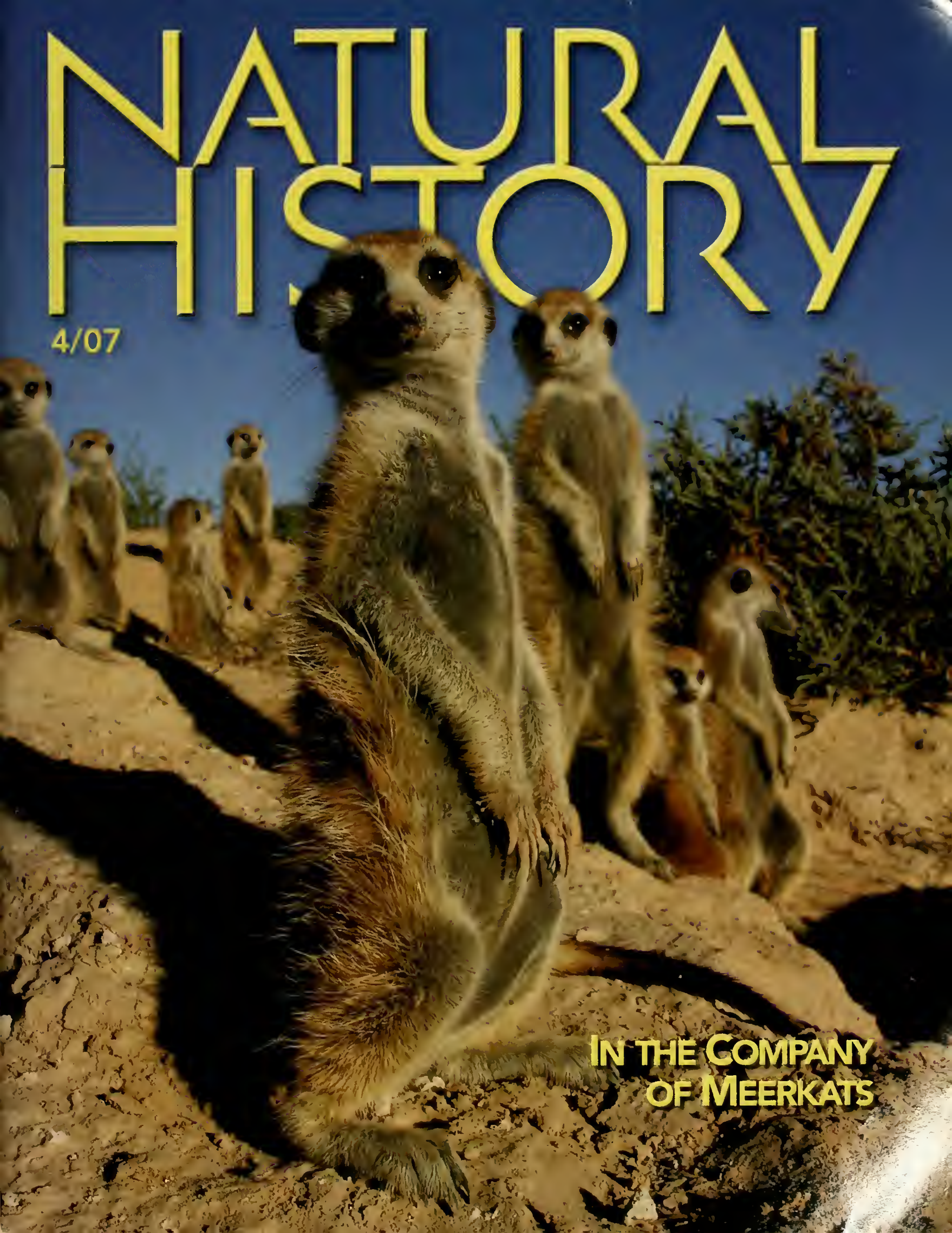
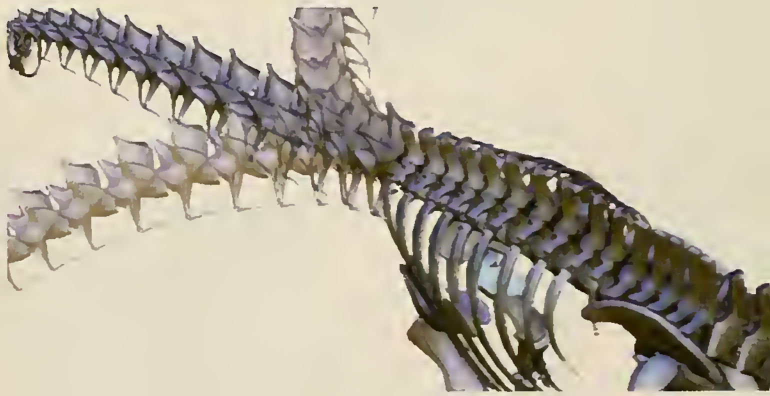
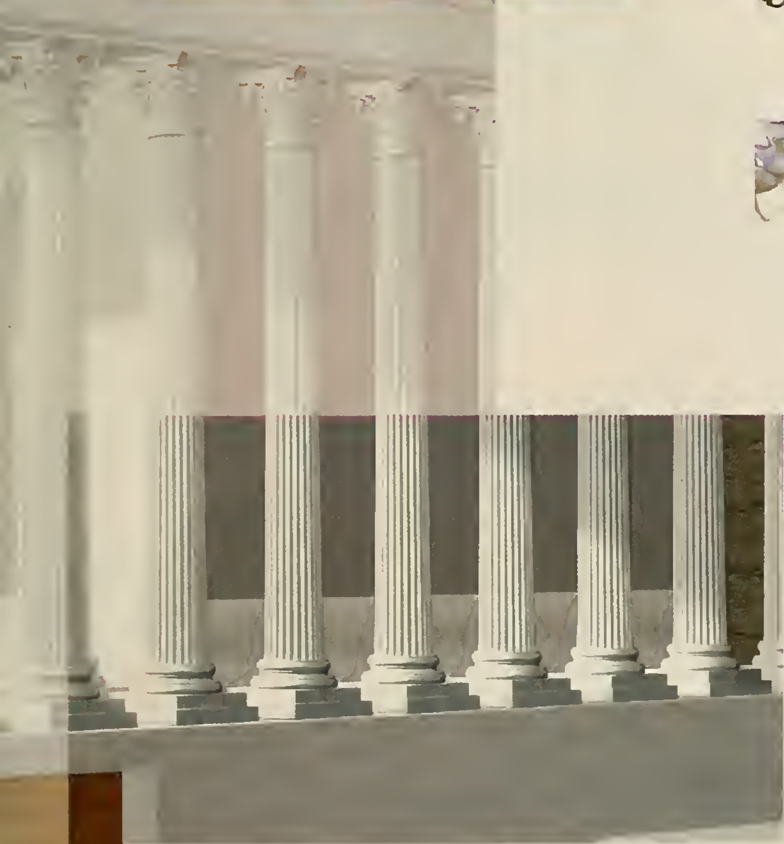

NATURAL HISTORY
4/07
IN THE COMPANY OF MEERKATS

NATURAL HISTORY

APRIL 2007 VOLUME 116 NUMBER 3

FEATURES





ON THE COVER: Meerkats strike a typical pose in the Kalahari Desert of southern Africa. Photograph by Andrew J. Young

NATURAL HISTORY

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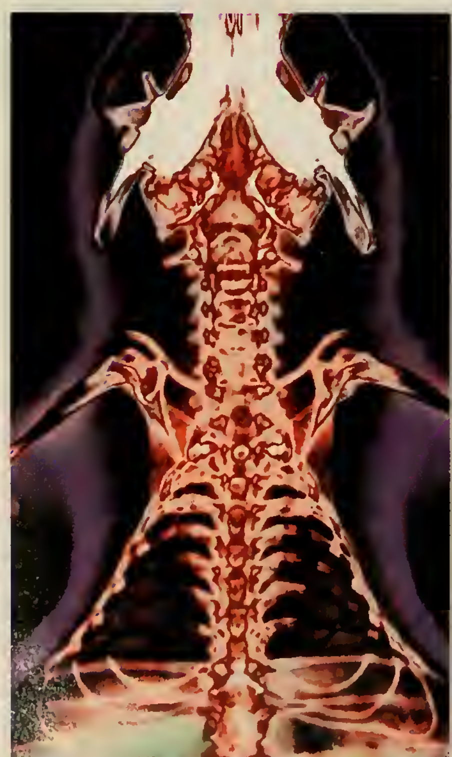

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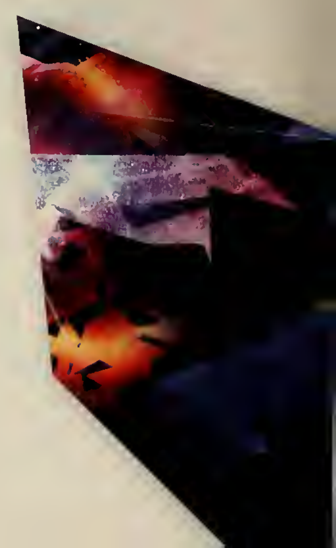

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Cosmic Connections

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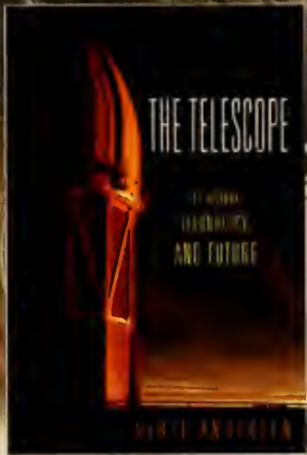

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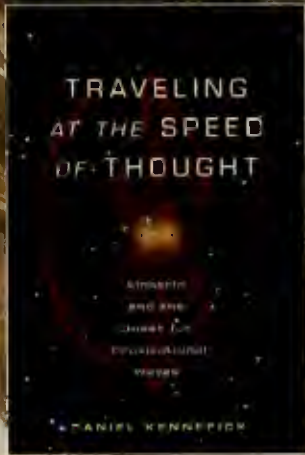

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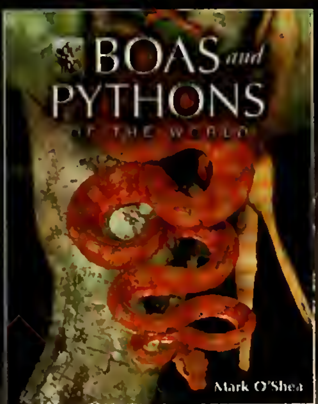

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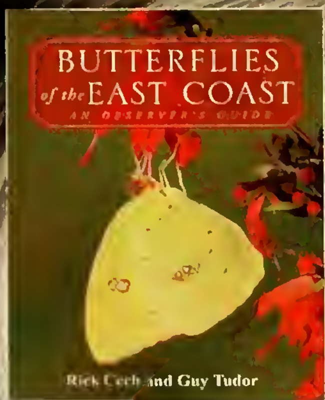

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THE NATURAL MOMENT

Bay of the Locust

Photograph by Satoshi Kuribayashi

THE NATURAL MOMENT

◄ *See preceding two pages*

Who among us would act the same way in a noisy, sweaty crowd of strangers as we would, say, alone on a serene mountaintop? Locusts, too, change their behavior drastically when in the company of others, and they go so far as to change physically, as well. In fact, entomologists originally mistook what are now called the solitary and gregarious locust phases to be distinct species.

Locusts that live alone are much like your skittish, garden-variety grasshopper. But when they gather into a critical mass, the same insects begin changing their color, size, travel plans, and more. Ultimately billions can swarm together into black clouds of biblical proportions, capable of crossing oceans and destroying vast tracts of cropland. Even now, an outbreak of desert locusts *(Schistocerca gregaria)* threatens farmers in Eritrea and Sudan, on the coast of the Red Sea.

The migratory locust *(Locusta migratoria)* pictured here was alone when photographer Satoshi Kuribayashi spotted it on a hilltop near Hirado in the Nagasaki prefecture of Japan. Yet the unusual perspective serves as a reminder of how much power the insect can have. To make his image—one that seems almost "Photoshopped"—Kuribayashi designed a long, narrow tube to extend the focal length of his lens. With most lenses, the depth of field shrinks as one zooms in on a small subject. With the special equipment, though, Kuribayashi managed to get both the locust and the distant bay in focus.

Actual size of the lone mountaineer: about two inches.

—*Erin Espelie*

UP FRONT

Multiple "Universes"

Writing these essays is the most exhilarating and exhausting thing I do in life. It is where I'm not only trying to convey information, I'm trying to convey love, the love of a subject. I don't always succeed, but when I do, I know of no greater source of professional happiness. —Neil deGrasse Tyson

Neil deGrasse Tyson (pictured below) is seldom at a loss for words. With his "Universe" column this month ("The Cosmic Perspective," page 22), he's written an even 100 columns of roughly 2,500 words each: more words, as he might put it, than there are miles from Earth to the Moon. But after he had patiently answered my questions about the column with a practiced ease, he told me he wanted to answer a question I didn't ask. And then he spoke in almost halting syllables, groping for the sentences I've quoted above, about the passion he brings to his column about the cosmos.

Writing a "Universe" column, Tyson says, is "the closest thing I can imagine to giving birth. I know women would say, 'You have no clue.' But

so much is coming out of me that when I finish a column, I wonder if I can regenerate the energy and the emotion to do it again in thirty days."

Tyson wrote his first column for *Natural History* in January 1995. The twelve years since then have been an extraordinarily exciting time for astrophysics, in part, he says, "because the biggest discovery in *science* was the discovery of dark energy, the fact that we live in an accelerating universe." What about the next twelve years? "I want missions to the water-bearing objects in the solar system, which include Mars and some of the moons of Jupiter. I want to know whether there's bacterial life, or any kind of life at all, thriving in those environments. That's something that's knowable in the next ten to fifteen years."

• • •

Two of this month's features complement major exhibitions at two of the nation's most important museums of science and natural history. "Dinosaurs: Ancient Fossils, New Discoveries" opened March 30 at the Field Museum in Chicago and runs through September 3. In "The Sauropod Chronicles" (page 34), Richard A. Kissel, a paleontologist at the Field, notes that sauropod dinosaurs (the big plant-eaters with the long necks) used to be thought of as giraffelike beasts that held their necks upright. In fact, Kissel reports, recent computerized reconstructions suggest they held their necks horizontally, flexing them downward to feed.

The second exhibition to complement one of our features is "Imperial Rome," on display from now through August 12 at the Houston Museum of Natural Science. Readers with a weakness for archaeology, geology, or history will find that Marie D. Jackson's article about the stone that built ancient Rome ("Vulcan's Masonry," page 40) offers a fascinating counterpoint to the Houston exhibition, and a glimpse into the genius of ancient Roman stonemasons. —Peter Brown


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The photographer **SATOSHI KURIBAYASHI** ("The Natural Moment," page 4) has spent the past thirty-eight years making extreme close-ups—mostly of insects—with camera equipment he specially modifies for the job. On two occasions the Photographic Society of Japan has named him photographer of the year, and in fall 2006 he won the Lennart Nilsson Award for scientific photography. Kuribayashi's most recent book is *In Front of the Ant* (Kane/Miller). More of his microlandscapes can be seen at his Web site (www5.ocn.ne.jp/~kuriken).

Originally from Australia, **LYNDA L. SHARPE** ("Meerkats At Play," page 28) joined the Kalahari Meerkat Project of the University of Cambridge in 1996. She spent eight years in the desert in South Africa studying the social behavior of meerkats, earning a doctorate from the University of Stellenbosch in Matieland, South Africa. Flower, one of the pups Sharpe followed from birth to adulthood, is the dominant female of the Whiskers meerkat group, now starring in the Animal Planet television series *Meerkat Manor.* Before her work with meerkats, Sharpe was at Monash University in Australia, where she studied play behavior in the puppies of captive African wild dogs and in carnivorous marsupials. She is doing postdoctoral research on sentinel behavior in dwarf mongooses at the University of Stellenbosch.

RICHARD A. KISSEL ("The Sauropod Chronicles," page 34) thanks his dad for frequent trips to the great dinosaur hall at the Carnegie Museum of Natural History in Pittsburgh, where mounts of *Apatosaurus, Diplodocus,* and *Tyrannosaurus* fueled his interest in all things extinct. Today, as a paleontologist who has studied dinosaurs and other ancient creatures, he has been delving more deeply into the history of his profession. Kissel is science program developer for the Field Museum in Chicago, where he is responsible for designing, coordinating, and teaching programs on paleontology and other science-based topics. He served as the primary scientific adviser for "Evolving Planet," the museum's new, 27,000-square-foot exhibition on the history of life on Earth.

During a year spent in Rome with her family, geologist **MARIE D. JACKSON** ("Vulcan's Masonry," page 40) became fascinated with the diversity of volcanic rock that forms the foundation of ancient Roman stone architecture. Her collaborations with Italian and American investigators have led to a new analysis of the building materials used by Roman stonemasons, which the Roman architect Vitruvius described in the late first century B.C. The research she presents in this article was published in the three scholarly journals *Archaeometry, Journal of the Construction History Society,* and *American Journal of Archaeology.* Her research focus has now turned to examining ancient Roman concretes. Jackson teaches at Northern Arizona University in Flagstaff.

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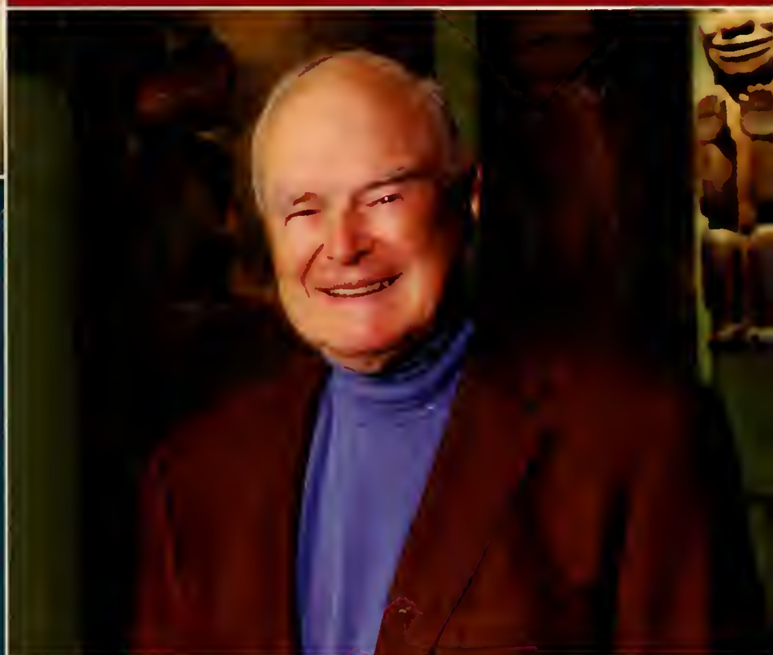
—Donald K. Clifford, Jr.

