SPECIAL ISSUE: DINOSAURS TAKE FLIGHT

NATURAL HISTORY

5/05

TERRIBLE LIZARDS: A NEW FAMILY PORTRAIT

NATURAL HISTORY

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SPECIAL ISSUE: DINOSAURS TAKE FLIGHT

FEATURES

ON THE COVER:
65 Million Years of Tyrannosaurs
by Frank DeNota

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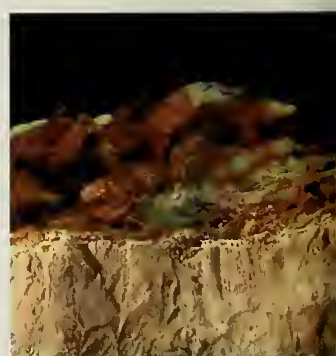

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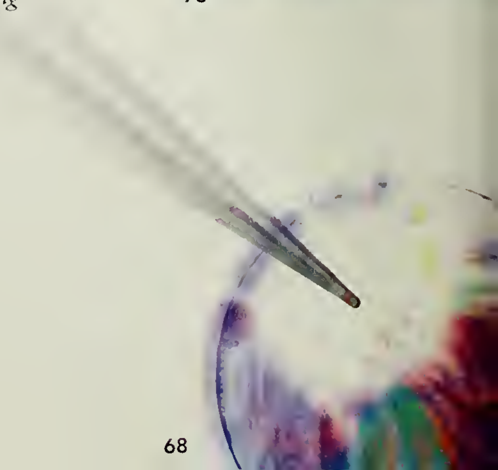

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THE NATURAL MOMENT

Preparing for Takeoff?

Photograph by Mick Ellison

THE NATURAL MOMENT

◄ *See preceding two pages*

In his April 1998 column for *Natural History,* the late Stephen J. Gould warned his readers that fossil forgeries were flooding out of Morocco. Now the hotbed of fakery seems to have shifted to China, where the black market demand for dinosaur bones is thriving. The 128-million-year-old fossil of *Microraptor gui,* pictured here, was originally modified—a false beak was glued on—before luck landed it in 2002 on the desk of Xu Xing, a paleontologist at the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing (and a co-author of "The Varieties of Tyrannosaurs," on page 34).

Microraptors seem to have a tradition of being improperly pieced together. The *Archaeoraptor*—a forged fossil that was hailed in 1999 as the link between dinosaurs and birds—was really a composite of an ancient bird species, *Yanornis martini,* and a microraptor's tail. The irony is that, with feathers covering its body, *M. gui* doesn't really need embellishment; it is quite birdlike on its own. Some paleontologists have suggested that the creature—just two and a half feet long—could glide from treetop to treetop.

All microraptors in the known fossil record, including *M. gui,* have been discovered embedded in the shale of Liaoning Province, northeast of Beijing. Photographer Mick Ellison captured this specimen in Xu's laboratory, but only after all questionable pieces had been removed. —*Erin Espelie*

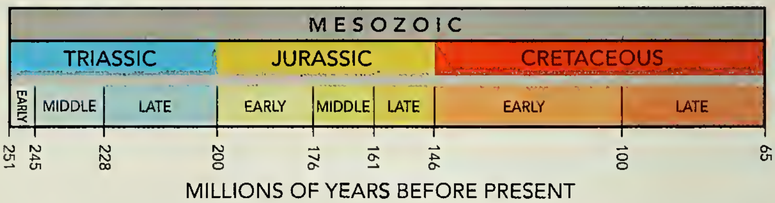
UP FRONT

Dinosaurs: Why We Care

Come one! Come all! Come children of all ages—the dinosaurs are back in town! That's right, kids, the world's most captivating creatures, those marvelous megafauna from the Mesozoic, the greatest attractions in all of natural history, are returning to the spotlight. This month, on May 14, a new exhibition, "Dinosaurs: Ancient Fossils, New Discoveries," opens at the American Museum of Natural History in New York City. And in honor of that special event, *Natural History* is presenting its first issue in ten years devoted entirely to everyone's favorite monsters.

So why *do* people care so much about dinosaurs? First, of course, many of them really were fearsome, scary, and terrifying. *Tyrannosaurus rex,* the mother of all monsters, weighed in at more than six tons and featured a jaw four feet long studded with six-inch-long teeth. Mark A. Norell and Xu Xing tell the story of *T. rex* and its extended family in "The Varieties of Tyrannosaurs" (page 34). The popularity of *T. rex* and the other dinosaurs has created such a publishing phenomenon that the discerning book buyer needs a knowledgeable guide. Fortunately, Thomas R. Holtz Jr. has assembled a convenient list "for the dinosaur fan, and no less for the parents thereof" ("A Dinosaur Lover's Bookshelf," page 62).

