffe. Order a Trial Shipment and you'll also receive a stylish coffeemaker—no further obligation.

41. L.L. BEAN
L.L. Bean, Freeport, Maine. Choose from a wide selection of new and classic products—tested and guaranteed to provide lasting quality and value. For your FREE catalog, circle our number.

42. PREMIER BATHROOMS
World's largest supplier of walk-in bathtubs. Call now for a free brochure!

43. THE TEACHING COMPANY
The Teaching Company brings you more than 200 courses by great teachers from prestigious colleges and universities on multiple formats for lifelong learners like you.

MONTANA

44. CUSTER COUNTRY, MONTANA
Custer, Sitting bull, and Lewis and Clark have been here. Why haven't you?

45. MONTANA TOURISM
Find what you're looking for in Montana! Fascinating cultural attractions, scenic beauty, outdoor adventure, enchanting lodges, shopping and western charm. Free Vacation Planner.

46. MONTANA'S MISSOURI RIVER COUNTRY
Experience dinosaur museums and field stations; scenic, unspoiled lands; wildlife watching; pioneer history; Lewis & Clark attractions and more.

47. MONTANA'S RUSSELL COUNTRY
Legendary in the paintings of yesterday and the digital pixels of today.

U.S. TRAVEL

48. ALABAMA GULF COAST
Spectacular beaches. Outstanding accommodations. And warmed by sunshine, history, culture and unspoiled natural beauty.

49. ARIZONA—THE GRAND CANYON STATE
Grab life and seize the day. Immerse yourself in a day full of adventure and a night full of fun.

50. CODY, WYOMING
Yellowstone National Park, Buffalo Bill's Historical Center, outdoor fun, rodeos, family fun and more. Free guide.

51. LITTLE ST. SIMONS ISLAND
Exclusive 10,000-acre Georgia island paradise, private seven-mile pristine beach, natural history tours, birding and recreational activities galore, gourmet regional cuisine and gracious accommodations await just thirty guests.

51. NORTH CAROLINA OUTER BANKS
The Outer Banks of North Carolina—Immerse yourself in culture and history. Here anytime is quality time.

52. THE GREAT STATE OF TEXAS
Discover a vacation you never knew existed. Discover mountains, prairies, open skies and endless coastlines. Discover it all in your FREE Texas State Travel Guide. Discover why Texas really is like a whole other country.

53. TUCSON, REAL. NATURAL. ARIZONA.
Discover a whole new side of nature in our fascinating desert landscape. And the weather's perfect for exploring our spectacular scenery any time of year.

THE GLORY OF GOLD

Exhibition opens November 18


© ARNE HODALIC/CORBIS

It is the stuff of legend from the lure of El Dorado to the bad bargains of King Midas and Rumpelstiltskin. Its durability is celebrated in wedding bands. It is a measure of wealth and, from Oscars to Olympic medals, it is an incomparable symbol of success. It is gold—the precious metal that has been coveted since it was first mined and minted by ancient civilizations.

Here to tell the remarkable story of gold's enduring appeal is *Gold*, a spectacular new exhibition that opens at the American Museum of Natural History on November 18 and is curated by James D. Webster, Chair and Curator in the Department of Earth and Planetary Sciences, with the advisement of Charles Spencer, Curator in the Division of Anthropology. In the popular tradition of previous Museum exhibitions *Amber: Window to the Past, Nature of Diamonds,* and *Pearls*, *Gold* takes visitors on a captivating journey of discovery, unearthing the history of this sought-after substance and its powerful influence on society from its critical role in currency to a place in contemporary culture; its value in jewelry to its more prosaic uses in industry and science.

Extraordinary natural specimens and cultural artifacts, culled from the geological and anthropological holdings of private collections and major museums, including the Museum's own, offer a feast for the eyes and glittering firsthand evidence of how gold is located, mined, and processed—and why it was capable of fueling frenzied gold rushes from South Africa to the Australian outback, California to the Klondike. Among the many brilliant items on display are ancient coins from China, Greece, and Rome; pre-Columbian jewelry; sunken treasure from ships that sailed in the 17th, 18th, and 19th centuries; and gold bars on loan from the U.S. Treasury. Also featured are a vanity box made by Cartier for Mary Pickford and a brooch designed by Paloma Picasso for Tiffany & Co. Tom Brokaw's Emmy award, Beyoncé's Grammy award, and the trophy won by Venetian Way in the 1960 Kentucky Derby represent "golden achievement."