"The American Museum of Natural History is one of the world's major educational and cultural venues. My charitable gift annuity gives me the pleasure of seeing my gift already at work in the Museum. And each time I receive a check from them, I feel a special pleasure in knowing I am part of the organization."
—John C. Bierwirth



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Blowing Hot and Cold

I am befuddled that Donald Goldsmith ["Ice Cycles," 3/07] finds it "sad" that "the present release of carbon dioxide, mainly through the burning of coal and oil, overcompensates for any cooling trend by several orders of magnitude." Why not conclude, instead, that it is possible that human activities that cause global warming may have saved us all from the onset of the next catastrophic ice age?
John D. Marshall
Beaverton, Oregon

Donald Goldsmith cites the analogy between Milutin Milankovitch's hypotheses and the long period before the acceptance of Alfred L. Wegener's continental-drift theory. Milankovitch actually published his theory much earlier than his 1941 book, which Mr. Goldsmith cites, and also collaborated with Wegener on the geologic evidence. Wegener's 1925 paper (with Eduard Brückner and Wladimir Köppen), "The Climates of the Distant Geological Past," includes a "radiation curve" by Milankovitch that matched four alpine ice ages.

Wegener asked Milankovitch to extend his research "to find out what the mechanical cause of polar wandering could be." But Wegener died in 1930, before their collaboration could continue.
Matt Brzostowski
Houston, Texas

DONALD GOLDSMITH REPLIES: John D. Marshall suggests that the release of carbon dioxide has saved us from an ice age. But because ice ages come on slowly, we would have plenty of time to plan a limited release of carbon dioxide to counteract any cooling trend. Our present behavior has no such motivation; it results instead from our refusal to consider the planetary impact of continuing to increase our burning of fossil fuels. One should not fight a cold snap by setting fire to one's house.

Octopus Eyes

I have a small correction to a caption that accompanies Jennifer A. Mather's article on octopuses ["Eight Arms, With Attitude," 2/07]. The eye of the octopus is described as having a cornea. In fact, the pupil is open to seawater, which is interesting in itself.

I also have a question: Octopuses have only one visual pigment in the photoreceptors of the retina. Because at least two visual pigments are required for color vision, how can the octopus change its color and even its texture in response to its environment, without being able see whether its changes match or contrast with the background?
Ivan R. Schwab, M.D.
University of California, Davis
School of Medicine
Sacramento, California

Jennifer A. Mather replies: Ivan R. Schwab is right about the lack of a cornea; I did not compose the original caption, and the error slipped by.

How a color-blind animal can match background colors is a question that has fascinated those who study cephalopods. First, cephalopods can match background contrast, and they do it well. Second, the reflective layers of iridophores and leucophores (which lie beneath the chromatophore pigment sacs) tend to reflect ambient light and thus match background color to a fair extent. Third, pattern generators ensure that the animal matches the visual texture of its environment. Finally, not all concealment involves background matching; some is disruptive instead. H.B. Cott's classic 1940 book, *Adaptive Coloration in Animals,* is instructive on the general principles.

Spinmeister

Charles Liu's assertion, in his article "Spin Control" [3/07], that engineers design pipeline systems "with Reynolds numbers no higher than about 2,000," is not correct. True, a Reynolds number of about 2,300 is the transition point between laminar and turbulent flow. But except in unusual cases, an engineer would design a pipeline for a Reynolds number much greater than 2,300. Turbulent flow leads to less drag between the fluid and the wall of the pipe, and so less energy per pound of fluid is needed to move that fluid along the pipe.
Roderick A. Dibble
Chagrin Falls, Ohio

Charles Liu replies: I thank Roderick A. Dibble for sharing his expertise. To be accurate, my text should read: ". . . with Reynolds numbers lower than about 2,000 to ensure laminar flow, and higher than about 3,000 to ensure turbulent flow."

Just as pipeline systems are strongly influenced by their boundary conditions—such as the contact between the pipe walls and the fluid—so, too, are astrophysical systems. In my view, that's why the result I reported was so significant.

Overactive Volcano

Contrary to what Robert Anderson states in his column "New Tubes" [3/07], Mount St. Helens is in Washington State. The volcano is still active, but not active enough to have moved to Oregon.
Ann Bjork
Seattle, Washington

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.*

Space Bling

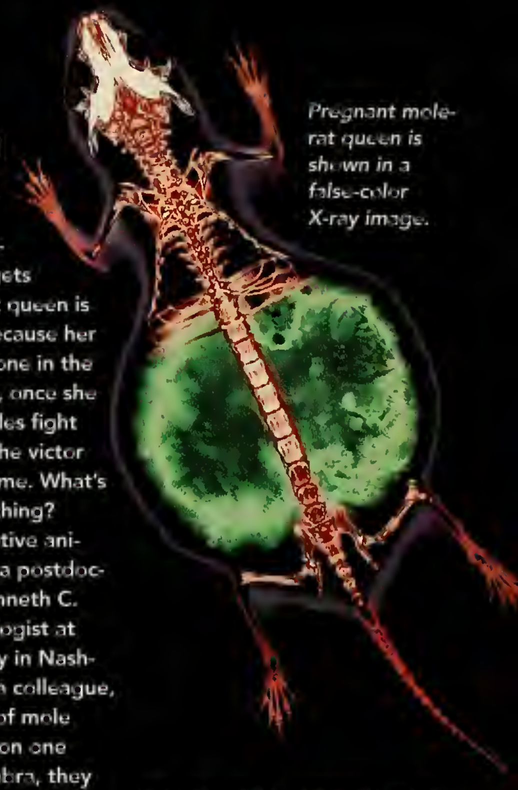
Carbonado diamonds, also called black diamonds, are nothing like their flashy cousins: they're an opaque black or gray, with a porous, sometimes charcoal-like texture. Conventional diamonds, moreover, form under pressure deep within the Earth and are shot toward the surface in hot, volcanic pipes, whereas the origin of carbonados has remained as dark as their color. They're found only in the Central African Republic and Brazil, and even there, they never occur in volcanic formations. A new study has finally illuminated the mystery, showing that carbonados came not from far below, but from far above—from outer space.

Jozsef Garai and his former graduate adviser, Stephen E. Haggerty, a geoscientist at Florida International University in Miami, along with two colleagues, analyzed the chemical bonds in carbonados by studying how they absorb infrared light. The technique, commonly employed with conventional diamonds, had been impossible to apply to carbonados because of silica impurities that mask absorption of relevant wavelengths of infrared light. The team devised a way to remove the impurities from crushed carbonados, then made the standard infrared analysis. They also aimed a much brighter infrared beam at impurity-free areas of carbonado slices. The result was the first complete infrared analysis of the carbonado diamond.

The study revealed the presence of hydrogen—a sign that the carbonados formed in a hydrogen-rich environment, such as outer space—and a lack of nitrogen clumps, which form only under pressure, deep in the Earth. Those features, along with others, indicate an extraterrestrial origin, possibly in a supernova explosion. Garai and Haggerty say carbonados probably landed on Earth some 3 billion years ago, perhaps as a single, mile-wide asteroid that broke apart before landing. Now that would have been a lot of carats. *(Astrophysical Journal)*

—Stéphan Reebs

Grow Long



Pregnant mole-rat queen is shown in a false-color X-ray image.

In a colony of naked mole rats, as in a beehive, only one female—the queen—gets to breed. A mole-rat queen is easy to recognize because her body is the longest one in the colony. Furthermore, once she dies, the other females fight to replace her, and the victor grows longer with time. What's causing all the stretching?

Working with captive animals, Erin C. Henry, a postdoctoral fellow, and Kenneth C. Catania, a neurobiologist at Vanderbilt University in Nashville, together with a colleague, took weekly X rays of mole rats. Concentrating on one representative vertebra, they measured the length of the fourth lumbar in "new queens" (females recently paired with a mate) and in a mole-rat bachelorette over a period of two and a half years.

Among the queens that underwent five or more pregnancies during the study period, the lengths of the fourth lumbars increased, on average, by 34 percent; in the bachelorette, the increase was less than 14 percent. Thus a longer body is probably a consequence of pregnancy. Most of the growth in the queens took place during the second half of each pregnancy, when gestation hormones peaked, suggesting that the hormones induce the growth spurts [see "Job Growth," 12/04–1/05].

The average litter of naked mole rats numbers twelve pups, but it can reach twenty-eight, the largest known for any mammal. Sure, it takes a big belly to accommodate that many fetuses, but why grow long, not wide? According to the investigators, queens must remain slim enough to patrol the narrow, subterranean tunnels of their colonies, in part to prevent other females from breeding. Mole-rat moms must literally go to great lengths for their babies. *(Journal of Experimental Biology)* *—S.R.*

Fishy Logic

"Pick your battles wisely" is sound advice that people forget all too often. We could learn a thing or two from *Astatotilapia burtoni*, a little cichlid fish from the shallows of Lake Tanganyika in central Africa. New research shows that *A. burtoni* possesses surprising powers of logic—for a fish. The males can deduce the pecking order among their rivals after watching only some of them fight each other.

Astatotilapia burtoni: one smart fish

Logan Grosenick and his adviser, Russell D. Fernald, a biologist at Stanford University, along with a colleague, placed "bystander" fish in the central part of an experimental tank. There the bystanders could watch staged, one-on-one fights between five rival males in compartments around the tank's perimeter. To establish a dominance hierarchy among the rivals, the investigators predetermined the outcome of each fight by handicapping one contender—removing it from the water to stress it, then placing it in the other's home tank. Only closely ranked rivals were pitted against one another. Thus the bystanders watched fish *A* fight and beat fish *B*, *B* fight and beat *C*, and so on through fish *E*.

After exposing eight bystanders to either two or four of the fights each day for eleven days, the investigators tested whether the bystanders had been able to infer the complete hierarchy despite the gaps in their knowledge. Each bystander was shown two males that had never fought—*A* and *E* or *B* and *D*—in compartments on opposite sides of the tank. In nearly all the trials, the bystander clearly identified the lower ranking of the two males, visiting him first and spending longer near him (a sensible preference, considering a bystander's improved odds at beating a low-ranking rival). That cognitive leap is roughly equivalent to the reasoning abilities children attain around age four. Not bad for a fish! *(Nature)*

—Nick W. Atkinson

Cold Wind from the East

During the most recent ice age, some 20,000 years ago, a thick ice sheet covered Canada and parts of the northern United States. The climate then was obviously quite different than it is today—but was it so different that the prevailing winds south of the ice sheet blew in a different direction? Xiahong Feng, an earth scientist at Dartmouth College in Hanover, New Hampshire, and several colleagues came up with a clever way to answer that question.

Feng's team analyzed pieces of ancient wood collected across the continent for two rare, heavy isotopes of the elements that make up water, deuterium (hydrogen-2) and oxygen-18. The isotopes came from the rainwater taken up by the trees when they were alive. Because rainwater molecules made of heavy isotopes fall to Earth before those made of light isotopes do, the higher the proportion of heavy isotopes in the ancient wood, the closer the rain clouds were to their origin, the ocean.

The investigators discovered that the relative amounts of deuterium and oxygen-18 in North American wood from the most recent ice age decline from east to west. Hence the winds prevailing across the continent blew from the east. After the ice age, beginning about 10,000 years ago, the wood shows a different pattern: the levels of the two isotopes reach minimum in the Midwest and rise toward both coasts, the mark of modern prevailing westerlies and the storms that take place on both coasts. *(Geology)*

—*S.R.*

Reading the Leaves

CO_2 sampler: no assembly required

There's nothing corny about global warming, perhaps the twenty-first century's most serious environmental and economic challenge. But a new study shows that corn can help map emissions of carbon dioxide (CO_2), an important greenhouse gas.

CO_2 released by burning fossil fuels includes much less of the isotope carbon-14 than does naturally occurring CO_2. Furthermore, plants incorporate carbon from atmospheric CO_2 into their greenery during photosynthesis. So Diana Y. Hsueh and her adviser, James T. Randerson, an earth scientist at the University of California, Irvine, and colleagues argue that plants provide a cost-effective means of sampling the CO_2 derived from fossil fuels. And what better plant for that job in North America than abundant, ubiquitous corn?

Hsueh and Randerson's team analyzed the carbon-14 in corn leaves gathered from sixty-seven locations across the United States and Canada, then made a map of North American CO_2 emissions derived from fossil fuels. What they discovered was hardly surprising: plenty of emissions in California and the eastern U.S. (the Ohio Valley in particular), both densely populated regions, and relatively few in the less-populous Rocky Mountains and the Great Plains. The agreement with known patterns of fossil-fuel use shows the technique is a reliable mapping tool that could help track emissions over time and pinpoint high-level sources. *(Geophysical Research Letters)*

—*S.R.*

Early Adapters

Some plants take decades to mature before reproducing; others complete their entire life cycles in a year. A new study shows that when it comes to global warming, fast-maturing plants might have a "leaf up" on slow-maturing plants because they can evolve quickly in response to climate variations.

Steven J. Franks, an evolutionary biologist at the University of California, Irvine, and two colleagues studied field mustard *(Brassica rapa)*, a weedy annual plant common throughout North America. The team collected field-mustard seeds from two sites in California in 1997, after several years of heavy rainfall, and again in 2004, after a five-year drought. They grew plants from the seeds, then experimentally subjected the plants' offspring to dry, moist, or wet growing conditions. Members of the postdrought lineage were clearly adapted to a parched environment: under dry conditions they had a higher survival rate than predrought-lineage members, and under all three growing conditions they flowered earlier. (During a drought, early flowering gives plants a better chance of reproducing before they wither.)

Field mustard

Franks's team then crossed pre- and postdrought plants, and grew the hybrid offspring alongside other pre- and postdrought plants. Sure enough, the timing of the hybrids' flowering was intermediate, confirming that flowering time is hereditary and changes with selective pressure from drought. In short, the field-mustard populations had evolved.

Franks did not test the adaptive responses of slow-maturing plants, which include many species of trees. Nevertheless, he reasons, the demonstrated adaptability of fast-maturing plants, such as field mustard, to climate variability gives them an advantage over slow-maturing plants, which simply have fewer generations, hence fewer chances to adapt, in a given time. Of course, Franks warns, if climate change becomes extreme, even the weeds won't evolve fast enough to keep up. *(PNAS)*

—*Rebecca Kessler*

SAMPLINGS

What Killed Napoléon?

Had Napoléon Bonaparte escaped or been released from his exile on the South Atlantic island of Saint Helena, some historians believe, European history might have taken a decidedly different course. But a recent investigation into the cause of the former emperor's death there in 1821, at age fifty-two, suggests otherwise.

The autopsy report for Napoléon listed stomach cancer as the cause of death. But in 1961 investigators discovered elevated levels of arsenic in his hair, spurring theories that he had been poisoned, perhaps by his supposed friend, the Comte de Montholon. Moreover, accounts of Napoléon's obesity in his later years seemed to refute the stomach-cancer hypothesis.

In a recent study, a team led by two pathologists—Alessandro Lugli of University Hospital of Basel in Switzerland and Robert M. Genta of the University of Texas Southwestern Medical Center in Dallas—took another look at the emperor's death. They evaluated his clinical history and autopsy reports, his physician's memoirs, and other pertinent historical documents in accord with the methods of modern pathology. They also compared his case to 135 recent confirmed cases of stomach cancer. Their conclusion: Napoléon had an advanced, debilitating stomach cancer that would have prevented him from altering the balance of European power had he left Saint Helena.

The team found no evidence that arsenic poisoning caused Napoléon's death (though he might well have been exposed to arsenic, perhaps innocuously), or that he had a familial predisposition to cancer. As for the emperor's weight, the same group showed in an earlier study, based on a collection of his trousers, that he lost some twenty-four pounds in his last year of life. Such weight loss is consistent with stomach cancer. The team thinks Napoléon was infected with the bacterium *Helicobacter pylori*, which could have caused an ulcer and ultimately led to his fatal cancer. *(Nature Clinical Practice Gastroenterology & Hepatology)*

—*Graciela Flores*

Paul Delaroche, Napoléon at Fontainebleau, March 31, 1814, *1840 (detail)*

The Carnivore's Dilemma

Land mammals that eat meat fall into two camps: the kiddie-menu crowd and the supersize-me set. Small carnivores usually go after bite-size prey, such as worms and mice, which don't take much effort to hunt. But even the most proficient hunter can catch only so many small prey a day. As species get bigger, the energy gained from catching small prey soon lags behind rising metabolic needs and hunting costs. For carnivores weighing more than about forty pounds, the size of a coyote, it pays to switch to large prey, so large carnivores hunt animals closer to their own size.

Short-faced bear, now extinct

A new model developed by Chris Carbone, a biologist at the Zoological Society of London, and two colleagues explains how the balance between gains and expenditures in energy determines—and limits—the carnivores' size and their prey selection. According to the model, as body size surpasses forty pounds, the metabolic costs of hunting rise more steeply than the energy gained. A carnivorous mammal weighing more than about a ton couldn't catch enough prey—no matter how large—to survive.

That's a good fit with reality: the largest known mammalian predators, such as the extinct short-faced bear, max out at around a ton. Those and even somewhat smaller meat-eaters probably live close to the edge in maintaining their delicate energy balance. Indeed, they have advanced energy-conservation tactics, such as lions' long bouts of inactivity or bears' hibernation. Carbone thinks that explains why more large carnivores run a bigger risk of extinction than small carnivores or vegetarians: they're more vulnerable to changes in the availability of prey. As nature's self-appointed custodians, we should take note. *(PLoS Biology)* —*S.R.*

Ménage à Trois

Hot geothermal soils aren't particularly hospitable to plant life, yet that's where *Dichanthelium lanuginosum*, a species of grass, thrives. It owes its survival to a symbiotic fungus, *Curvularia protuberata*, that lives in its tissues—or so plant biologists thought. But new research has uncovered a third party to the affair: a virus.

Grown separately, neither the grass nor the fungus survives temperatures above 100 degrees Fahrenheit; when grown together, the two do just fine at a sweltering 149 degrees. But the fungus, it turns out, is protective only when a virus is infecting its tissues. The discovery was made by Luis M. Márquez, an ecologist, and Marilyn J. Roossinck, a viral evolutionary ecologist, both at the Samuel Roberts Noble Foundation in Ardmore, Oklahoma, along with two colleagues.

Grasses inoculated with a virus-free form of the fungus acted just like grasses that were entirely fungus-free: when grown in soil warmed daily to 149 degrees, they became shriveled and pale, and eventually died. Then, to confirm that the virus was responsible for the increased thermal tolerance, the investigators reintroduced the virus into the virus-free fungus. Sure enough, the newly infected fungus conferred the same level of heat tolerance in the grass as the naturally infected fungus did. Moreover, the infected fungus had a similar protective effect when transferred to the tomato plant, *Solanum lycopersicon*. Tomato is only distantly related to grass, suggesting that the virus affects a physiological mechanism for heat tolerance common to many plants.