Another reason dinosaurs are so fascinating is that they pose so many puzzles. Dinosaurs flourished from the Late Triassic until the end of the



Cretaceous, and they left tantalizing clues about their lost world (for a plot of their interrelations, see "All in the Family," also by Thomas Holtz, page 40). In "Bringing Up Baby" (page 30), David J. Varricchio relates how new fossil evidence is shedding light on parental care among dinosaurs. Yet, to the delight of its practitioners, plenty of questions in dinosaur science remain (see "Butting Heads," page 48).

The third attraction about dinosaurs is their link with modern birds. As Matthew T. Carrano and Patrick M. O'Connor explain in their article "Bird's-eye View" (page 42), that link has opened up an extraordinary window on the world of dinosaurs. A fourth appeal is the great mystery of what caused the nonbird dinosaurs to disappear so suddenly . The leading suspect is an asteroid that slammed into Earth (see "Loading the Cannon," by Charles Liu, page 68). But more generally, the dinosaurs' demise has highlighted a sobering truth: planet Earth is part of a very dangerous universe (see "Knock 'Em Dead," by Neil deGrasse Tyson, page 25).

Throughout the magazine, you'll see the icon at right, based on the fossilized footprint of a theropod dinosaur. As Adrienne Mayor points out in her article "Tales from the Badlands" (page 56), to Native Americans the fossil looked like the footprint of a giant, prehistoric bird. That's what it looks like to paleontologists today, too. It's a reminder that dinosaurs are still flying, all around us. —PETER BROWN

CONTRIBUTORS


Ellison

MICK ELLISON ("The Natural Moment," page 4) studied art at the Maryland Institute College of Art in Baltimore and the Edinburgh College of Art in Scotland. He is a staff artist and photographer in the division of paleontology at the American Museum of Natural History (AMNH) in New York City.


Varricchio

Early years spent on a farm, reading Sherlock Holmes stories and watching bad sci-fi movies, may have launched **DAVID J. VARRICCHIO** ("Bringing Up Baby," page 30) on his career of paleontological detective work. His research interests include taphonomy, as well as reproduction in theropod dinosaurs. Varricchio is an assistant professor of paleontology at Montana State University–Bozeman.


Norell


Xu

No stranger to the pages of *Natural History*, **MARK A. NORELL** ("The Varieties of Tyrannosaurs," page 34) is chairman and curator of the division of paleontology at AMNH. Norell is also the curator of AMNH's new exhibition, "Dinosaurs: Ancient Fossils, New Discoveries," opening May 14. Norell's co-author, **XU XING,** a paleontologist with the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing, is also a research fellow at AMNH. The two have collaborated on a number of scientific papers, including one describing their recent discovery of the feathered tyrannosaur *Dilong paradoxus*.


Holtz

When he discovered, at age three, that he wouldn't grow up to *be* a dinosaur, **THOMAS R. HOLTZ JR.** decided to do the next best thing: he became a paleontologist. He is a lecturer in the geology department at the University of Maryland, in College Park, where he specializes in carnivorous dinosaurs. Holtz is the chief architect of the cladogram that appears on pages 40 and 41 ("All in the Family"), and he has also chosen and reviewed a splendid collection of books about dinosaurs, for readers of all ages ("A Dinosaur Lover's Bookshelf," page 62).


Carrano


O'Connor

MATTHEW T. CARRANO ("Bird's-eye View," page 42) is the curator of dinosauria at the Smithsonian Institution's National Museum of Natural History. He grew up near Yale University's Peabody Museum of Natural History, where he says he spent many formative afternoons. His research interests include the evolution and biomechanics of dinosaurs. Carrano's co-author, **PATRICK M. O'CONNOR,** was drawn to the study of evolutionary morphology in dinosaurs and birds while excavating specimens in Madagascar. He is now an assistant professor of anatomical sciences at the Ohio University College of Osteopathic Medicine, in Athens.


Mayor

To write *Fossil Legends of the First Americans*, **ADRIENNE MAYOR** ("Tales from the Badlands," page 56) traveled more than 8,000 miles, visiting archives, fossil sites, libraries, and museums, and interviewing both paleontologists and Native American informants. Her book is being published this month by Princeton University Press. Mayor is an independent scholar based in Princeton, New Jersey.

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Chewing the Fat

I agree with Susan Okie's article "Fat Chance" [2/05] that both DNA and our modern society are to blame for the epidemic of obesity. Nevertheless, overweight individuals should not be left with the fatalistic impression that they can do nothing to permanently reduce their weight. I am one of the 5 percent who has lost weight and kept it off.

The two key elements of my success are a diet I can live with and exercises I enjoy.