Throughout the exhibition, which was designed and produced by the American Museum of Natural History's Department of Exhibition, visitors have numerous opportunities to explore the unique characteristics of gold—the physical properties that make it invaluable for coinage, ornamentation, and technological uses now and into the future. Illustrating the metal's malleability, for example, is an entire room covered in just three ounces of gold. A sample of gold the size of a pencil eraser embedded in a 220-pound boulder demonstrates how much rock must be processed to recover even the smallest amount of gold. Finally, a special scale raises the question, are you worth your weight in gold?

Gold is organized by the American Museum of Natural History, New York (www.amnh.org), in cooperation with The Houston Museum of Natural Science. This exhibition is proudly supported by The Tiffany & Co. Foundation.

Join us for presentations by AMNH scientists James D. Webster and Charles Spencer on opening day, Saturday, November 18, from 12:00 noon to 1:00 p.m.

Young Naturalist Awards

A research-based essay contest for students in grades 7–12 to promote participation and communication in science

Following in the tradition of scientific expeditions, the American Museum of Natural History's **Young Naturalist Awards** program, now in its ninth year, encourages students in grades 7 through 12 to hypothesize about the natural world while exploring close to home—in their backyards, nearby ponds, or woodlands. The resulting essays are judged on research methods, analysis, and clarity of writing.

Below are the names of the 2006 winners and the inspiration for their essays, with the titles shown in bold. Full texts, along with the contest guidelines, are available at www.amnh.org/youngnaturalistawards.

Shocked by a headline in her local newspaper, "Health Menace Lurks in Lakes," 7th grader Rachel Jones wondered about the health of a lake near her Orlando, Florida, home. The result was her paper, **Toxic Algae: A Threat to Florida Waters?**

Curious why two mockingbirds chose to nest near a busy road, close to his and other homes, 7th grader Ryan Wham of Woodland, Texas, conducted **An Analysis of Mockingbird Nesting Behavior in Residential Areas.**

In **Waterworks: A Purification Process**, Kendra Guerrero, an 8th grader in San Angelo, Texas, searched for an inexpensive way to make drinking water safe after reading about contaminated water problems in Haiti.

The smell of oil and "gooey soil" on his shoes when he walked behind a defunct refinery pushed 8th grader Kyle Ressel of Duncan, Oklahoma, to pursue **A Study of Claridy Creek: Water Pollution and the Effects of Phytoremediation on Contaminants.**

Jeffrey Fan, a 9th grader in Plainsboro, New Jersey, noticed that one section of a local pond was more polluted than another, so he embarked on an **Investigation of Water and Soil Quality Upstream and Downstream in a Pond Environment.**

After 9th grader Max Schneck learned his little sister was to be tested for lead, he looked into the possible threat posed by the expressway near their Dix Hills, New York, home in **Lead Levels in Residential Soil in Proximity to a Superhighway.**

Anastasia Roda, a 10th grader in Lancaster, Pennsylvania, investigated the effect of a nuclear reactor on water quality in **Human Factor III: The Impact of a Boiling Water Nuclear Reactor.**

Surprised by how drastically a pond changed when beavers built a dam and lodge on it, 10th grader Alexandra Souliotis of Afton, Virginia, decided to explore **The Work Habits of the North American Beaver.**

What do towering anthills have to tell us about harnessing the Sun's energy? This is the question pondered by 11th grader Anna Trugman of Los Alamos, New Mexico, in **Environmental Engineering of *Pogonomyrmex* Harvester Ant Mounds.**

Looking through some old photographs, 11th grader Caroline Wallace perceived a marked decline in Spanish moss (*Tillandsia usneoides*) on the trees of her hometown, Houston, Texas. She considered the implications in ***Tillandsia usneoides:* An Indicator Species to Air Pollution.**

On a long commute to school, Megan Starr of West Barnstable, Massachusetts, noticed how salt from the roads and air pollutants from cars had burned the tree leaves and pine needles. The 12th grader went from this observation to a study of **Ozone Pollution and White Pines: Phase II.**

Noting that "blue crabs are cannibalistic once they reach the juvenile stages where they grow claws," Justin Tibbels, a 12th grader in Baltimore, Maryland, considered the potential value of isolating them in **The Effect of Hatchery Cell Size on Growth of Juvenile Blue Crabs, *Callinectes sapidus* Rathbun.**

COURTESY ANASTASIA RODA

Many of this year's research projects focused on water quality. Here a student measures the water velocity of a creek.

Museum Events

AMERICAN MUSEUM ō NATURAL HISTORY

www.amnh.org

UPCOMING SPECIAL EXHIBITION AT THE AMNH

Frogs: A Chorus of Colors

This hugely popular exhibition returns for an encore.