All plants harbor fungal symbionts, some of which carry viruses, but this example is the first known case of a virus, a fungus, and a plant living together cooperatively. Others surely remain to be discovered. *(Science)* —*G.F.*

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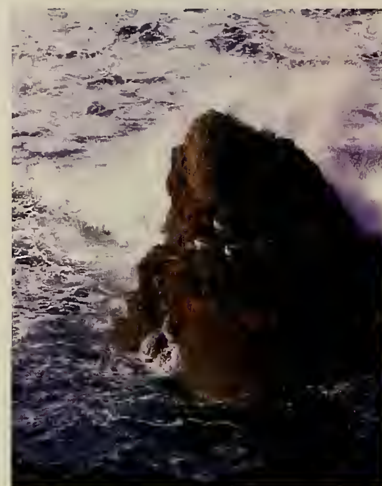

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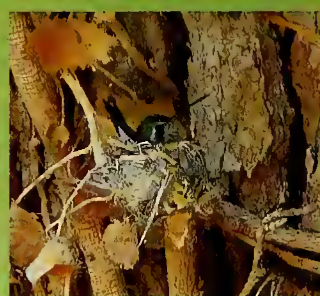

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NOW AIR GREENLAND HAS A DIRECT FLIGHT FROM Baltimore to Kangerlussuaq, Greenland's main airport—and it only takes five hours. The largest island in the world, Greenland is situated where the Atlantic meets the Arctic Ocean. Eighty-five percent of the country is covered in ice sheet, and the rest—an area about the size of France—is ice-free.

While those in search of an extreme adventure might explore the ice cap or play a round of ice golf, most tourists experience the magnificent icy landscape on a dogsled. Whether on a short trip of a two-week adventure, you can expect an unforgettable experience, thanks to the breathtaking scenery and wildlife, not to mention the sled dogs and dogsled drivers. In summer, because of the midnight sun, it is light around the clock, and the low-hanging sun brings a dreamlike backdrop to the landscapes. You won't sleep much, but who would want to? You might also fly over the ice cap and a sea full of icebergs or take a cruise around the drifting bergs: the only ways to get around are by air or boat, since Greenland has neither roads nor railroads connecting towns.

About a third of Greenland comprises the world's largest national park. Located in the northeast, the park shelters polar bears, walruses, reindeer, musk oxen, and a growing stock of wolves, as well as many bird species. Whales are easy to spot, and seals and walruses are plentiful.

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More northern hints, and definitely on the east coast. Those Vikings were travellers.

It has the oldest funeral monument in North America, dating back thousands of years, to a time before the pyramids.

Hmm. Aboriginal, for sure.

So, we have north and east — northeast — on the Atlantic coast, and it's a culture with a 625-page dictionary full of funny-sounding words that deal mainly with the catching of fish. And if that doesn't give it away, you can take this to the bank: the Flat Earth Society says it's one of the four corners of the world.

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UNIVERSE: THE 100TH ESSAY

The Cosmic Perspective

For this month's special anniversary of his "Universe" column, Neil deGrasse Tyson explains how embracing cosmic realities can give us a more enlightened view of human life.

By Neil deGrasse Tyson

Of all the sciences cultivated by mankind, Astronomy is acknowledged to be, and undoubtedly is, the most sublime, the most interesting, and the most useful. For, by knowledge derived from this science, not only the bulk of the Earth is discovered . . . ; but our very faculties are enlarged with the grandeur of the ideas it conveys, our minds exalted above [their] low contracted prejudices.

—James Ferguson, *Astronomy Explained Upon Sir Isaac Newton's Principles, And Made Easy To Those Who Have Not Studied Mathematics* (1757)

Long before anyone knew that the universe had a beginning, before we knew that the nearest large galaxy lies two and a half million light-years from Earth, before we knew how stars work or whether atoms exist, James Ferguson's enthusiastic introduction to his favorite science rang true. Yet his words, apart from their eighteenth-century flourish, could have been written yesterday.

But who gets to think that way? Who gets to celebrate this cosmic view of life? Not the migrant farmworker. Not the sweatshop worker. Certainly not the homeless person rummaging through the trash for food. You need the luxury of time not spent on mere survival. You need to live in a nation whose government values the search to understand humanity's place in the universe. You need a society in which intellectual pursuit can take you to the frontiers of discovery, and in which news of your discoveries can be routinely disseminated. By those measures, most citizens of industrialized nations do quite well.

Yet the cosmic view comes with a hidden cost. When I travel thousands of miles to spend a few moments in the fast-moving shadow of the Moon during a total solar eclipse, sometimes I lose sight of Earth.

When I pause and reflect on our expanding universe, with its galaxies hurtling away from one another, embedded within the ever-stretching, four-dimensional fabric of space and time, sometimes I forget that uncounted people walk this Earth without food or shelter, and that children are disproportionately represented among them.

When I pore over the data that establish the mysterious presence of dark matter and dark energy throughout the universe, sometimes I forget that every day—every twenty-four-hour rotation of Earth—people kill and get killed in the name of someone else's conception of God, and that some people who do not kill in the name of God kill in the name of their nation's needs or wants.

When I track the orbits of asteroids, comets, and planets, each one a pirouetting dancer in a cosmic ballet choreographed by the forces of gravity, sometimes I forget that too many people act in wanton disregard for the delicate interplay of Earth's atmosphere, oceans, and land, with consequences that our children and our children's children will witness and pay for with their health and well-being.

And sometimes I forget that powerful people rarely do all they can to help those who cannot help themselves.

I occasionally forget those things because, however big the world is—in our hearts, our minds, and our outsize atlases—the universe is even bigger. A depressing thought to some, but a liberating thought to me.

Consider an adult who tends to the traumas of a child: a broken toy, a scraped knee, a schoolyard bully. Adults know that kids have no clue what constitutes a genuine problem, because inexperience greatly limits their childhood perspective.

As grown-ups, dare we admit to ourselves that we, too, have a collective immaturity of view? Dare we admit that our thoughts and behaviors spring from a belief that the world revolves around us? Apparently not. And the evidence abounds. Part the curtains of society's racial, ethnic, religious, national, and cultural conflicts, and you find the human ego turning the knobs and pulling the levers.

Now imagine a world in which everyone, but especially people with power and influence, holds an expanded view of our place in the cosmos. With that perspective, our problems would shrink—or never arise at all—and we could celebrate our earthly differences while shunning the behavior of our predecessors who slaughtered each other because of them.

Back in February 2000, the newly rebuilt Hayden Planetarium featured a space show called "Passport to the Universe," which took visitors on a virtual zoom from New York City to the edge of the cosmos. En route the audience saw Earth, then the solar system, then the 100 billion stars of the Milky Way galaxy shrink to barely visible dots on the planetarium dome.

Within a month of opening day, I received a letter from an Ivy League professor of psychology whose expertise was things that make people feel insignificant. I never knew one could specialize in such a field. The guy wanted to administer a before-and-after questionnaire to visitors, assessing the depth of their depression after viewing the show. "Passport to the Universe," he wrote, elicited the most dramatic feelings of smallness he had ever experienced.

How could that be? Every time I see the space show (and others we've produced), I feel alive and spirited and connected. I also feel large, knowing that the goings-on within the three-pound human brain are what enabled us to figure out our place in the universe.

Allow me to suggest that it's the professor, not I, who has misread nature. His ego was too big to begin with, inflated by delusions of significance and fed by cultural assumptions that human beings are more important than everything else in the universe.

In all fairness to the fellow, powerful forces in society leave most of us susceptible. As was I . . . until the day I learned in biology class that more bacteria live and work in one centimeter of my colon than the number of people who have ever existed in the world. That kind of information makes you think twice about who—or what—is actually in charge.

From that day on, I began to think of people not as the masters of space and time but as participants in a great cosmic chain of being, with a direct

genetic link across species both living and extinct, extending back nearly 4 billion years to the earliest single-celled organisms on Earth.

I know what you're thinking: we're smarter than bacteria.

No doubt about it, we're smarter than every other living creature that ever walked, crawled, or slithered on Earth. But how smart is that? We cook our food. We compose poetry and music. We do art and science. We're good at math. Even if you're bad at math, you're probably much better at it than the smartest chimpanzee, whose genetic identity varies in only trifling ways from ours. Try as they might, primatologists will never get a chimpanzee to learn the multiplication table or do long division.

If small genetic differences between us and our fellow apes account for our vast difference in intelligence, maybe that difference in intelligence is not so vast after all.

Imagine a life-form whose brainpower is to ours as ours is to a chimpanzee's. To such a species our highest mental achievements would be trivial. Their toddlers, instead of learning their ABCs on *Sesame Street,* would learn multivariable calculus on *Boolean Boulevard.* Our most complex theorems, our deepest philosophies, the cherished works of our most creative artists, would be projects their schoolkids bring home for Mom and Dad to display on the refrigerator door. These creatures would study Stephen Hawking (who occupies the same endowed professorship once held by Newton at the University of Cambridge) because he's slightly more clever than other humans, owing to his ability to do theoretical astrophysics and other rudimentary calculations in his head.

If a huge genetic gap separated us from our closest relative in the animal kingdom, we could justifiably celebrate our brilliance. We might be entitled to walk around thinking we're distant and distinct from our fellow creatures. But no such gap exists. Instead, we are one with the rest of nature, fitting neither above nor below, but within.

Need more ego softeners? Simple comparisons of quantity, size, and scale do the job well.

Take water. It's simple, common, and vital. There are more molecules of water in an eight-ounce cup of the stuff than there are cups of water in all the world's oceans. Every cup that passes through a single person and eventually rejoins the world's water supply holds enough molecules to mix 1,500 of them into every other cup of water in the world. No way around it: some of the water you just drank passed through the kidneys of Socrates, Genghis Khan, and Joan of Arc.

How about air? Also vital. A single breathful draws in more air molecules than there are breathfuls of air in Earth's entire atmosphere. That means some of the air you just breathed passed through the lungs of Napoleon, Beethoven, Lincoln, and Billy the Kid.

Time to get cosmic. There are more stars in the universe than grains of sand on any beach, more stars than seconds have passed since Earth formed, more stars than words and sounds ever uttered by all the humans who ever lived.

Want a sweeping view of the past? Our unfolding cosmic perspective takes you there. Light takes time to reach Earth's observatories from the depths of space, and so you see objects and phenomena not as they are but as they once were. That means the universe acts like a giant time machine: the farther away you look, the further back in time you see—back almost to the beginning of time itself. Within that horizon of reckoning, cosmic evolution unfolds continuously, in full view.

Want to know what we're made of? Again, the cosmic perspective offers a bigger answer than you might expect. The chemical elements of the universe are forged in the fires of high-mass stars that end their lives in stupendous explosions, enriching their host galaxies with the chemical arsenal of life as we know it. The result? The four most common chemically active elements in the universe—hydrogen, oxygen, carbon, and nitrogen—are the four most common elements of life on Earth. We are not simply in the universe. The universe is in us.

Yes, we are stardust. But we may not be of this Earth. Several separate lines of research, when considered together, have forced investigators to reassess who we think we are and where we think we came from.

First, computer simulations show that when a large asteroid strikes a planet, the surrounding areas can recoil from the impact energy, catapulting rocks into space. From there, they can travel to—and land on—other planetary surfaces. Second, microorganisms can be hardy. Some survive the extremes of temperature, pressure, and radiation inherent in space travel. If the rocky flotsam from an impact hails from a planet with life, microscopic fauna could have stowed away in the rocks' nooks and crannies. Third, recent evidence suggests that shortly after the formation of our solar system, Mars was wet, and perhaps fertile, even before Earth was.

Those findings mean it's conceivable that life began on Mars and later seeded life on Earth, a process known as panspermia. So all earthlings might—just might—be descendants of Martians.

Again and again across the centuries, cosmic discoveries have demoted our self-image. Earth was once assumed to be astronomically unique, until astronomers learned that Earth is just another planet orbiting the Sun. Then we presumed the Sun was unique, until we learned that the countless stars of the night sky are suns themselves. Then we presumed our galaxy, the Milky Way, was the entire known universe, until we established that the countless fuzzy things in the sky are other galaxies, dotting the landscape of our known universe.

Today, how easy it is to presume that one universe is all there is. Yet emerging theories of modern cosmology, as well as the continually reaffirmed improbability that anything is unique, require that we remain open to the latest assault on our plea for distinctiveness: multiple universes, otherwise known as the "multiverse," in which ours is just one of countless bubbles bursting forth from the fabric of the cosmos.

The cosmic perspective flows from fundamental knowledge. But it's more than just what you know. It's also about having the wisdom and insight to apply that knowledge to assessing our place in the universe. And its attributes are clear:

The cosmic perspective comes from the frontiers of science, yet it is not solely the provenance of the scientist. It belongs to everyone.

The cosmic perspective is humble.

The cosmic perspective is spiritual—even redemptive—but not religious.

The cosmic perspective enables us to

grasp, in the same thought, the large and the small.

The cosmic perspective opens our minds to extraordinary ideas but does not leave them so open that our brains spill out, making us susceptible to believing anything we're told.

The cosmic perspective opens our eyes to the universe, not as a benevolent cradle designed to nurture life but as a cold, lonely, hazardous place.

The cosmic perspective shows Earth to be a mote, but a precious mote and, for the moment, the only home we have.

The cosmic perspective finds beauty in the images of planets, moons, stars, and nebulae but also celebrates the laws of physics that shape them.

The cosmic perspective enables us to see beyond our circumstances, allowing us to transcend the primal search for food, shelter, and sex.

The cosmic perspective reminds us that in space, where there is no air, a flag will not wave—an indication that perhaps flag waving and space exploration do not mix.

The cosmic perspective not only embraces our genetic kinship with all life on Earth but also values our chemical kinship with any yet-to-be discovered life in the universe, as well as our atomic kinship with the universe itself.

At least once a week, if not once a day, we might each ponder what cosmic truths lie undiscovered before us, perhaps awaiting the arrival of a clever thinker, an ingenious experiment, or an innovative space mission to reveal them. We might further ponder how those discoveries may one day transform life on Earth.

Absent such curiosity, we are no different from the provincial farmer who expresses no need to venture beyond the county line, because his forty acres meet all his needs. Yet if all our predecessors had felt that way, the farmer would instead be a cave dweller, chasing down his dinner with a stick and a rock.

During our brief stay on planet Earth, we owe ourselves and our descendants the opportunity to explore—in part because it's fun to do. But there's a far nobler reason. The day our knowledge of the cosmos ceases to expand, we risk regressing to the childish view that the universe figuratively and literally revolves around us. In that bleak world, arms-bearing, resource-hungry people and nations would be prone to act on their "low contracted prejudices." And that would be the last gasp of human enlightenment—until the rise of a visionary new culture that could once again embrace the cosmic perspective.

Astrophysicist NEIL DEGRASSE TYSON *is the Frederick P. Rose Director of New York City's Hayden Planetarium at the American Museum of Natural History. His most recent book,* Death by Black Hole: And Other Cosmic Quandaries *(W.W. Norton, 2007), is a collection of his favorite* Natural History *essays from the past dozen years.*

NATURAL HISTORY
APRIL 2007

Meerkats At Play

Evolution demands that activities costing a lot of energy provide survival value in return. But what do these rambunctious little mammals gain from having so much fun?

By Lynda L. Sharpe
Photographs by Andrew J. Young

In the cool freshness of dawn, two meerkat pups raced down the dune toward me. Turning suddenly, they reared up on their stumpy hind legs and clasped each other like little sumo wrestlers. Shuffling to and fro, each pup tried to topple the other, each arching its head back to avoid its opponent's snapping teeth. Without warning, Bandit (or so we named him for his extra-large, dark eye patches) lost his footing and tumbled backward in a spray of red sand. As he lay wriggling on his back, paws waving in the air, Imp, a smaller but feisty pup, leapt on top of him, pinned him down, and nipped enthusiastically at any appendage that came within her reach.

The two young meerkats were acting out one of the greatest mysteries in the world of animal behavior. They were playing. And those of us who study that behavior have no idea why.

Unlike virtually every other kind of animal behavior, play seems to serve no purpose. It is easy to see what an individual gains from grooming, or fighting, or nest building. But play? And if play really has no purpose, why do young mammals (including humans) invest so much time and energy in it?

I kept watching as Imp chased Bandit beneath a spiky shrub. The pair darted back and forth, leaping exuberantly as they snapped and parried. It was clear that they were having a high old time. After all, play is fun; it gives pleasure. Isn't that reason enough to do it? The trouble with such reasoning is that play can also have harmful consequences, which could reduce an individual's chances of surviving to reproduce. Unless play provides some compensatory benefits, evolution would have eliminated the tendency to play. So what benefits do individuals get from playing? My own behavior—crouching in the Kalahari Desert of southern Africa surrounded by eighteen meerkats—was part of an attempt to answer that question.

The meerkat, a species of mongoose, is one of the most sociable mammals in nature. The animals live in highly cooperative groups of as many as fifty individuals. Group members all chip in to rear the young and guard against predators. As

Two meerkats wrestle joyfully, tumbling over each other in the Kalahari Desert of southern Africa. Such play-fighting, to which the animals devote around 3 percent of their day, costs a lot of energy. So unless play also confers an adaptive benefit, evolution would have favored meerkats that do not play. Because meerkat groups are known for social harmony, the animals seemed good candidates for investigating whether play leads to better social bonding—less aggression, stronger alliances among individuals, and greater contributions to the group.

I watched "my" group—which had been named Elveera, after the founding individual—a pair of adolescents groomed the ticks from each other's noses, while the alpha female, Tenuvial, presented a wormlike larva to one of the pups. I could see how meerkats had earned a reputation for altruism and an "all-for-one-and-one-for-all" approach to life.

The Elveera group was one of thirteen such groups being studied by the Kalahari Meerkat Project, established in 1993 by Tim Clutton-Brock, a behavioral ecologist at the University of Cambridge. Thanks to several years of work by Clutton-Brock's research team (which I joined in 1996), these wild animals had become used to having a person in their midst, and so I could sit among them without disturbing their behavior. To them, I was a harmless prop in the scene. As if to prove the point, Bettik (Imp's mother) trotted over and scrambled awkwardly up my arm, her long claws scratching my skin. Using me as a shrub or a stump, she perched precariously on my shoulder to scan the sky for predators, so the rest of the group could nap in safety.

Adult meerkat emerges from its burrow into the morning light. Meerkats older than six months take turns babysitting newborns at the group's burrow. If play functioned to enhance social bonding, one might expect meerkats that play more to babysit more, since they would be more committed to the group. But that is not the case.

Suddenly Bettik whistled a piercing alarm, startling the other meerkats—and me. She leapt from my shoulder and dashed with the others to the entrance of the group's burrow. Little Bandit and Imp, however, playing at the foot of the dune slope, had a long way to run. High above, circling in the pale morning sky, a tawny eagle was on the lookout for just such incautious meerkat pups, a perfect example of the potential cost of play. This time, however, Bandit and Imp shot down the burrow, emerging moments later to peep out cautiously from between the forelegs of their elder brother.