Marion Ehrlich
Wilmington, Delaware

The problem with a steady diet of junk food and television is not that it makes some kids fat, but that it makes all kids unhealthy. Responsibility for this lifestyle rests with the parents. It has not been easy to raise my son on a whole-foods diet in a home without a television or electronic games, but it has been possible.

Ann Wisehart
Santa Barbara, California

Given how difficult it is to get a person to overeat to gain weight, it is unlikely that such factors as large portions, television, and snack foods are truly at fault. Like most epidemics, obesity is most likely caused by a single etiologic agent.

Some possibilities might include a virus—after all, prior to the 1990s, who would have suspected that a bacterium causes peptic-ulcer disease? Other culprits could be an environmental contaminant that makes our receptors less sensitive to leptin, or maybe something in French fries that acts on the appetite-stimulating NPY/AGRP neurons.

H. David Stein, M.D.
Larchmont, New York

Susan Okie misrepresents the roles of two scientists, Rudolph L. Leibel and Jeffrey M. Friedman, by misstating Leibel's contributions to the new field of obesiology. She writes, "The gene for leptin was identified and sequenced as the result of an intensive collaborative effort between Leibel and his Rockefeller colleague . . . Friedman." Actually, Friedman's contributions to the study of obesity are far greater than Leibel's.

The concept of a soluble humoral factor that signals satiety to the brain was first published in 1973 by D.L. Coleman (see "Effects of Parabiosis of Obese with Diabetes and Normal Mice," *Diabetologia*, **9**:294–298, 1973). Friedman, not Leibel, had the idea to use positional cloning to isolate the gene mutation that leads to obesity and diabetes in mutant mice. He brought Coleman's exciting hypotheses to the molecular level and isolated the leptin gene. The manner in which the article describes Leibel's contribution to this landmark discovery is inaccurate.

Wolfgang Liedtke, M.D.
Duke University Medical Center
Durham, North Carolina

Susan Okie replies: I congratulate Marion Ehrlich on her success in maintaining a healthy weight. Because of differences in genetic susceptibility to obesity, however, this kind of conscious behavior change may be more achievable for some overweight people than for others.

H. David Stein's suspicion that the obesity epidemic might be caused by a single, still unidentified agent is one that some scientists share. Indeed, certain viruses have been found to induce obesity in birds or animals; the possibility that such an agent occurs in humans is an active field of research.

Wolfgang Liedtke feels that I gave too little credit to his mentor, Jeffrey M. Friedman, for the discovery of leptin. It was not my intention to offer a detailed history of recent scientific progress in the understanding of obesity, either in this article or in the chapter of my book from which it was adapted. The leptin gene was identified in a long-term collaborative project conducted at Rockefeller University by Friedman, Rudolph L. Leibel, and other investigators. The gene was identified in Friedman's laboratory by cloning and sequencing its mutant form in the obese mouse. Nevertheless, Leibel and other Rockefeller colleagues who collaborated closely with Friedman were not accorded credit as coauthors on the *Nature* paper announcing the identification of the gene.

From the Ground Up

In his article "How Trees Get High" [3/05], Adam Summers writes, "At the

(Continued on page 12)

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Time Probes

Awakening the "Dead"

30,000 B.C. — Biologists have discovered a new bacterium. True, such discoveries are made many times a month—but this bacterium was found alive in 32,000-year-old Alaskan ice. When Richard B. Hoover, a NASA astrobiologist, melted a chunk of the ice back at the lab, out swam short rods with rounded ends. Talk about longevity!

Elena V. Pikuta of NASA, along with Hoover and several other biologist colleagues, cultured the microorganism and studied its DNA and physiology. They soon learned they were dealing with a new species of the genus *Carnobacterium*. Eight other *Carnobacterium* species are known today; all are cold specialists, and all can survive either with or without oxygen. Some might even live in your fridge.

So how how did the new bacterium, dubbed *C. pleistocenium*, manage to lie dormant for so long? The answer isn't clear yet. But the discovery raises hopes that similar organisms could be found on other planets that have or once had ice (think Mars). Unlocking their secrets of dealing with the cold could lead to new methods of cryopreservation. Another, less hopeful possibility is that the warming of the globe's ice-bound regions may introduce long-dormant bacteria into today's bacterial gene pool, with unpredictable effects. (*International Journal of Systematic and Evolutionary Microbiology* 55:473–78, 2005)

—*Stéphan Reebs*

Alaskan permafrost holds some hardy surprises.

Green Tide

250,000,000 B.C. — Earth's most devastating mass extinction of the past half-billion years swept across our planet about 250 million years ago, bringing the Permian period to an end. Some estimates put the casualty rate at more than 90 percent of marine species and 70 percent of land species. So, who did the deed?