May 26–September 9, 2007

Visit www.amnh.org for more.

EXHIBITIONS

Gold
Opens November 18, 2006
See page 76.

Lizards & Snakes: Alive!
Through January 7, 2007
Live lizards and snakes are the center of attention in this engaging exhibition that explores these creatures' remarkable adaptations. Fossil specimens, life-size models, and interactive stations complement the more than 60 live animals representing 26 species.

R. MICKENS/AMNH

An emerald tree boa rests on a branch.

Lizards & Snakes: Alive! is organized by the American Museum of Natural History, New York (www.amnh.org), in collaboration with Fernbank Museum of Natural History, Atlanta, and the San Diego Natural History Museum, with appreciation to Clyde Peeling's Reptiland. *Lizards & Snakes: Alive!* is made possible, in part, by grants from The Dyson Foundation and the Amy and Larry Robbins Foundation.

Voices from South of the Clouds
Through January 2, 2007
China's Yunnan Province is revealed through the eyes of the indigenous people, who use photography to chronicle their culture, environment, and daily life.

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

Yellowstone to Yukon
Through January 15, 2007
Spectacular photographs emphasize the diverse flora, fauna, and geology of the Yellowstone to Yukon corridor—an area connecting habitats so that wide-ranging animals can travel unimpeded by human structures and developments.

This exhibition was developed by the American Museum of Natural History's Center for Biodiversity and Conservation in concert with the Yellowstone to Yukon Conservation Initiative and the Wilburforce Foundation and is made possible by their support. Additional generous support provided by the Woodcock Foundation.

Vital Variety
Ongoing
Beautiful close-up photographs highlight the diversity of invertebrates.

MARGARET MEAD FILM & VIDEO FESTIVAL

Wednesday–Sunday, 11/8–12
The 30th anniversary of this ethnographic and documentary film festival includes screenings, question-and-answer sessions, roundtables with filmmakers, and more. Visit www.amnh.org/mead for details.

LECTURES

Adventures in the Global Kitchen: Day of the Dead
Thursday, 11/2, 7:00 p.m.
Zarela Martínez celebrates this Mexican holiday with tamales and other tasty treats.

ROSE CENTER FOR EARTH AND SPACE

Friday, November 3
6:00 and 7:30 p.m.

Dan Faulk Quartet

PEOPLE AT THE AMNH

Eric Hamilton
Senior Manager, Program Administration
National Center for Science Literacy, Education, and Technology

R. MICKENS/AMNH

Eric Hamilton, who has both bachelor's and master's degrees in illustration, recognizes not only the scientific value of the Museum's famous dioramas, but also appreciates them for their enduring artistry. "Every morning, I walk into a building filled with world-renowned scientists and educators, and still I think of this as a great art museum." He points out the remarkable blending of three-dimensional models and painted backgrounds.

Eric's passion for art permeates every aspect of his work. His whimsical illustrations grace the family guide for the exhibition *Lizards & Snakes: Alive!* and sections of OLogy, the Museum's award-winning interactive Web site for kids, among other Department of Education publications.

In addition, Eric's multifaceted job as Senior Manager, Program Administration, includes general administration, budget and office management, outreach for the National Center, and overseeing programs such as the Young Naturalist Awards (see p.77 for this year's winners). To promote the Museum's educational efforts, Eric travels frequently, attending local and national education and technology conferences.

Eric's active role in the Museum and elsewhere has not gone unnoticed. The Association of Educational Publishers, which awards individuals and institutions that demonstrate excellence in the educational publishing industry, honored him this year as their Member of the Year.


D. FINNIN/AMNH

Museum sleepover

The Revenge of Gaia
Tuesday, 11/14, 7:00 p.m.
James Lovelock, originator of the Gaia theory, which views Earth as a living meta-organism, discusses our looming global crisis and what we can do to mitigate it.

I, Woz
Tuesday, 11/28, 7:00 p.m.
Steve Wozniak, cofounder and inventor of Apple computer, tells the story of Apple's early days and the innovative thinking that led to the Macintosh.

Art/Sci Collision:
DNA: Not Merely the Secret of Life
Tuesday, 11/28, 7:00 p.m.
Nadrian C. Seeman, New York University, finds connections between art and science by working creatively with DNA.