Although young meerkats clearly risk predation or injury during play, they incur an even more substantial cost in energy. Our research in the Kalahari has shown that meerkat pups that are bigger than their siblings grow into more efficient foragers, and they are more likely to become dominant within a group and to breed. So why on earth do young meerkats squander energy on play instead of investing it in growth? Surely play must have a function, and I was determined to find out what it was.

The failure of science to determine the function of play has not been for lack of trying. Investigators, particularly in the 1970s and 1980s, have conducted studies across a range of animal species. People assumed that once accurate information was gathered about the mechanics of play, its function would become self-evident. After all, that approach had worked with almost every other behavior observed in animals. But it did not work for play.

What we do know is that the "content" of a youngster's play reflects what is important to adults of the same species: lion cubs stalk and pounce; antelope fawns gallop and pronk. We also know that play is stimulated by novel objects, novel partners, and novel substrates, such as mud or snow. And of course theorists have come up with many hypotheses, suggesting more than thirty possible benefits of play.

For example, play may stimulate the development of the brain, increase cardiovascular fitness, or help regulate the use of energy. Perhaps play in young animals is a way to practice skills they will need in adulthood, such as fighting, mating, or hunting. Perhaps it is an effective way to learn how to recognize kin, evaluate risk, or cope with stressful situations. The pleasure of play might provide the positive reinforcement needed to strengthen social bonds between individuals, thereby reducing ag-

Group play among meerkats often leads to a furry ball of tangled body parts.

gression, enhancing alliances, and improving group cohesion. Unfortunately, none of those theories has been rigorously tested, and there is little evidence to support or refute any of them.

The sun was now well above the horizon, and the meerkats were wide-awake. The entire group began to play vigorously. As a knot of five pups twisted and rolled over my feet, I knew that there could be no crucial, controlled experiment; there was no way I could prevent a meerkat from playing just to see what happened. Even among captive animals, investigators have found it impossible to stop young mammals from playing without so disrupting their lives that any subsequent changes in their behavior are uninterpretable. How, then, could I test theories about play?

Some theories simply do not lend themselves to testing in the field. But for assessing the possible social benefits of play, wild meerkats seem ideal subjects. You see, though meerkats are highly social, they belong to a family known as the Viverridae in which almost all the species are solitary. As the African climate dried out and the forest turned into savanna, the ancestral mongooses, which foraged out in the open by day, became extremely vulnerable to predation. By sticking together and sharing guard duty, mongooses could substantially reduce their risk. In fact, our observations show that large group size in meerkats is associated with higher rates of growth, survival, and fecundity.

Yet before mongooses could take advantage of the benefits of group living, they had to overcome their inherited antipathy toward other members of their own species. So could play be the key? If play could enhance the bonds between individuals, reducing their aggression and encouraging them to stick together, its evolutionary benefits would be unmistakable. And observers would see meerkats fully exploiting play for just that purpose.

To determine whether meerkats at play were strengthening their social bonds, I had to find out how much each individual played, then look at how differences in the frequency of play affected each animal's behavior. If the social-bonding hypothesis was correct, I reasoned, meerkats that play a lot should be more strongly attached to their fellows than meerkats that play rarely. "Bonded" animals, moreover, should be less aggressive and more strongly committed to the group: they should help more often with group activities and delay their own departure from the group as young adults.

I decided to focus on eight meerkat litters, each from a different group—forty-five pups in all—and then follow them throughout their lives. Recording how much the meerkats played proved harder than I had expected. On some days the entire group would play for more than an hour—as was happening this morning at Elveera. On other days, there was no play at all. Also, it was a year of good rains in the Kalahari, so a sea of golden devil thorn flowers made it hard to spot the meerkats as they dove in and out among the blossoms. Worst of all, meerkat play moves so fast that it was almost impossible to see the identifying marks I'd made by trimming small patches of fur or painting dabs of black hair dye on my subjects' bodies. The only body parts that reliably protruded from a scrum of wrestling meerkats were the tails. So each morning, before collecting data, I had to crawl around on my stomach amid the sunning meerkats, clutching an array of multihued marker pens, and surreptitiously draw vibrant rings on the tails of all my study animals.

In spite of the difficulties, I managed to quantify how much each animal played, and found that individual differences were quite large. In the Elveera litter of nine pups, one large, blonde pup called Mimi played twice as often as Bandit or a shy pup named Elf. So one of my questions became, simply: was Mimi less aggressive than Bandit or Elf?

As it happened, there was a good way to quantify aggressive behavior to help answer this question. From four to ten weeks of age, when meerkats learn to find food on their own, each pup must compete for prey items donated by older members of the group. The adults tend to feed whichever pup is closest by, so whenever the group goes foraging, the youngsters fight each other ferociously to get the closest possible position to one or more of the group's most generous feeders. By following each pup in turn, and recording what happened whenever another pup came within a meter of my focal pup, I found I could determine which individuals were most inclined to act aggressively.

Close to my feet, Imp, the smallest pup, was tagging along behind Tenuvial, begging lustily; making an ear-piercing racket actually encourages adults to donate prey items to the pups. Within moments, dark-eyed Bandit launched a fierce attack on Imp. The two pups hurtled toward each other, crashed together, and rolled over and over, squealing, growling, and biting mercilessly. In the end, Bandit emerged victorious to usurp Imp's place beside Tenuvial. Fighting is common among pups of this age, but if the social-bonding theory is correct, the combatants that engage most often in such ghastly struggles would be pairs that rarely share in play. Furthermore, preferred playmates would fight with each other less frequently. So are those predictions correct?

As it turns out, they are not. There was no correlation between how much an individual (or a litter) played and how aggressively it behaved. Blonde Mimi spent twice as much time as Elf did in play, but she launched just as many attacks on her littermates as Elf did. Similarly, preferred playmates such as Bandit and Mimi were just as likely to fight

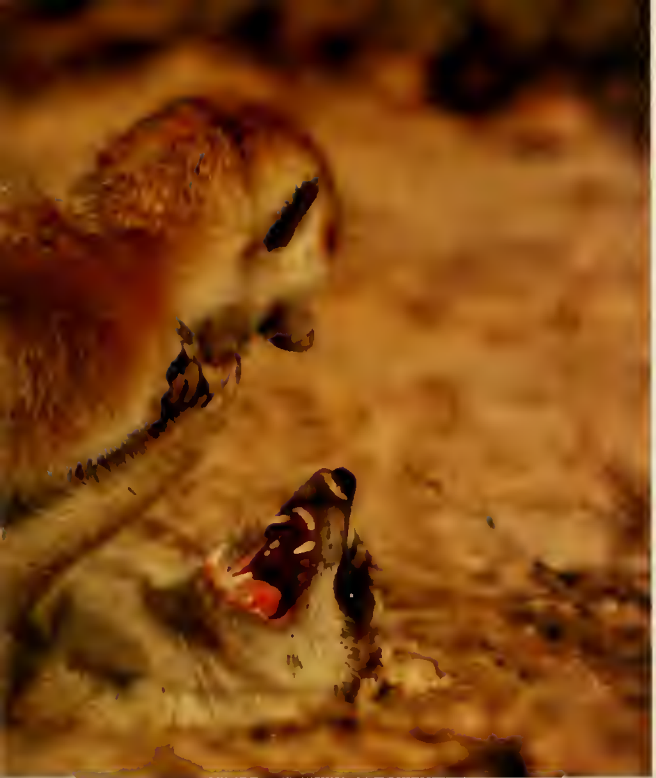
Meerkat play closely mirrors real fighting, but the author's research shows that play does not improve an individual's fighting skills or its ability to win a real fight for dominance. She also found that meerkats that prefer to play together are not less likely to engage in real fights.

while begging for food as were pups such as Bandit and Elf that rarely shared in play.

Play also had no short-term effect on aggression. Pairs of pups out foraging were just as likely to attack each other within ten minutes of playing together as were pairs of pups that had not just played. And female meerkats that played relatively often with the group's alpha female were just as likely to be bullied and harassed by her (when she was feeling aggressive during late pregnancy) as were females that had not played with the alpha.

Social-bonding theory does not just predict that play reduces aggression; it also maintains that play strengthens an individual's attachment to its playmates, promoting alliances and enhancing group cohesion. Did meerkats that played more often—Mimi and a pinch-faced meerkat named Goblin—subsequently show greater commitment to their group? And did pairs that liked to play together team up later to form special alliances in adulthood?

To begin answering those questions, I recorded how much each of my meerkats contributed to the activities of its group. My working assumption was that the more closely an individual was bonded to its group, the more it would want to contribute to the group. Furthermore, I reasoned, the more closely bonded an individual, the longer it would remain with the group and so the more it stood to



gain from its contributions to group well-being.

Fortunately, it was fairly straightforward to collect data on group contributions. By the time my study animals were three or four months old, they were already dashing about excitedly, helping rear the next generation of pups. I recorded how often each animal donated prey items to the new pups, and on how many days it babysat. Babysitting seemed particularly altruistic: the babysitter had to go without food for the day in order to remain at the breeding burrow with the newborn pups, while the rest of the group went foraging. I also measured how often each meerkat performed sentinel duty, and how often it helped clear debris from the group's sleeping burrows and bolt-holes.

Collecting data on alliances was also relatively straightforward. Meerkats usually remain with their natal group until they are about two years old (despite reaching sexual maturity between seven and eleven months). When the meerkats finally left their natal group, I could note which ones left earliest (the behavior expected of poorly bonded individuals) and which ones formed so-called dispersal alliances (that is, left their natal group together).

So did play strengthen a meerkat's commitment to its group, enhancing group cohesion? No. Mimi, Goblin, and other pups dedicated to play did not end up contributing more to the group than meerkats that played infrequently. In fact, within the Elveera group, Bandit became the most dedicated babysitter despite his relative lack of play. Similarly, individuals that played more frequently than their peers did not delay leaving their group. The highly playful Goblin left home to join a neighboring group when he was only eleven months old. Bandit, by contrast, stayed in the Elveera group until he was three. Among the females, Mimi, Imp, and two of their sisters left home at twenty months of age to set up their own group with males from another group. In contrast, Elf (the nonplayer) remained behind in Elveera.

What about the role of play in helping individuals establish lifelong alliances, such as dispersal partnerships? Meerkats typically disperse with one or more groupmates of the same sex. Furthermore, dispersing animals in large parties are less stressed, better fed, and more likely to oust competitors than animals that disperse alone or in pairs. Could that be the purpose of meerkat play, to cultivate bonds between potential dispersal partners?

Once again, on scrutiny, the supposed connection disappears. Meerkats that played together most often did not appear to be more closely attached. Frequent playmates did not groom each other any more often than they groomed other group members, and they were just as likely to engage in teenage squabbles over status. Male meerkats were no more likely to team up with their preferred playmates when embarking on short-term forays to neighboring groups to check out the "talent." And as for dispersing, the individuals with which my study animals dispersed were not the ones they had played with most often.

In short, despite all my efforts, I did not find out why meerkats play. What I did show, at least, is that they do not play to strengthen social bonds. And if meerkats aren't using play in that way, it's almost certainly because play is simply not capable of generating the physiological changes needed to reduce aggression or increase social attachment.

Back in the Elveera group, the meerkats finally stopped foraging and withdrew into the tangled shade of a fallen camel thorn tree for their midday siesta. While the adults sprawled on their tummies, legs splayed out to make more contact with the shade-cooled sand, I let myself relax and enjoy the company of my study animals. In the long strip of shade beneath the fallen trunk, the nine pups lay side by side in a neat line. Too tired for their usual exuberant play, they lay on their backs, waving their stumpy legs in the air, and lazily gnawed on their neighbor's ears, nose, and toes. I smiled at their mystery. □

For more information about meerkats, go to www.naturalhistorymag.com and click "Online extras," then "Web links," and finally "April 2007" to find links related to this article.

The Sauropod Chronicles

The largest creatures ever to have walked the Earth were animals such as Apatosaurus*—aka* Brontosaurus*. Paleontologists are revising the picture of how they lived. Again.*

By Richard A. Kissel

Paleontological crew (above) at the American Museum of Natural History, ca. 1904, works at mounting Apatosaurus excelsus (aka Brontosaurus excelsus), the first nearly complete fossil skeleton of a sauropod to be put on public display. An 1891 reconstruction of B. excelsus by the Yale paleontologist Othniel Charles Marsh is shown at the top of the page.

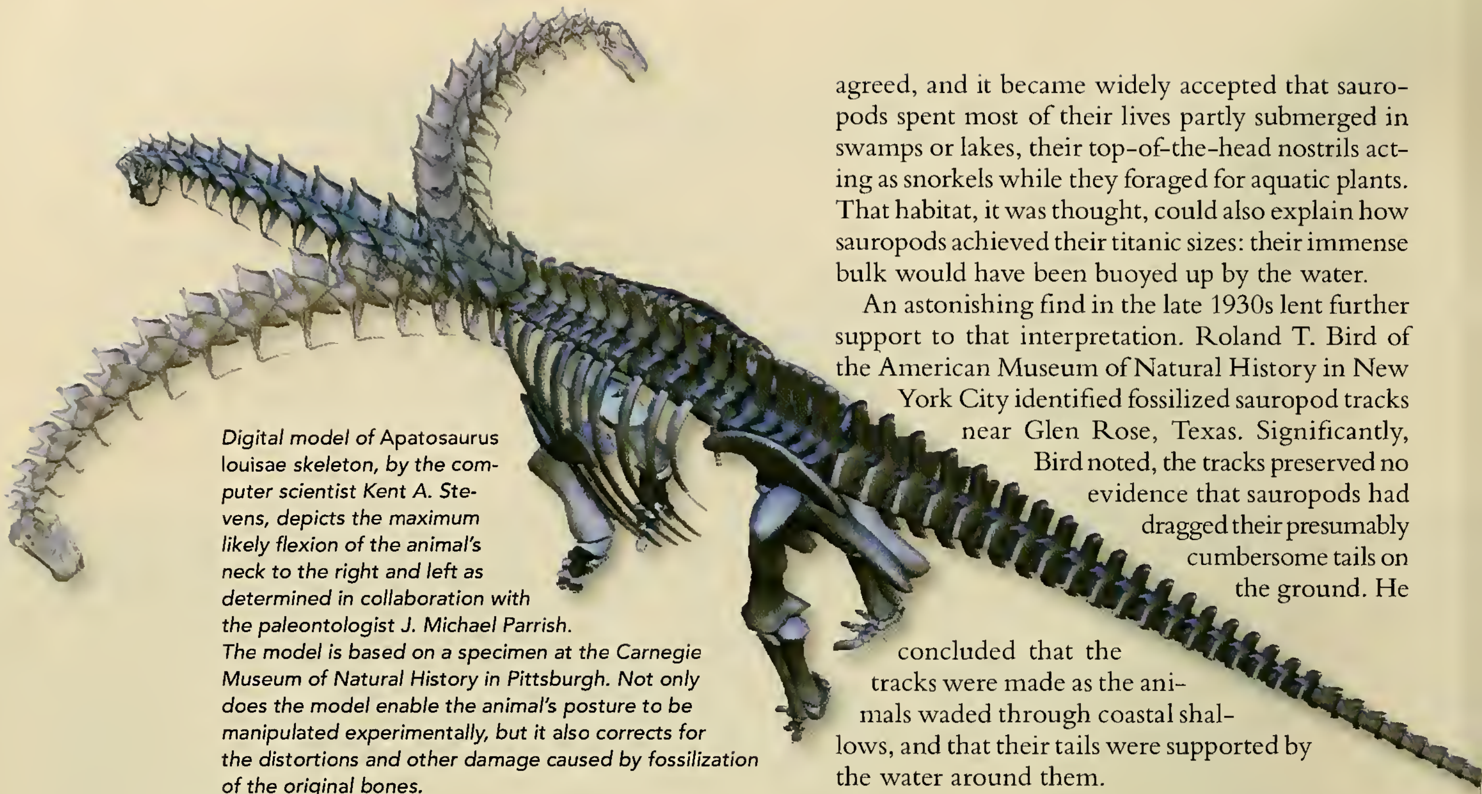
In 1842, the English anatomist and pioneering paleontologist Richard Owen introduced the word "dinosaur" to distinguish a new category of reptiles. Today dinosaurs are familiar to people of all ages, and perhaps none are more familiar than the sauropods. They are instantly recognizable for their small heads borne on long, graceful necks; their heavy, sinuous tails; and their enormous bodies, all supported on four stout limbs. So far, paleontologists have unearthed more than 120 species.

The earliest known sauropod appeared about 215 million years ago, during the Late Triassic period, and the last of the kind lived until the end of the Cretaceous period, 65 million years ago—when a worldwide cataclysm wiped out all dinosaurs except the birds. All sauropods were herbivorous, and most of them were massive. The largest ones, such as *Argentinosaurus* of South America, reached more than a hundred feet in length and may have weighed as much as eighty tons. Even a small one, such as *Saltasaurus*, measured more than twenty feet from head to tail, tipping the scales at three tons. Most sported no obvious defenses—the sharp spikes or sheath of bony armor found in other plant-eating dinosaurs—so mass alone may have been their means to intimidate or discourage predators.

Just as intriguing as the sauropods themselves is the story of their discovery and of paleontologists' efforts to understand their lives. Like all other scientific disciplines, paleontology has a history punctuated by change. Its advances accrue not only from the discovery of new fossils but also from new ways of examining and interpreting them. Among the questions about sauropods that have provoked ongoing controversy are even some that—one might think—should have been quickly settled on the basis of the animals' gross skeletal anatomy: How did they move about, and what postures could they assume? Shorn of their cartilage and ligaments, however, bones can be arranged in unnatural positions, and uncertainties about the range of motion of neighboring bones (as well as over the extent of the animals' muscular strength) raise doubts about how living sauropods held and moved their bodies and extremities. A century ago paleontologists and their crews began to install the heavy fossils on mounts for display. In some ways they guessed correctly; in others, investigators now know, they fell wide of the mark. Computers have become part of the discipline's modern analytic arsenal, and they have already been turned loose on two related questions: What was the likely orientation of a sauropod neck, and what was its range of motion? Without lifting a single fossil, paleontologists may now have some answers.

In 1877 several vertebrae and the sacrum (the fused vertebrae that connect with the pelvis) of a large sauropod were discovered near the town of Morrison, in north central Colorado. Then, for the first time in 150 million years, the great reptile trekked across the plains of North America—though not supported on calloused feet and driven by a hunger for vegetation, but carried on steel rails and powered by steam. Awaiting the fossils was the paleontologist Othniel Charles Marsh of Yale College. After examining the bones, Marsh concluded they belonged to a dinosaur, between fifty and sixty feet long, which was then unknown to science. Marsh named the

Reconstruction of Amphicoelias altus as a water-dwelling creature (upper left), by the artist Charles R. Knight, was made under the direction of the paleontologist Edward Drinker Cope. Published in 1897, it may be the first image to depict a sauropod "in the flesh." Above: 1910 reconstruction of Diplodocus, *by Mary Mason Mitchell, followed the views of the paleontologist Oliver P. Hay, who argued that sauropods, like other reptiles, had sprawling limbs. Both reconstructions have now been superseded.*



Digital model of Apatosaurus louisae *skeleton, by the computer scientist Kent A. Stevens, depicts the maximum likely flexion of the animal's neck to the right and left as determined in collaboration with the paleontologist J. Michael Parrish. The model is based on a specimen at the Carnegie Museum of Natural History in Pittsburgh. Not only does the model enable the animal's posture to be manipulated experimentally, but it also corrects for the distortions and other damage caused by fossilization of the original bones.*

species *Apatosaurus ajax*. (Some years later investigators realized not only that Marsh had underestimated the length of the tail, but also that the fossils did not come from a mature individual; adults of the species reached lengths of more than seventy feet.)

Apatosaurus was just one of many dinosaurs to make a name for itself during the late nineteenth century, when Marsh and other paleontologists from the East, notably Edward Drinker Cope of Philadelphia, had crews of men scouring the Badlands of the West in search of ancient beasts. Another of the species Marsh named, in 1879, was *Brontosaurus excelsus*. In 1903, four years after Marsh's death, Elmer S. Riggs of the Field Museum in Chicago determined it belonged to the same genus as *Apatosaurus*. Under the rules of scientific nomenclature, the name *Brontosaurus* was officially retired, though it continued in popular use.

The first description of a complete sauropod skull did not appear until 1884. The skull bore a surprising feature: the external nares—the openings in the skull for the nostrils—were situated not at the tip of the snout, but near the top of the skull, above and between the eye sockets. That position contrasted with the nares of all other dinosaur skulls known at the time. It is characteristic, however, of certain animals that spend most or all of their time in the water, such as whales. Nostrils high on the head are well situated to break the surface and take in air.

Marsh and Cope therefore suggested that sauropods were semiaquatic creatures. Most paleontologists agreed, and it became widely accepted that sauropods spent most of their lives partly submerged in swamps or lakes, their top-of-the-head nostrils acting as snorkels while they foraged for aquatic plants. That habitat, it was thought, could also explain how sauropods achieved their titanic sizes: their immense bulk would have been buoyed up by the water.

An astonishing find in the late 1930s lent further support to that interpretation. Roland T. Bird of the American Museum of Natural History in New York City identified fossilized sauropod tracks near Glen Rose, Texas. Significantly, Bird noted, the tracks preserved no evidence that sauropods had dragged their presumably cumbersome tails on the ground. He concluded that the tracks were made as the animals waded through coastal shallows, and that their tails were supported by the water around them.

In the second half of the twentieth century, however, paleontologists considered lines of evidence not addressed by Marsh and his colleagues. One approach was to widen the search for anatomical parallels between sauropods and living animals. Distantly related species, flourishing on Earth perhaps millions of years apart, can sometimes look remarkably similar, a phenomenon known as convergent evolution. The similarities result not from common inheritance, but from evolutionary adaptation to similar environmental challenges, diets, or climates.

In the study of sauropods, it proved instructive to compare them to today's elephants, which are also plus-size animals. Beneath the mass of skin and muscle, the long bones of the elephant's limbs are massive, the bones of the wrist and ankle are compact and tightly fitted together, and the bones of the feet and toes are short and compact. In essence, the legs of an elephant are built like the columns of a great temple. Nearly identical features occur in the legs of sauropods. What does the paleontologist make of that? Sauropod legs were similarly adapted to support the animal's weight on dry land.

In some early illustrations, sauropods were depicted not only wading in swamps but, at times, entirely submerged and holding their necks high to breathe at the water's surface [*see upper illustration on preceding page*]. Those interpretations were particularly unrealistic. An average-size sauropod, such as *Apatosaurus*, would have found it impossible to breathe in that posture. Its chest, some fifteen feet underwater, would have been under too much pressure.

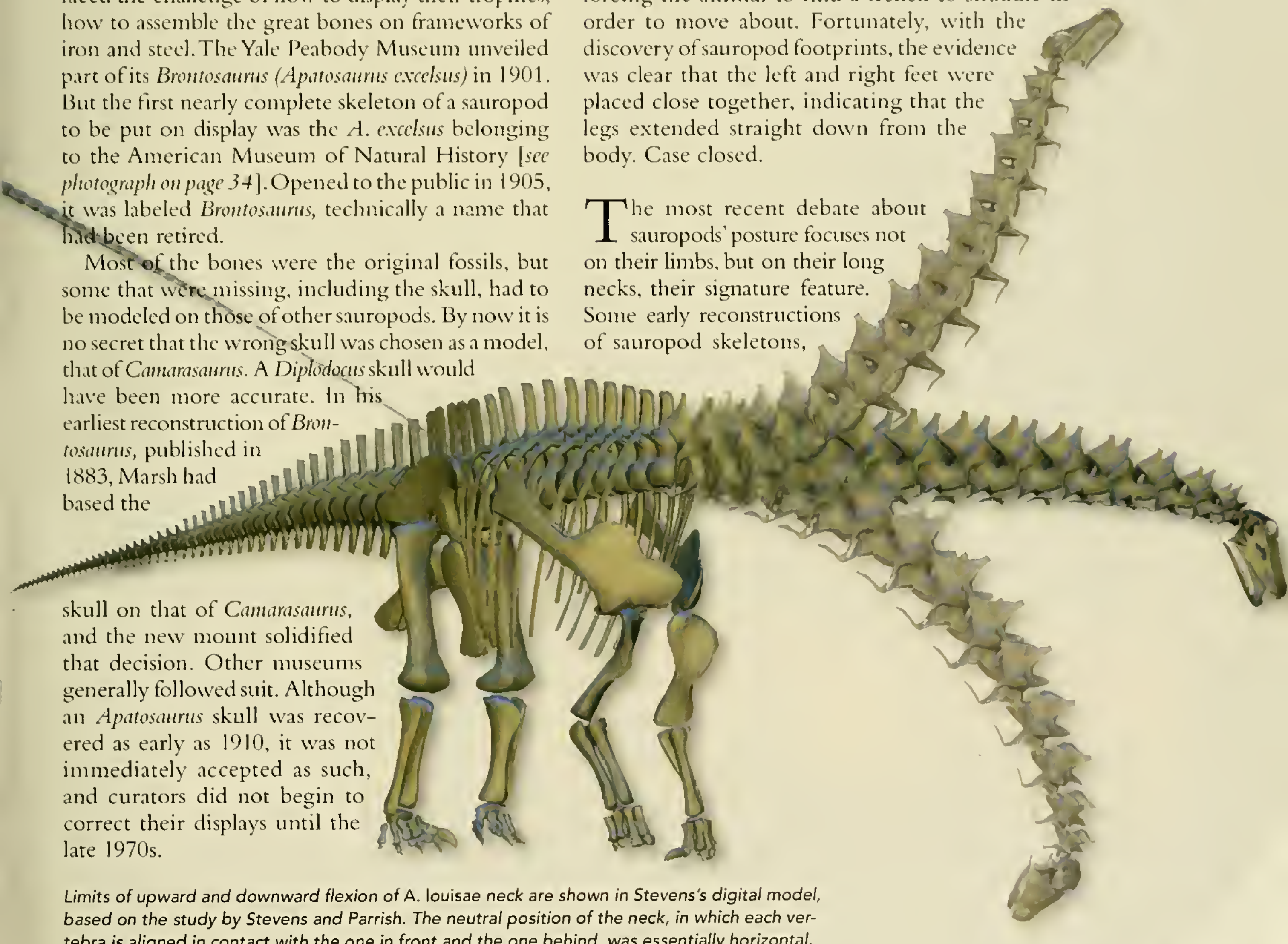
The rocks from which sauropod fossils are recovered also do not support an amphibious scenario. If sauropods were semiaquatic, their fossils should be embedded in the coals of ancient swamps or the limestones formed by lagoons. But that is not always the case. Sauropod bones and tracks are also found in the sandstones typically deposited by and near streams in relatively dry, upland environments. As evidence mounted, the idea that sauropods lived in swamps and other shallow waters was discarded.

As sauropod skeletons were unearthed and transported east in the late 1800s, museums quickly faced the challenge of how to display their trophies, how to assemble the great bones on frameworks of iron and steel. The Yale Peabody Museum unveiled part of its *Brontosaurus (Apatosaurus excelsus)* in 1901. But the first nearly complete skeleton of a sauropod to be put on display was the *A. excelsus* belonging to the American Museum of Natural History [*see photograph on page 34*]. Opened to the public in 1905, it was labeled *Brontosaurus*, technically a name that had been retired.

Most of the bones were the original fossils, but some that were missing, including the skull, had to be modeled on those of other sauropods. By now it is no secret that the wrong skull was chosen as a model, that of *Camarasaurus*. A *Diplodocus* skull would have been more accurate. In his earliest reconstruction of *Brontosaurus*, published in 1883, Marsh had based the skull on that of *Camarasaurus*, and the new mount solidified that decision. Other museums generally followed suit. Although an *Apatosaurus* skull was recovered as early as 1910, it was not immediately accepted as such, and curators did not begin to correct their displays until the late 1970s.

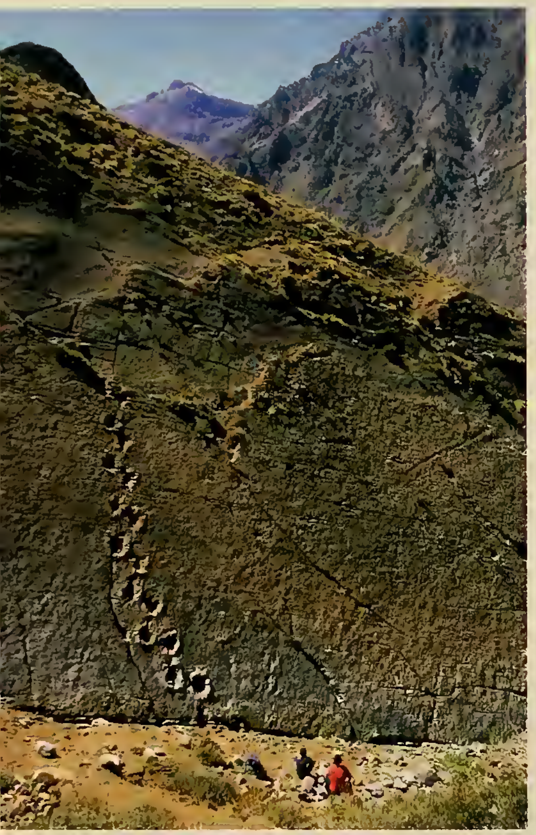
Disagreement over just how the bones fitted together was inevitable. Before the discovery of sauropod tracks, a fundamental issue (literally!) was the position of the legs. The American paleontologist Oliver P. Hay and the German anatomist Gustav Tornier maintained that, since dinosaurs were reptiles, the legs of sauropods must have functioned like those of a lizard or a crocodile, sprawling out from the side of the body [*see lower illustration on page 35*] Others strongly disagreed. In 1910 William J. Holland of the Carnegie Museum of Natural History in Pittsburgh countered that for a sauropod to have adopted a reptilian sprawl, the joints of the legs would have had to have been severely dislocated. Furthermore, a sprawling posture would have caused a sauropod's deep rib cage to project below its feet, forcing the animal to find a trench to straddle in order to move about. Fortunately, with the discovery of sauropod footprints, the evidence was clear that the left and right feet were placed close together, indicating that the legs extended straight down from the body. Case closed.

The most recent debate about sauropods' posture focuses not on their limbs, but on their long necks, their signature feature. Some early reconstructions of sauropod skeletons,



Limits of upward and downward flexion of A. louisae neck are shown in Stevens's digital model, based on the study by Stevens and Parrish. The neutral position of the neck, in which each vertebra is aligned in contact with the one in front and the one behind, was essentially horizontal. Even at the upward limit, the neck posture was not as vertical as that in giraffes, to which sauropods have often been compared. Nevertheless, the head could reach five feet below ground level, suggesting the animal could stand on shore and browse on aquatic plants.

including the ones by Marsh and by the American paleontologist and fossil-hunter John Bell Hatcher, projected the neck forward from the body, in a near-horizontal, or even downward-sloping, position. But given the length of sauropod necks, it was hard not to look to giraffes. Although giraffes frequently feed on low-growing vegetation, the natural posture of the giraffe neck is the extended, near-vertical position. By analogy, images proliferated of sauropods holding their necks upward to browse from the tallest trees.



Sauropod tracks, now fossilized in Upper Jurassic rocks at Termas del Flaco, Chile, were made between 145 million and 150 million years ago.

But do the fossils themselves corroborate an elevated neck? To investigate that is no easy matter, for one major reason: the fossils are really big. The weight of just one fossilized bone can cause great pain to the lower back of any paleontologist foolish enough to attempt a lift. With no ready means to manipulate the bones of a skeleton, or even to move lighter full-size casts, the paleontologist's ability to test sauropod biomechanics—how those giants moved—has been extremely limited.

All of that changed in 1999, when Kent A. Stevens, a computer scientist at the University of Oregon in Eugene, and J. Michael Parrish, a biologist and paleontologist at Northern Illinois University in DeKalb, published a landmark study that challenged the picture of high-browsing sauropods. With a computer program called DinoMorph, Stevens created digital models of sauropod skeletons. In so doing he and Parrish not only freed themselves from handling full-size fossils or casts, but they could also digitally remove distortions in the original vertebrae left by fossilization.

The DinoMorph models of *Apatosaurus* and *Diplodocus* skeletons led to surprising results: once the neck vertebrae were neutrally aligned, each in perfect contact with the one in front and the one behind, the neck extended forward from the shoulders at a slight downward angle, bringing the head near the ground. That posture harkened back to the original reconstructions of Marsh and Hatcher.

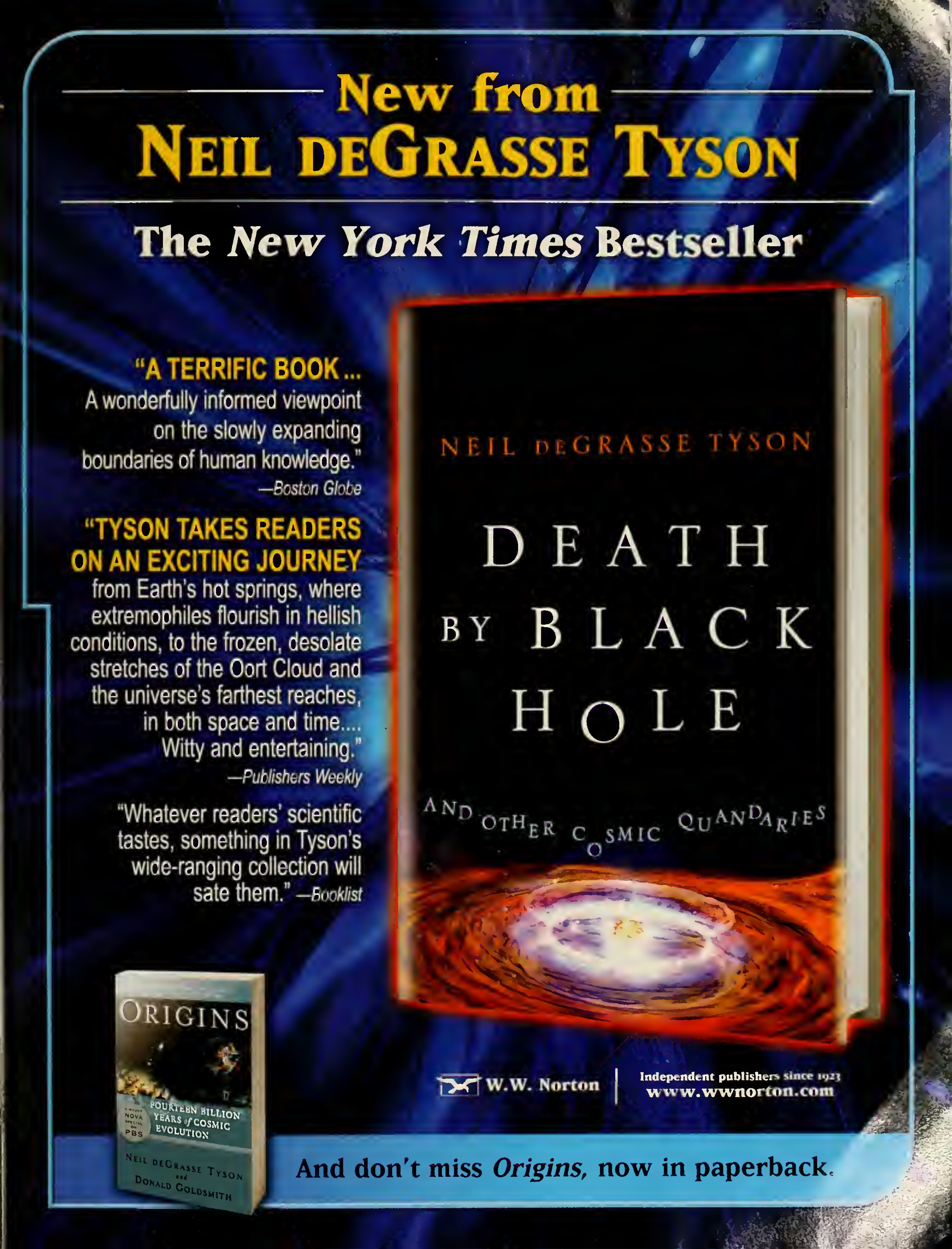
Moreover, the necks of the two sauropod species proved relatively inflexible, compared with the way many common reconstructions portrayed them [*see illustrations on the two preceding pages*]. From a normal standing position, *Apatosaurus,* with a shoulder height of ten feet and a neck length of seventeen feet, could raise its head no more than twenty feet above the ground. *Diplodocus,* whose neck was three feet longer but even less flexible, could reach only thirteen feet high, from a shoulder height of nine feet. Both *Apatosaurus* and *Diplodocus* could sweep their heads thirteen feet to the left or right: again, less flexibility than had often been portrayed. Yet both could bend the neck down, lowering the head as much as five feet below ground level.

The new evidence suggests that *Apatosaurus* and *Diplodocus* were probably best suited for feeding on low-growing plants. Perhaps the two sauropods were even given to standing along the edges of rivers or lakes, lowering their heads to feed on plants in the water. It is a somewhat ironic commentary on the scientific method to realize that information-age pixels have led investigators back to the idea that Marsh and his colleagues first proposed in ink more than a century ago. *Apatosaurus* and *Diplodocus* are back to their diet of aquatic plants. Now, though, they're enjoying the view from shore.

What does the future hold for the understanding of sauropods? One emerging issue is the position of their nostrils. In spite of the nares at the top of the head, Lawrence M. Witmer, an anatomist at Ohio University in Athens, argues that the actual fleshy openings were much nearer the tip of the snout. He bases his view on comparisons of sauropod bones with those of crocodiles, lizards, and birds. Once again, a long-held truth is being questioned.