FAMILY AND CHILDREN'S PROGRAM

NEW! A Night at the Museum Sleepovers
Saturday, 11/18 (Visit www.amnh.org *for future dates.)*
This special sleepover preview for families and groups with children ages 8 to 12 offers the unique opportunity to experience the Museum after hours. Stare down a herd of wild buffalo, confront a *T. rex*, and witness galaxies colliding, all before settling down to sleep in the Milstein Hall of Ocean Life.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

Virtual Universe
Sizing Up the Universe
Tuesday, 11/7, 6:30–7:30 p.m.

This Just In...
November's Hot Topics
Tuesday, 11/21, 6:30–7:30 p.m.

Celestial Highlights
When the Sun Stops
Tuesday, 11/28, 6:30–7:30 p.m.

LECTURE

Planets
Monday, 11/13, 6:30–7:30 p.m.
Science writer Dava Sobel, author of *Longitude* and *Galileo's Daughter*, offers lyrical musings on the planets and what they mean to her.

HAYDEN PLANETARIUM SHOWS

Cosmic Collisions
Journey into deep space to explore cosmic collisions, hypersonic impacts that drive the dynamic formation of our universe. Narrated by Robert Redford.

Cosmic Collisions was developed by the American Museum of Natural History in collaboration with the Denver Museum of Nature & Science; GOTO, Inc., Tokyo, Japan; and the Shanghai Science and Technology Museum. Made possible through the generous support of CIT. *Cosmic Collisions* was created by the American Museum of Natural History with the major support and partnership of the National Aeronautics and Space Administration's Science Mission Directorate, Heliophysics Division.

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

Presented in association with MTV2 and in collaboration with renowned artist Moby.

INFORMATION

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

TICKETS AND REGISTRATION

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

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

ENDPAPER

It's About Time

By Dolly Setton

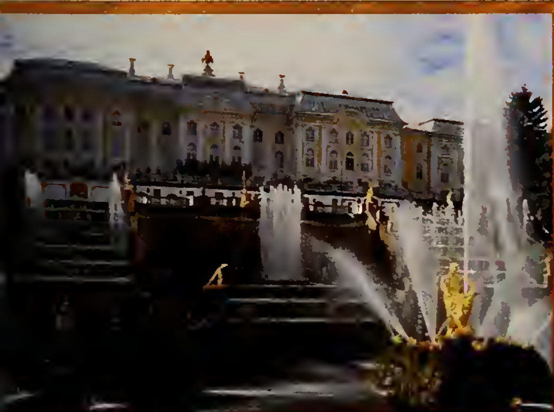
Worlds to Discover...

For more than 130 years the American Museum of Natural History has launched scientific expeditions across seven continents, mapping the origin and progression of life on this planet and exploring the richness and variety of world cultures. Inspired by this spirit of expedition, Members and friends of the Museum have been exploring the world on AMNH Expeditions for more than 50 years in the company of AMNH scientists. AMNH Expeditions transports travelers beyond the halls of the Museum to experience firsthand the world's greatest wildlife areas, archaeological sites, and cultural treasures from pole to pole and everywhere in between.

From the Flaming Cliffs of the Gobi Desert to the glistening blue icescapes of Antarctica, AMNH Expeditions offers unique itineraries that benefit from the exclusive Museum resources of AMNH and our international network of scientific associates. To learn more about AMNH Expeditions, join us on our next program!

Programs	Dates	Rates*
January 2007		
El Salvador & Guatemala	1/7-22	$6,450
Darwin's Galapagos	1/14-31	$12,850
February 2007		
New Zealand aboard *Clipper Odyssey*	2/9-21	from $6,990
Vietnam & Cambodia aboard *Mekong*	2/20-3/7	from $7,350
Papua New Guinea aboard *Melanesian Discoverer*	2/24-3/10	from $9,850
Egypt & the Nile River aboard *Sun Boat III*	2/2-3/5	from $8,390
March 2007		
Intriguing Japan aboard *Spirit of Oceanus*	3/1-17	from $8,990
Kingdom of the Monarchs	3/4-9	$3,085
The Mighty Amazon aboard *Corinthian II*	3/8-18	from $5,995
East India by *Private Air*	3/2-18	$18,850
April 2007		
Silk Road	4/10-5/1	TBD
Chile and Argentina on *Mare Australis*	4/18-5/1	from $6,890
Mexico's Copper Canyon aboard *Chihuahua al Pacifico*	4/29-5/7	$3,995

American Museum of Natural History Central Park West at 79th Street, New York, New York 10024-5192




Desperate Crossing
The Untold Story of the Mayflower
Sunday, November 19th 8pm/7c
It was a True Test of Manhood
Even for the Women and Children
H
THE HISTORY CHANNEL
History.com