In 1863, four years after Darwin revolutionized the biological sciences with his *Origin of Species,* Thomas H. Huxley published a collection of three short essays titled *Evidence as to Man's Place in Nature.* Throughout the work, Huxley shared his thoughts on human evolution and our close kinship with the apes, but he recognized that, with future discoveries, his conclusions might not stand. So it is with the study of sauropods. For now, we specialists think we have them right. But as Huxley concluded in his third essay, "Time will show." □

For more information about sauropod dinosaurs, go to www.naturalhistorymag.com and click "Online extras," then "Web links," and finally "April 2007" to find links related to this article.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Vulcan's Masonry

The builders of ancient Rome clad soft, porous volcanic tuff with harder travertine and marble, creating enduring, majestic structures out of local materials.

By Marie D. Jackson

Walk with me through the Roman forum, but imagine it through the eyes of an ancient Roman from the provinces, visiting the capital for the first time in many years. It is exactly 2,000 years ago. As we walk along the familiar Sacred Way through the new arch of Augustus, surrounded by monuments that exemplify the timeless excellence of our public architecture, you'll recognize the splendid new renovations to the ancient Temple of Castor and Pollux. Now the Basilica Julia is on our left, with its luminescent rows of marble columns still under construction. Let's continue forward, past the elaborate enlargements underway at the Temple of Concord.

I sense your pride in this splendid public space, and I share it. We live in a great *urbs*, in a time of high cultural accomplishment. There's more: a short walk will take us to the new forum that our emperor, Augustus (you remember him as Octavian, the nephew and later the adopted son of Julius Caesar), has constructed to celebrate the religious and historical foundations of his ascent to supreme power over the growing Roman Empire.

At the center of the Forum of Augustus is the magnificent Temple of Mars Ultor (Mars the Avenger).

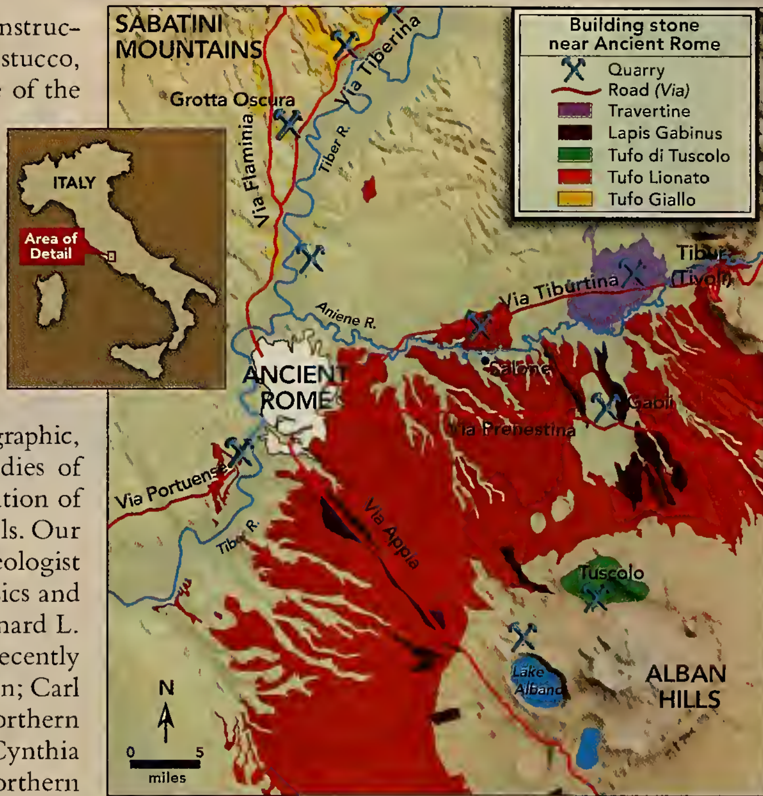
Temple of Mars Ultor, shown dressed in marble in a hypothetical reconstruction (above) and as it is today (opposite page), was the focal point of the Forum of Augustus. Some marble is still present in the remains of a few columns and as cladding on a few steps, but the Romans constructed the temple mainly from local volcanic rock that they then faced with marble. One kind of volcanic rock, so-called Tufo Lionato (brown stone in the cutaway section in the center foreground, above), is still visible under the columns and in the left wall of the forum. Lapis Gabinus (gray stone in the reconstruction) makes up the bulk of what was once a hundred-foot-high boundary wall, built to protect the temple from fire. The white line of stone in the remains of the boundary wall is travertine, a sedimentary stone also quarried locally, which looks much like marble.

This temple is dedicated to the god of war for avenging Rome after the assassination of Julius Caesar. Notice how the steep staircase rises to the portico, the temple's open entryway, with its eight lofty, fluted marble columns topped with intricate Corinthian capitals. What is most extraordinary, Augustus has had a fire-resistant boundary wall built against the back of the temple.

Today, two millennia after its construction, the modern visitor's first impression of the Forum of Augustus is that there is very little left. The Augustan building program transformed Rome into an imperial capital glowing with imported marble; by now, however, over the centuries, most of the marble from the Temple of Mars Ultor and its surrounding structures has been carried away. But the structures of the forum also reflect the building materials and techniques that the Roman architect and engineer Marcus Vitruvius Pollio considered important. And as if to prove his point, dark gray and reddish brown volcanic tuffs—known as Lapis Gabinus (stone from Gabii) and Tufo Lionato (lion-colored tuff)—of the forum walls and temple foundation remain largely intact.

Construction on the Forum of Augustus began in the late first century B.C., soon after Vitruvius completed a treatise titled *De architectura* ("On Architecture") that he dedicated to the emperor. The treatise is the only comprehensive account of Roman architecture to survive from classical antiquity. In it, Vitruvius recorded the empirical observations of largely anonymous Roman builders and stonemasons, who were well acquainted with their volcanic landscape and the building stones it provided. He also described their technique: use the volcanic tuffs as lightweight, readily quarried

building stone, then face the tuff construction with a veneer of more durable stucco, travertine, or marble. The expertise of the Roman stonemasons was fundamental to the Augustan building program, and many of the principles of stonemasonry, as set down in *De architectura,* are reflected in what remains throughout the forum.



To make a close study of Roman building and its principles, my colleagues and I formed a multidisciplinary research team that integrates geological fieldwork, petrographic, mineralogical, and engineering studies of the Roman rocks, and a new translation of Vitruvius' report on building materials. Our team includes Fabrizio Marra, a geologist at the National Institute of Geophysics and Vulcanology in Rome; the late Richard L. Hay, who was a mineralogist most recently at the University of Arizona in Tucson; Carl G. Cawood, a civil engineer at Northern Arizona University in Flagstaff; and Cynthia Kosso, a historian who is also at Northern Arizona University.

Our work has aimed to grasp the depth of Vitruvius' understanding of natural objects and processes. His empirical observations of the diverse characteristics of locally quarried building stones enabled him to select the best combinations of rocks for cut-stone masonry. Indeed, our study shows that the durability of Roman monuments can be traced, in part, to the innovations of Roman builders: the existing monuments are a testament to their creativity, their willingness to experiment, and their practical genius for making the most of the relatively soft and weak volcanic tuffs at hand. The Roman builders created the public expression of a new world order under Rome's first emperor.

Many schoolchildren know that Rome is built on seven hills. Few, however, learn that the hills are overlain by volcanic deposits. In fact, the topography of the central Italian peninsula carries the strong imprint of volcanoes—Mount Vesuvius, for instance, last erupted in 1944.

Beginning about 560,000 years ago, explosive eruptions from the Sabatini Mountains and the Alban Hills [*see map on this page*] deposited large volumes of volcanic material over the area that would become Rome. That material, known as tephra, included particles of glass, crystal, and rock in assorted sizes, which were transported through the air or across the ground. The tephra cooled and consolidated, eventually developing natural mineral cements to form a kind of porous, volcanic stone called tuff.

Early stone construction in Rome, during the sixth and fifth centuries B.C., made use of the soft volcanic tuff from within the city; it was widely available, literally underfoot, and easy to extract, requiring little more than saws and hand tools. Those early Romans quarried stone along hillsides and in underground chambers beneath the Palatine and Capitoline hills. Unfortunately, the stone was of low quality and crumbled readily under stress. At the end of the fifth century B.C., however, the Romans conquered the nearby Etruscan cities to the north, gaining access to the more durable varieties of tuff along the Tiber River. In the fourth century B.C., they built the Via Appia (Appian Way) to the south, along which oxcarts transported good-quality tuff building stones back to Rome.

The Romans also began to quarry the area around Tibur (modern Tivoli) for travertine, a hard, slightly yellowish or grayish white sedimentary rock that formed in a shallow lake when calcium carbonate precipitated from mineral-rich waters warmed by nearby volcanic activity. To the untrained eye, ivory-colored travertine can pass as marble; on closer inspection, however, distinctive hummocky mounds are visible, made up of the fossilized remains of calcite-precipitating bacteria.

By the time Vitruvius wrote *De architectura,* Romans were calling on seven kinds of tuff, along with travertine, to develop an innovative architecture based on cut-stone masonry integrated with small, functional elements of concrete. Vitruvius describes the material characteristics of Roman tuff, travertine, and lava building stones in detail:

> Now order demands that I explain about quarries, from which both squared blocks and the supplies of rough, unhewn stone for building are obtained and readied. These, in turn, will be found to have unequal and dissimilar qualities. Some are soft and yielding around the city itself, in the manner of the *rubrae* stones, the *pallenses* stones. . . . Some are of moderate strength, like the *tibur* stones, . . . and others of this type. Some are hard, like lavas.

The *rubrae*, or red, stones were reddish brown Tufo Lionato excavated near Salone, along the Aniene River; the *pallenses* were pale yellow Tufo Giallo della Via Tiberina ("yellow tuff from the Tiber Road"), extracted near Grotta Oscura; and the *tibur* stones were travertine [*see map on opposite page*].

In his *Geographica*, Strabo, a Greek geographer and a contemporary of Vitruvius, highlights the trio of building stones used in the Forum of Augustus for their proximity to the city of Rome:

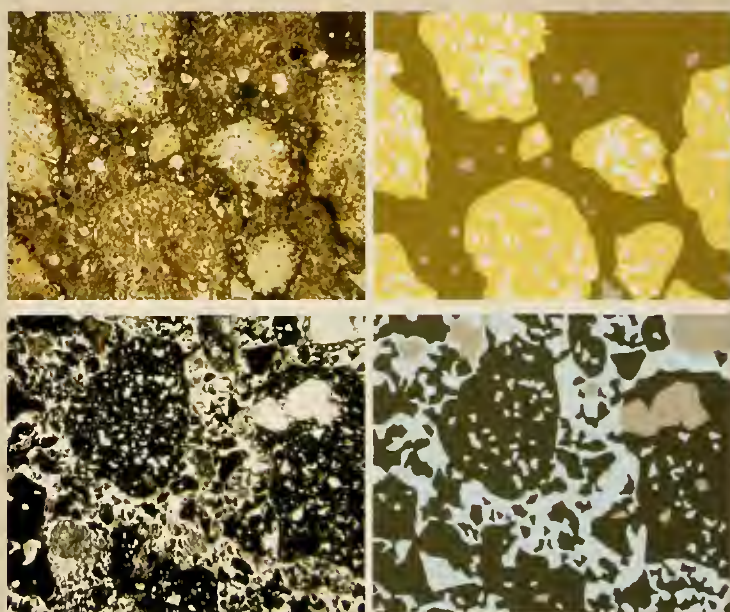
> The [Aniene] river flows out through a very fruitful plain past the quarries of Tiburtine [travertine] stone, and of the stone of Gabii [Lapis Gabinus], and of what is called the "red stone" [Tufo Lionato]; so that the delivery from the quarries and the transportation by water are perfectly easy.

Much farther afield, about 200 miles northwest of Rome, were the quarries near modern Carrara, Italy, which supplied the marble employed in the Temple of Mars Ultor. Marble is a metamorphic rock formed by the recrystallization of sedimentary carbonate rocks, such as limestone. The strength of Carrara marble is similar to that of travertine from Tivoli. But its beauty when polished is unparalleled, because light readily penetrates its surface, giving the stone a luminous, vibrant glow.

The late Richard Hay, a mineralogist with a lifetime of experience studying volcanic rocks, and I made detailed, microscopic observations of the tuffs sampled from ancient Roman quarries. Our aim was to identify their mineralogical components and associate them with the physical properties of the composite building stones. Generally, the glassy Roman tuffs were quarried from ignimbrites—rock formed from voluminous flows of hot gases and fine-grained glass fragments that solidified after an explosive eruption. The building stones made of Tufo Giallo and Tufo Lionato came from massive ignimbrites with little internal structure or layering.

In contrast, Lapis Gabinus includes abundant lava rock fragments. When hot magmas encountered water underground or at the surface, powerful explosions fractured older rocks, mainly lava and sometimes limestone, that lay beneath the vent of the volcano. The coarse rock fragments of lava became intermixed with the magma, and so the tuffs include abundant embedded fragments of dark-gray lava and occasional bits of light, yellowish gray limestone. Italians call the texture peperino, because it reminds them of ground black pepper. One such peperino tuff was Lapis Gabinus, still visible in the tall boundary wall of the Forum of Augustus.

Vitruvius clearly understood the poor durability of the Roman tuffs: "So long as these soft stones are sheltered under stucco they will hold up and do their work," he wrote. "But if they are laid bare or exposed in the open air, ice and frost accumulate within them, and they crumble apart and dissolve." Indeed, all the tuffs readily take up water, and when they do, they lose between 15 and 40 percent of their dry strength. They are particu-



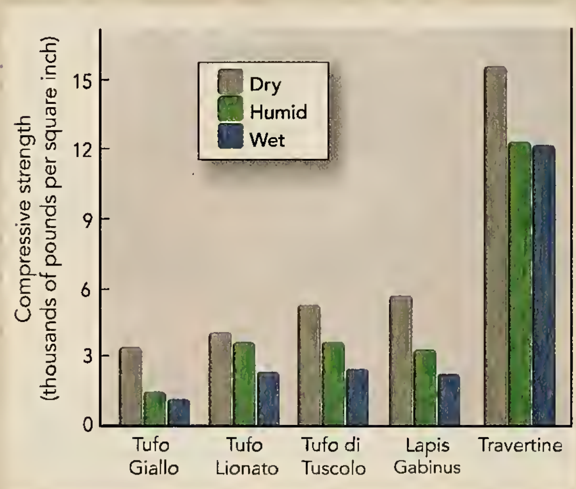
Micrographs highlight the differences between hard and soft volcanic tuffs. Tufo Giallo (top left), a relatively soft tuff, includes numerous fine fragments of glass (dark brown in the diagram at top right) and pumice (yellowish brown), which readily absorbs water; the soft tuff also has many cavities (white), formed by gas that was trapped as the stone solidified, but only a few crystals (gray). Both the pumice and the cavities contribute to the tuff's vulnerability. Harder tuffs such as Lapis Gabinus (above left) include a great deal of robust lava rock (dark gray in diagram, above right) and hard crystal (light gray), all held together in a matrix of natural cement (light blue). The images are magnified 11X.

larly susceptible to decay when they are directly exposed to daily fluctuations in relative humidity, to winter rains, and to the freezing temperatures to which Rome is sporadically subjected.

One way to address the problem of decaying soft tuffs, such as Tufo Lionato and Tufo Giallo, was to allow them to dry in the open air and then select only the best-quality blocks for cut-stone masonry. Vitruvius describes the process:

> When it is time to build, the stones should be extracted two years before, not in winter but in summer; then toss them down and leave them in an open place. Whichever of these stones, in two years, is affected or damaged by weather should be thrown in with the foundations. The other ones that are not damaged by means of the trials of nature will be able to endure building above ground.

Roman builders had another way of dealing with tuff decay: They seldom left tuff masonry exposed. Instead, they preserved the porous stone with stucco or with travertine or marble cladding, whose water absorption is far less than that of the tuffs. That strategy made for strong, lightweight buildings that were nonetheless attractive and resembled the marble structures of ancient Greece. A stroll through modern Rome reveals many ancient columns constructed of tuffs, some of which still retain protective cladding or semipermeable coatings of stucco. For example, the Theater of Marcellus, dedicated by Augustus in 13 B.C. to commemorate the death of his young nephew, was constructed mainly of cut-stone Tufo di Tuscolo (tuff from Tuscolo), both reinforced and clad with travertine [*see photograph on opposite page*]. The structure stood three stories high and incorporated forty-one arches with travertine facings, which are preserved on part of its external facade. Even today the structure preserves an impressive array of Tufo di Tuscolo arches reinforced with travertine keystones and imposts (the uppermost parts of the columns supporting an arch's span).



Compressive strength, or the greatest weight-bearing pressure a stone can withstand before fracturing, is plotted for several important building stones used in ancient Rome. Roman builders and architects were well aware that tuffs are weak when water-soaked, as Vitruvius states. Hence they clad the tuff masonry with travertine facings to reinforce it and protect it from direct exposure to moisture.

To assess Vitruvius' descriptions of the relative strengths and durability of Roman building stones, Carl Cawood and I designed rock-testing experiments under oven-dry, humid, and water-soaked conditions. The tests were intended to approximate Roman climatic conditions and their effects on tuffs and travertine [*see illustration on this page*]. Glassy tuffs, such as Tufo Giallo and Tufo Lionato, have low compressive strengths—they fracture and fall apart under moderate pressures. Both of those tuffs incorporate abundant volcanic glass fragments, including pumice, a frothy glass [*see micrographs on preceding page*]. And both are highly porous, readily absorbing water when, for instance, the Tiber River floods or the relative humidity is high. Water absorption greatly reduces their weight-bearing strength.

Compared with the glassy tuffs, we found that tuffs that incorporate an abundance of lava and crystal fragments, such as Lapis Gabinus and Tufo di Tuscolo, have higher compressive strengths—they can bear higher pressures without fracturing. The lava fragments provide an interlocking framework of hard grains to which natural mineral cements within the tuff strongly adhere. Moreover, these tuffs are denser, take in less water, and have greater elasticity than brittle Tufo Giallo and Tufo Lionato.

"True travertine from Tivoli and all stones of the same type withstand heavy loads and harsh weather," noted Vitruvius, "but from fire they cannot be safeguarded. And similarly, when they touch fire they crack apart and fall to pieces." Our rock-testing experiments confirm those observations as well. Travertine has far greater compressive strength than the tuffs. Its water absorption is low, less than 1 percent of the total weight of the stone, and so in rain or high relative humidity, travertine retains about 80 percent of its compressive strength. Travertine both reinforced and protected soft-tuff masonry in Roman architecture. Yet, again in accord with Vitruvius' observations, stone formed of calcite crystals—travertine, limestone, and marble—fractures when subjected to the intense heat of urban fires, which often exceed 1,500 degrees Fahrenheit. At high temperatures, calcite lengthens along one crystallographic axis and shrinks along its perpendicular

Theater of Marcellus, pictured as it exists today, was dedicated by Augustus in 13 B.C. It was constructed mainly of cut-stone Tufo di Tuscolo (tuff from Tuscolo), also used in the construction of the Colosseum eighty years later. The structure was reinforced and clad with travertine. Visitors today marvel at the structure's array of Tufo di Tuscolo arches (brownish stone), reinforced with travertine (white stone) in the keystones and imposts, or tops of the columns that support the two sides of an arch's span. The finished wall in pink brick is a modern restoration.

axes; such uneven thermal expansion and contraction create internal stresses that shatter the stone.

Returning to the Forum of Augustus, we can now begin to appreciate the architectural skill and the knowledge of natural materials that underlay its ornamental facings of Carrara marble. The complex tuff masonry of the forum, along with stabilizing travertine cut-stone masonry, were entirely hidden from view. Suetonius, a Roman historian writing in the early second century A.D., comments: "Since the city was not adorned as the dignity of the empire demanded . . . , [Augustus] so beautified it that he could justly boast that he had found it built of brick and left it in marble." In the *Res Gestae*, Augustus' autobiographical catalog of personal achievements, the emperor enumerates the many new monuments he constructed and the many public buildings, temples, and bridges he repaired. Those works often required that marble facings be installed over tuff block-work or functional concrete masonry. As Augustus transformed the stucco-covered tuff buildings of Rome into elegant, marble-clad structures, he created a magnificent imperial capital whose architectural glories still stand today.

In sum, however, none of that would have been possible without the genius of Roman builders in the first century B.C. Their lasting achievements depend, in turn, on their astute observations, as natural scientists, of the diverse material characteristics of the rocks that formed the surrounding volcanic landscape. They selected certain tuffs for specific structural elements, on the basis of their durability and weight-bearing strength. They used lava rock–rich Lapis Gabinus and Tufo di Tuscolo in foundations and in weight-bearing walls, and glass-rich Tufo Giallo and Tufo Lionato in second-story walls and in concrete vaults. The technological choices recorded in the classical Roman monuments and in *De architectura* reflect Roman builders' empirical understanding of the role of particle composition and the relative proportions of glass, crystal, and rock fragments in determining the durability of the tuff building stones.

For centuries, ancient Roman tuff building stone remained buried or protected within renovated monuments. Archaeological excavations of the past two centuries have now exposed the tuffs to accelerated decay. To prevent further deterioration and eventual corrosion, the tuff building stones should be placed under protective cover, as Vitruvius recommended more than 2,000 years ago. ☐

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By Laurence A. Marschall

Chicago by night

The Grid: A Journey Through the Heart of our Electrified World
by Phillip F. Schewe
Joseph Henry Press; $27.95

Benjamin Franklin, for all his scientific acumen, never dreamed that the electricity he tinkered with would someday join food, water, shelter, and clothing on the list of bare necessities. Yet here we are in the twenty-first century, profoundly dependent on the slender wires that connect us to the grid. Without electricity, food would spoil, pumps would not deliver water, our homes, bereft of heating or cooling, would soon become unlivable and our clothes, unwashed, would soon become unwearable. Consider the inconveniences, major and minor, that accompany a sudden blackout, such as the one that paralyzed the northeastern United States in the summer of 2003—people trapped in elevators, gasoline pumps shut down, streets turned dark and dangerous.

To be off the grid, in short, is to be out of the mainstream of modern culture—which is why, except for a few back-to-the-landers and Old Order Amish, everyone in the world is, or wants to be, plugged in. Phillip F. Schewe, in his eclectic survey of the past century and a quarter of electrification, casts a perceptive eye on how that momentous transformation came about, and where it may be heading.

Thomas Edison, not surprisingly, was the father of the grid. At 3 P.M. on September 4, 1882, he threw a lever in his first power plant at 255–57 Pearl Street in Manhattan, sending current along a network of underground wires to 400 electric lamps in buildings nearby. By November, the number of lamps drawing sustenance from Pearl Street had tripled, and within a year *The New York Times* had 300 bulbs burning in its own building. Edison power plants and electrical lines were soon going up in Budapest, Milan, Moscow, Santiago, and a host of other cities around the world.

But if Edison deserves the credit for engineering the first centralized electric power system, other, lesser-known heroes are responsible for its kudzulike growth. Power plants like the Pearl Street station were not suited to today's nationwide grid because they produced direct current (DC), a current that flowed steadily in one direction. The problem was that DC current could not, at the time, be sent over long distances without substantial losses of energy.

The solution was AC, or alternating current, whose flow reversed itself many times a second. The rapid reversals made it possible to step AC current up to a high voltage, which loses less energy than low-voltage current during transmission. At ultrahigh voltages, AC current could transport power efficiently over wires for hundreds of miles.

The first entrepreneur to make the connection between AC current and the business potential of long-distance energy distribution was George Westinghouse. Not long after Pearl Street produced its first power, Westinghouse began setting up a network of generating stations and transmission lines based on AC. The idea was to site power plants where energy was abundant, near coal mines and waterfalls, and send it to faraway urban centers where potential users were concentrated. Equally important, Westinghouse hired an immigrant engineer named Nikola Tesla. Brilliant and unconventional, Tesla designed efficient AC generators to make electricity cheaply, and compact AC motors that were more convenient and reliable than the steam and water turbines then common in workshops and factories.

Although Schewe has a Ph.D. in physics and writes a weekly newsletter for the American Institute of Physics, his book focuses less on engineering and more on the political, economic, and cultural challenges that the growth of the grid entailed. Maybe that's not so surprising: Schewe is also a playwright whose works have been staged in New York and Washington, D.C. *The Grid* may never make it to Broadway, but, to use Schewe's phrase, it is a "drama of volts," illuminating an aspect of our world that most of us too often take for granted.

Steller's Island: Adventures of a Pioneer Naturalist in Alaska
by Dean Littlepage
The Mountaineers Books; $17.95

At the Zoological Institute of the Russian Academy of Sciences in St. Petersburg is a slab of white bone with an oddly ridged surface. The ridges seem to serve no obvious physiological purpose—unless perhaps one is an expert in the oral anatomy of extinct species. The bone comes from the mouth of a giant marine mammal, Steller's sea cow, which once used a pair of these plates in place of teeth to masticate long strands of kelp it pulled

from the frigid waters of the North Pacific. The animal bears the eponym of one of the first and last Europeans to see a live sea cow in its native habitat: Georg Wilhelm Steller, the young naturalist on Vitus Bering's pioneering voyage to the Aleutians and along the coast of Alaska that embarked from Siberia in 1741.

So difficult was Arctic travel in those days that it was fortunate that anyone at all survived to describe the sea cow. Almost half of the expedition's company, including Bering himself, died of scurvy before the voyage was over. Shipwrecked on a remote island, the company spent the winter of 1741–42 huddled in improvised shelters. Not until the following August did Stellar and forty-five survivors finally limp back to a Siberian port in a boat made from the wreckage of their original sailing craft. The palate bone, as a consequence, is one of the few artifacts

Skeleton of Steller's sea cow, a giant marine mammal

Steller collected that managed to make it back to civilization.

What did come out of the trip were Steller's observations, collected in his monumental monograph, *The Beasts of the Sea,* first published in 1751. And among the marine mammals Steller discusses in his book, most of them only vaguely known to European biologists of the time, sea cows were by far the largest. He and his shipmates managed to kill a full-grown female and dissect it on the beach, the only extant scientific report of one in the flesh.

Looking at sketches of the creature, the modern observer sees something like a stretch-limo version of a sea lion, its blimpish body connecting a two-lobed tail and a flattened snout. Steller's specimen measured twenty-five feet from nose to tail. Its tongue was a foot long, its blubber was six inches thick, and its stubby front flippers were equipped with claw-like appendages that helped it dig kelp strands from rocks. To survive in cold water, it must have consumed enormous quantities of food. Its stomach was the size of a large walk-in closet, and its digestive tract, when unfolded along the shore, stretched 500 feet from mouth to rectum, twenty times the creature's length. (For comparison, the human digestive tract is only about five times an average person's height.)

Steller observed a population of sea cows that was barely able to survive; their habitat had probably been warmer when they migrated to the Arctic millions of years earlier. Even if they had not been hunted to extinction by 1768, they might have disappeared.

Steller also described a variety of other creatures that survive today—an incredible act of scientific discipline since, as a castaway in a cold and bitter land, he had to struggle merely to stay alive. He was an acute observer of the physical characteristics and behavior of such creatures as sea otters, sea lions, and northern fur seals. He noted, for instance, that the sea otter, which had little body fat, managed to insulate itself by continually growing a new coat and shedding its old one, a few hairs at a time.

Dean Littlepage, an Alaskan writer, re-creates Steller's adventures, drawing heavily on the logbooks and journals of Steller and his companions. There's a bit of Littlepage's own expertise in outdoor journalism on display here too, as the author backpacks around Kayak Island, where Steller first came ashore in North America. It's no longer a blank


RosettaStone
ITALIAN

spot on the map, as it was in Steller's time, but Littlepage helps the reader understand the excitement the young explorer must have felt 250 years ago, fresh-eyed and eager to be amazed.

Flower Confidential: The Good, the Bad, and the Beautiful in the Business of Flowers
by Amy Stewart
Algonquin Books of Chapel Hill
$23.95

Sitting down to write this review, a scant forty-eight hours before Valentine's Day, I realized that, like more than 55 percent of my fellow holiday gift-givers, I have not yet bought any flowers. That curious statistic comes from *Flower Confidential,* which strips bare more about the cut-flower industry than most people buying a heartfelt bouquet would want to know.

In the case of the roses for my beloved—which I swear I will order in just a few minutes—Amy Stewart tells me that their form and fragrance may have been designed by a corporate breeding laboratory in Holland or California. But, she goes on, they were probably grown in a crowded greenhouse in the Andes. Around the beginning of January, local laborers made the rounds of the hothouse aisles, placing little mesh sleeves (aptly nicknamed *condones,* or "condoms") over each bud of "my" roses to keep them from opening too soon. A month later, the workers cut each stem, dipped each flower into a barrel of fungicide, and arranged the swelling buds in bunches for shipping.

At work in a Colombian flower factory

Large trucks ferried the crop to the airport, where it was placed on a plane. Purchased by an export firm, the flowers were soon bound for New York or Miami. From there they were trucked, as rapidly as possible, to my local florist. And as soon as I make my phone call, he will add a few garnishes and flourishes and deliver them, with the appropriate message of devotion, sometime before the sun has set on February 14—less than a week after they began their journey from South America.

Stewart takes her readers on every stage of this odyssey, with a critical eye and the panache of a seasoned journalist. A confessed flower junkie,

Eats birds and flies.

[Rana catesbeiana]

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the Houston Museum *of* *natural science*

Sponsors: The Hamill Foundation Houston Museum of Natural Science Volunteer Guild she can't resist the blooms, even when she's visiting a flower plantation on the industrial scale. "As I stood . . . and looked out across several dozen rows of sunny orange gerberas in bloom," she writes from Holland, "I thought that I'd probably never seen so much exuberance in one place. This is not a flower with nuance. It radiates pure, uncomplicated happiness."

Elsewhere, she shops for flowers the way Imelda Marcos must have shopped for shoes:

> I fell hopelessly in love with this store when I was in Miami and spent an entire day driving from one Field of Flowers location to the next because I just couldn't get enough of it. . . . I was hooked. I filled my drab hotel room with odd and unusual flowers I picked up at the three shops, and left them behind for the housekeeping staff to wonder about.

But Stewart is no Pollyanna. As her title suggests, she does not view the flower business through rose-colored glasses. Most flowers for the trade are no longer grown on family farms and sold by elegant old ladies—if they ever were. They are commodities, and as such are fully enmeshed in the creeping ivy of globalism. Flower workers, particularly in developing nations where mass-market blooms are grown, endure long hours and may suffer the effects of poorly regulated pesticides. By the time the five dollars I might pay for an up-market rose stem in New York City trickles down to the laborer who harvested it, only a few cents remain for his or her time and effort.

Consider, then, the lilies of the field, Stewart is saying—and all they go through on the way to your table. "If it seems like flowers have lost their soul in this process," she concludes, "well, they have."

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.*

nature.net

Pop Charts

By Robert Anderson

Nowadays, when I fly, my two children compete for the window seat. But I remember when I used to be glued to the airplane window on approach to Los Angeles. The grid of streets and the sinuous system of freeways spread out for hundreds of square miles before me was always a vivid reminder of the remarkable expansion of our species. Just before landing, I would also note the traffic grinding along the 405 freeway. Our reproductive success, it seems, exacerbates almost every problem we face, from regional conflicts to global warming and the loss of biodiversity.

On the Internet scores of organizations analyze the numbers, sound warnings, and offer ways to soften the impact of future population growth. *NOVA*'s Web site "World in the Balance" (www.pbs.org/wgbh/nova/worldbalance) is a good introduction to the subject. Beneath the heading, a "popclock"—a ubiquitous feature on population sites—counts each moment's increase in our numbers (as I write, it is speeding past 6,569,308,148). In the "Interactives" section, click on "Human Numbers Through Time" for a series of nine maps that show the spread of our species across the globe (to animate the maps, click through to the last one and then select "play all," which appears just above the map on the right). For authoritative current statistics on many of the social factors that affect birthrates throughout the world, go to the Population Reference Bureau (www.prb.org) and click "Datafinder."

Globally, in this century, the least developed regions will undergo nearly all the growth. For a quick look at where people live, go to the Hive Group (www.hivegroup.com/world.html), which specializes in visualizing business data. Here you can readily compare the populations of various countries.

The Social and Spatial Inequalities Research Group at the University of Sheffield in England has an addictive Web site called Worldmapper that shows how humanity and resources are distributed (www.sasi.group.shef.ac.uk/worldmapper). The countries are sized to reflect the numbers, whether they describe population, health, literacy, or any of hundreds of other societal attributes. Under "Map Categories" select "Basic" for various population maps, including ones predicting the numbers for 2050 and 2300. The growth rate of global population has now slowed to about 1.15 percent per year, which may not seem high. But to get a sense of what that really means, go to "Understanding Exponential Growth," by Greg Bothun of the University of Oregon (zebu.uoregon.edu/2003/es202/lec06.html). Near the top of the page you'll find a link to a simulator where you can explore how population will affect greenhouse-gas emissions. At the bottom click on "next lecture" to learn more about the math of population dynamics.

As clever as our species is, we are not immune to many of the same physical restraints that keep other animal populations in check. Gigi A. Richard, a geologist at Mesa State College in Grand Junction, Colorado, ponders how many people the planet can ultimately sustain. Her startling conclusion: fewer than are alive today (www.ilea.org/leaf/richard2002.html). She cites biologist Dave Klein's classic study of the "carrying capacity" for reindeer on St. Matthew Island, Alaska. After the reindeer outstripped the island's food supply, their population simply crashed (see www.gi.alaska.edu/ScienceForum/ASF16/1672.html). Such ecological disasters culled human populations in the past; perhaps the most ominous example was the demise of the people of Easter Island (click on "Out of House and Home," also at the "World in the Balance" Web site, the first one listed above). Inevitably, part of the story of this century will be about how we come to grips with our "success."

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

EXPLORER GUIDE

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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.

By Joe Rao

Mercury is a morning object during April, but it has sunk too low into the bright morning twilight to be viewed from northern latitudes.

Venus, blazing at magnitude −4.1, is the grand evening "star" this month, far outshining all the other stars and planets. It appears almost due west after sunset every night; look for it during and after twilight. If you watch carefully this month, you'll notice that the planet rises a little higher with each passing week, staying up from one and a half to almost two hours after the end of evening twilight. If you see a weird bright light hanging like some distant lantern low on the west-northwestern horizon as late as 10 or 11 P.M. local daylight time (LDT), it's only Venus.

Throughout the month Venus remains at nearly the same place above the horizon at dusk, while the stars in the background seem to slide behind it. On the evening of the 11th the planet's brilliant light hangs about two and a half degrees to the left of the Pleiades. The dim, +4.4-magnitude star 37 Tauri slips just a third of a degree (less than the diameter of the full Moon) south of Venus on the 15th, and the orange, first-magnitude star Aldebaran passes seven degrees below and to the left of Venus on the 21st.

Although small and gibbous, the planet is certainly worth a look in a telescope. Hunt it down in bright twilight or even in daylight, while it's still high in the sky. The best telescopic views of Venus are in a bright sky.

Mars rises south of east about two hours before sunup, and hangs nearly motionless above the east-southeastern horizon all month at dawn. Meanwhile, the faint stars of Aquarius slide behind the Red Planet and toward the upper right. Shining at magnitude +1.1 at midmonth, Mars in a telescope is disappointingly tiny. On the morning of the 29th, try using Mars as a guide to find the planet Uranus. Mars passes just 0.7 degree south of that distant world. In binoculars or through a small telescope, Uranus appears as a dim, tiny "star" at magnitude +5.7, with a greenish-blue tint, only about 0.01 as bright as Mars.

Jupiter rises in the southeast, about ten degrees to the left of the bright ruddy star Antares, just before 1 A.M. LDT at the beginning of the month, and just before 11 P.M. at month's end. Telescopic observers can catch Jupiter at its highest in the south shortly before the beginning of morning twilight. The four largest moons of Jupiter can readily be seen with a small telescope or even through steadily held binoculars. The moons take from about two to seventeen days to orbit Jupiter, visibly changing their relative positions from hour to hour and from night to night. On the morning of the 23rd, for instance, you can see two moons on each side of Jupiter, whereas on the morning of the 28th, all four appear lined up on one side of the planet.

As twilight falls, Saturn emerges close to the meridian at magnitude +0.3, and remains visible well past midnight. The planet lies in the constellation Leo, the lion, all month, appearing some two and three-quarters times as bright as the first-magnitude star Regulus, glimmering about a dozen degrees east of Saturn. Any telescope that can reveal Saturn's rings can also show its 9th-magnitude moon Titan, which is always within four ring-lengths of the planet. Titan circles Saturn once every sixteen days. Look for it to the east of Saturn around the 4th and the 20th, and to the west around the 12th and 28th. As darkness falls on the evening of the 24th, a waxing gibbous Moon passes above and to the right of Saturn.

The Moon is full on the 2nd at 1:15 P.M. Our satellite wanes to last quarter on the 10th at 2:04 P.M and to new on the 17th at 7:36 A.M. The Moon waxes to first quarter on the 24th at 2:36 A.M.

Unless otherwise noted, all times are eastern daylight time.

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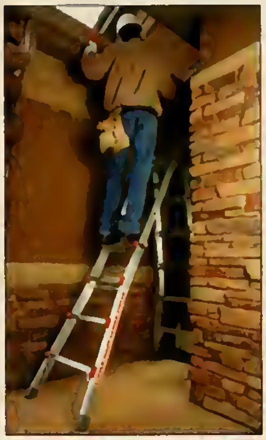

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Dinosaurs Walk the Earth—Again

NEW IMAX FILM

If ever there were a perfect subject for the magic of the large-format screen, it would be the prehistoric giants whose existence and extinction have captivated human imagination since their fossils were first unearthed in the 19th century. True to that promise, *Dinosaurs Alive!* is a thrilling adventure of science and discovery now showing in the LeFrak IMAX Theater that uses scientifically accurate, computer-generated images to bring to life these magnificent, mystifying creatures from the earliest dinosaurs of the Triassic Period to the monsters of the Cretaceous.

In one of the most dramatic sequences, a *Velociraptor* and a *Protoceratops* die locked in combat, claws and jaws grasping at each other, as a sand dune sweeps over them, literally stopping them in their tracks until, after millions of years, erosion exposes their skeletons for scientists to discover. In another animation, the massive, long-necked sauropod *Seismosaurus* thunders about, its 110-foot-long body a vivid contrast to the more diminutive Triassic dinosaurs also shown on screen.

Over the course of the film, viewers follow AMNH paleontologists past and present from the exotic expanses of Mongolia's Gobi Desert to the sandstone buttes of New Mexico tracing some of the greatest dinosaur finds in history. Included is beautifully preserved footage from the 1920s of scientist and adventurer Roy Chapman Andrews, believed to be the inspiration for the fictional character Indiana Jones, on his seminal expeditions to the Gobi, where he and his team found hundreds of dinosaurs remains, including the first *Velociraptor*, the first dinosaur nest with eggs, and fossils of mammals that lived alongside the dinosaurs.

Fortunately, Andrews took along a Hollywood cameraman, and his rare early footage, juxtaposed against the IMAX-formatted footage of recent expeditions by AMNH paleontologists Mike Novacek and Mark Norell, provides audiences with a unique perspective on the field of paleontology over time.

IMAX films at the Museum are made possible by ConEdison.

An Elegant Gallery Reopens

As a rule, it is the contents of an exhibition hall that merit public attention. This month, however, the Museum celebrates not only the opening of a fascinating art show, but the reopening of the display space itself, the beautifully restored Audubon Gallery on the Museum's fourth floor.

The 3,000-square-foot gallery has been painstakingly refurbished, perhaps even surpassing its original 1930s glory. Double doors open to a serene rectangular hall, with 19-foot coffered ceilings graced by eight exquisite lamps, their large bowls trimmed with metal silhouettes of terns in flight. The inner doors, moldings, and wainscoting have been refinished and the walls covered in a cream linen that was chosen based on remnants of the original fabric. New lighting also subtly complements the room's architectural details, which include magnificent marble moldings.

John James Audubon is, of course, famous for his bird paintings. However, the inaugural exhibition, *Unknown Audubons: Mammals of North America*, features more than 50 vivid depictions of mammals, along with artifacts such as books, Audubon's guns, and select taxidermy. Most of the mammal images appeared in the naturalist's last great work, *The Viviparous Quadrupeds of North America*, completed with the help of his two sons, John Woodhouse Audubon and Victor Gifford Aududon, and their father-in-law, the Reverend John Bachman, who wrote much of the text.

C. CHESEK/AMNH

Once the repository of works by Audubon and such celebrated wildlife painters as Louis Agassiz Fuertes, Joseph Wolf, and Francis Lee Jaques, the original Gallery was designed by the architectural firm Trowbridge and Livingston, best known for its 1935 plan for the then brand-new Hayden Planetarium, as well as such New York landmarks as the B. Altman Building and the St. Regis Hotel.

AMNH and the Invisibles

We tend to think of all things microbial as agents of disease. But there are countless unseen organisms that are beneficial, even crucial, to sustaining human life. And yet much remains unknown about their numbers, the role they play in the ecosphere, and the possible threat posed to their existence by environmental change.

With a view to raising the profile of these essential microorganisms, scientists will gather on April 26 and 27, for the Center for Biodiversity and Conservation's 12th annual symposium: *Small Matters: Microbes and Their Role in Conservation*. The two-day symposium represents a significant interdisciplinary initiative, offering one of the first opportunities for microbiologists and conservation practitioners—from biogeochemists to wildlife managers—to come together to explore the intersection between microbe diversity and conservation. Presentations and panel discussions will address how this "unseen majority" profoundly affects the fate of all other life on Earth, the extent to which conservation practices do or don't take microbial life into account, and more.

On the evening of April 26, the general public is invited to join the scientific audience for the 2007 Mack Lipkin Man and Nature lecture, *Save the Microbes, Save the World: The Fate of Microbial Life on a Changing Planet*. NPR's Julie Burstein, *Studio 360*, leads a discussion on the importance of microbes as they relate to human health, biodiversity conservation, global climate change, early life on Earth, and even astrobiology.

Please call 212-769-5200 or visit http://cbc.amnh.org for details.

Podcasts Paved with Gold

WWW.AMNH.ORG

Now you can take a personal tour of the Museum's special exhibition *Gold* with one of its curators. First, download a free podcast to your own portable player, then follow along with James D. Webster, Curator and Chairman, AMNH, Department of Earth and Planetary Sciences, as he walks and talks his way from case to case, exploring the history of this much-coveted precious metal.

This *Gold* tour, complete with images, is made available through an ongoing collaboration between the American Museum of Natural History and Science & the City, the online newsletter of the New York Academy of Sciences. Just visit www.amnh.org/podcast, where you will find the *Gold* tour with Dr. Webster as well as downloads of lectures by noted scientists and authors on a variety of subjects including the *Gold*-related Volcanic Activity and Formation of Gold Deposits.

D. FINNIN/AMNH

The "Boot of Cortez," the largest gold nugget found in the Western Hemisphere, weighs over 26 pounds.

PEOPLE AT THE AMNH

Karen Newitts
Visual Manager, Retail and Licensing

D. FINNIN/AMNH

If there's anything cooler than having an aunt who works at the American Museum of Natural History, it's having an aunt who works in the Museum's gift shops.

All five nieces and nephews got gifts from the Museum this Christmas, and at this writing a newborn sixth nephew was about to be surprised with his first pair of "little leather dino booties."

Karen's job is to establish the "look, feel, and style" of the shops, periodically adjusting the displays to keep them fresh, and designing themed shops for special exhibitions. She helped create the Gold Shop, and is hard at work on upcoming shops.

She came to the Museum eight years ago after a series of retail jobs that were fun but didn't speak to her deep love of nature, which she traces to family summers in Maine, reading *Ranger Rick* magazines as a child, and watching television. "All my life I watched the nature channels, the PBS's."

Passionate about the sea, Karen commutes nearly two hours each way from Long Branch, New Jersey, where she lives 20 seconds from the beach with her husband, Gary, a visual designer turned paramedic.

Quick to point out that 100 percent of shop profits go to supporting Museum education and research, Karen says of her job, "It's a feel-good. I love that. These are all gifts that give." And she knows she's done that job well when, walking through a shop, she overhears a visiting adult or child exclaim, "I have to have it!"

Museum Events

AMERICAN MUSEUM OF NATURAL HISTORY

www.amnh.org

EXHIBITIONS

Gold

Through August 19, 2007

This glittering exhibition explores the captivating story of the world's most desired metal. Extraordinary geological specimens, cultural objects, and interactive exhibits illuminate gold's timeless allure.

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, with additional support from American Express® Gold Card.

The Butterfly Conservatory

Through May 28, 2007

Visitors mingle with live, free-flying butterflies in a tropical environment.

IDELL CONAWAY

Christmas tree worm

Undersea Oasis: Coral Reef Communities

Through January 13, 2008

Brilliant color photographs capture the dazzling invertebrate life that flourishes on coral reefs.

Beyond

Opens April 14, 2007

Exquisite images from unmanned space probes take visitors on a journey through the alien and varied terrain of our planetary neighbors.

The presentation of both *Undersea Oasis* and *Beyond* at the American Museum of Natural History is made possible by the generosity of the Arthur Ross Foundation.

GLOBAL WEEKENDS

International Earth Day

Sunday, 4/22, 1:00 p.m.

Native American song, Japanese drumming, and a presentation of dramatic photographs celebrate our connection to nature.

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

LECTURES

The Natural History of the Bible

Tuesday, 4/10, 7:00 p.m.

Daniel Hillel discusses how Israel's land and water resources have changed since biblical times.

The Wild Trees

Thursday, 4/12, 7:00 p.m.

Richard Preston evokes the majesty of one of nature's greatest works, the coast redwood.

Marine Mythology

Tuesday, 4/17, 7:00 p.m.

Richard Ellis shares intriguing myths and legends about "monsters" of the deep sea.

Art/Sci Collision: Of Human-Robot Bondage

Wednesday, 4/18, 7:00 p.m.

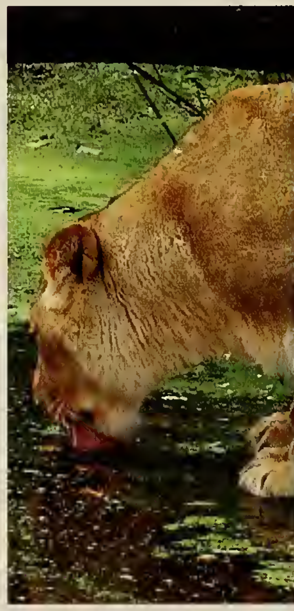
A panel considers how the emerging reality of human-machine relationships affects our understanding of ourselves.

This program is made possible, in part, by the Allaire Family and Ruth A. Unterberg.

Cats of Africa

Thursday, 4/19, 7:00 p.m.

This presentation explores behaviors of wild cats and reveals how new techniques in molecular genetics are helping conservation efforts.



Treasures of the Past

Tuesday, 4/24, 7:00 p.m.

AMNH Curator Peter Whiteley and Margaret A. Wood showcase the Museum's Southwest Native American collection and discuss craft traditions and contemporary interpretations.

Adventures in the Global Kitchen: The Incredible, Edible Dandelion

Tuesday, 4/24, 7:00 p.m.

Learn about the dandelion with Anita Sanchez. Program includes recipes and dishes to taste.

WORKSHOPS

Spring Bird Walks in Central Park

Eight-week sessions begin on 4/10, 4/11, and 4/12.

Visit www.amnh.org for details.

Observe the spring migration of birds in Central Park with Museum naturalists.

Animal Drawing

Eight Thursdays, 4/12–5/31

7:00–9:00 p.m.

The celebrated dioramas, dinosaur skeletons, and other distinctive features of the Museum are the setting for an intensive after-hours drawing course.

Reading Your DNA

Three Thursdays, 4/26–5/10

7:00 p.m.

Participants will make their own DNA "fingerprints" in this hands-on workshop.

FAMILY AND CHILDREN'S PROGRAMS

Identification Day

Saturday, 4/14, 1:00–4:00 p.m.

Bring in your favorite backyard finds, basement curios, and flea market discoveries for Museum scientists to attempt to identify.

This program is made possible, in part, by an anonymous donor.

ROSE CENTER FOR EARTH AND SPACE

Sets at 6:00 and 7:30 p.m.

Friday, April 6

Visit www.amnh.org for lineup.

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

HUMAN ORIGINS SATURDAYS
Secrets of Skulls
Saturday, 4/14
11:00 a.m.–12:30 p.m. (Ages 8–10, each child with one adult)
1:30–3:00 p.m. (Ages 10–12, each child with one adult)
Compare skull casts of early humans.

Discover DNA
Saturday, 4/21
11:00 a.m.–12:30 p.m. (Ages 8–10, each child with one adult)
1:30–3:00 p.m. (Ages 10–12, each child with one adult)
Kids and their parents can isolate their own DNA.

NEW! **Alien Workshop**
Saturday, 4/28
11:00 a.m.–12:30 p.m. (Ages 4–5, each child with one adult)
1:30–3:00 p.m. (Ages 6–7, each child with one adult)
Children will participate in astrobiology experiments and take home their own "alien."

AMNH ADVENTURES SPRING CAMPS
Monday–Friday, 4/2–6
9:00 a.m.–4:00 p.m.
Each weeklong session includes hands-on investigations, behind-the-scenes tours, and visits with Museum scientists.

Fossils and DNA
(For 2nd and 3rd graders)

Destination Space: Astrophysics
(For 4th and 5th graders)

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

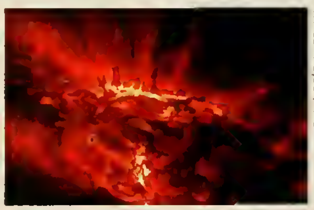
TICKETS AND REGISTRATION
Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.
All programs are subject to change.

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

CENTER FOR BIODIVERSITY AND CONSERVATION
12TH ANNUAL SPRING SYMPOSIUM
Small Matters: Microbes and Their Role in Conservation
Thursday and Friday, 4/26 and 27, 9:00 a.m.–5:00 p.m.
See p. 61.

THE MACK LIPKIN MAN AND NATURE LECTURE
Microbes: Can't Live With 'Em, Can't Live without 'Em
Thursday, 4/26, 7:00 p.m.
See p. 61.

HAYDEN PLANETARIUM PROGRAMS
TUESDAYS IN THE DOME
Virtual Universe
Neighboring Stars (and Planets)
Tuesday, 4/3, 6:30–7:30 p.m.



TRACE PROJECT, NASA

A sunspot

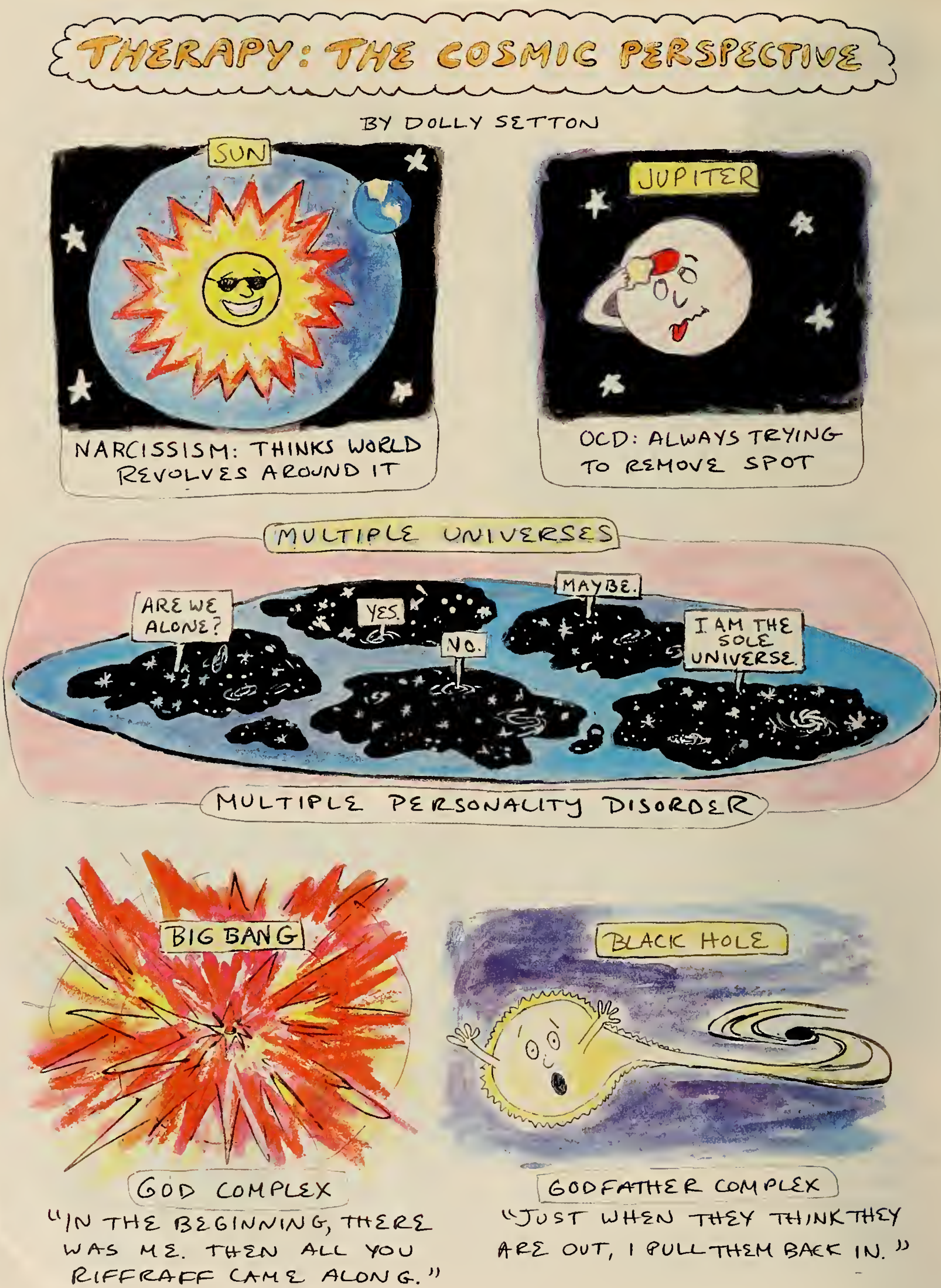
Celestial Highlights
Now Starring in Our Evening Sky: Venus
Tuesday, 4/24, 6:30–7:30 p.m.

HAYDEN PLANETARIUM SHOWS
Cosmic Collisions
Journey into deep space—well beyond the calm face of the night sky—to explore cosmic collisions, hypersonic impacts that drive the dynamic formation of our universe. Narrated by Robert Redford.

Cosmic Collisions was developed 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.


THERAPY: THE COSMIC PERSPECTIVE
BY DOLLY SETTON
SUN
NARCISSISM: THINKS WORLD REVOLVES AROUND IT
JUPITER
OCD: ALWAYS TRYING TO REMOVE SPOT
MULTIPLE UNIVERSES
ARE WE ALONE?
YES.
NO.
MAYBE.
I AM THE SOLE UNIVERSE.
MULTIPLE PERSONALITY DISORDER
BIG BANG
GOD COMPLEX
"IN THE BEGINNING, THERE WAS ME. THEN ALL YOU RIFFRAFF CAME ALONG."
BLACK HOLE
GODFATHER COMPLEX
"JUST WHEN THEY THINK THEY ARE OUT, I PULL THEM BACK IN."


We're Wild for Wings!
Pavilion of Wings
Where you can experience the beauty and fun of live free-flying butterflies.
Sunday, April 15, 2007 - Monday, September 3, 2007
The Natural History Museum invites you to stroll through a beautiful enclosed environment filled with live free-flying butterflies! Located on the Museum's south lawn, the pavilion contains hundreds of butterflies and moths from all over the United States.
Watch our website for special Butterfly Events!
Admission for Pavilion of Wings is not included in regular Museum admission. Prices are $3 for adults, $2 for students and seniors, and FREE for Museum Members and children under 5. Tickets are sold for entry on the half-hour starting at 10:00am. The last tickets are sold at 4:00pm.
Natural History Museum of Los Angeles County
900 Exposition Blvd., Los Angeles, CA 90007
213-763-DINO www.nhm.org


STAND IN AWE? YES.
FOLLOW IN HIS FOOTSTEPS?
NOT RECOMMENDED.
Ed Viesturs was hailed by National Geographic as one of the strongest high-altitude mountaineers on Earth. He has gazed from the summit of Mount Everest six times, and climbed all 14 of the world's 8,000-meter mountains, without supplemental oxygen; a feat few people will ever accomplish. There are exceptional explorers on this planet – but only one Ed Viesturs.
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