One prime suspect has been extreme "euxinia" near the surface of the ancient Tethys Sea. In euxinic seas, possibly because of shifting currents, normally bottom-dwelling sulfide moves up into the "photic zone," where oxygen-dependent photosynthesis takes place. The water soon becomes full of hydrogen sulfide and depleted of oxygen.

Sulfide is toxic to most organisms, but green sulfur bacteria thrive on it. So if photic-zone euxinia was widespread around the time of the Late Permian extinction, you'd expect to see signs of green sulfur bacteria in the rocks. Sure enough, Kliti Grice, a geochemist at the Curtin University of Technology in Perth, Australia, and her colleagues discovered that Late Permian sediments from both western Australia and southern China hold an abundance of the unique molecular fossils derived from the bacteria's odd biochemistry.

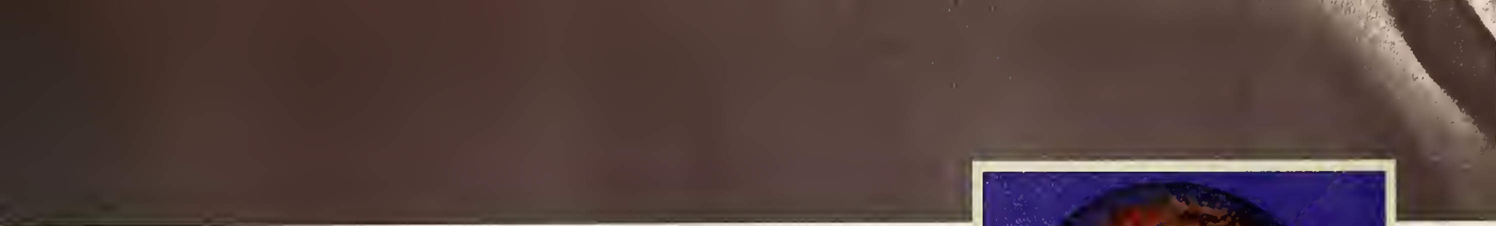
OK, euxinia may have killed off many residents of the sea. But how did it affect residents of the land? Grice's team suggests that the lapping of sulfide-laden waters onto continental shelves might have given rise to plumes of hydrogen sulfide gas that wafted across the landscape and poisoned the terrestrial species in its path. (*Science* 307:706–709, 2005) —*S.R.*

Eau de Chypre

1900 B.C. — When Cleopatra betook herself to the Mediterranean town of Tarsus at the command of Mark Antony, she is said to have perfumed the sails of her barge, causing the winds to stir his heart and herald her arrival. But archaeologists are finding evidence for the large-scale production of perfume thousands of years before the Roman republic. An ancient perfume factory, recently unearthed from a hillside in southern Cyprus, suggests that efforts to mask one's natural stink (and lure a lover) go back at least 4,000 years. The perfumery, the oldest in the Mediterranean, predates Cleopatra by two millennia.

Maria Rosaria Belgiorno, an archaeologist at the Institute of Technologies Applied to Cultural Heritage, in Rome, and her colleagues discovered the remains of the perfumery while excavating the Middle Bronze Age site Pyrgos-Mavroraki. In what was once a large industrial building, complete with textile-making equipment and an olive press, Belgiorno's team discovered a wealth of stone and clay perfume-making paraphernalia: bowls, funnels, jugs, ladles, large spouted vessels, small vials. Even more intriguing, they have extracted traces of olive-oil-based fragrances from the clay and the soil. On chemical analysis, the fragrances—bitter almond, citrus bergamot, rosemary, turpentine (aromatic pine oil, not paint thinner)—turn out to be among the essences still deployed by Cleopatra wannabes.

—*Caitlin E. Cox*



A Taste for Dinos

130,000,000 B.C. — When dinosaurs strode the Earth, early mammals were walking nearby. Until now, however, the received opinion has been that the mammals were rat-size insect eaters, discreet and nocturnal, cowering in the dark as the mighty dinosaurs struck fear into their hearts. But two complete skeletons recently discovered in the Lujiatun fossil beds of northeastern China (where many feathered dinosaurs and early birds have been discovered) have forced paleontologists to rethink that view.

Found by Yaoming Hu and his colleagues from the Chinese Academy of Sciences in Beijing and the American Museum of Natural History in New York, the larger of the two skeletons belonged to a three-foot-long mammal endowed with a squat, powerful body and a carnivore's teeth. Christened *Repenomamus giganticus* by its discoverers, the creature now ranks as the largest known mammal from the era of the dinosaurs. Nearby was the fossil of a smaller, cat-size *Repenomamus* named *R. robustus*, whose stomach provided another revelation: a neat pile of bones from a juvenile dinosaur of the genus *Psittacosaurus*.

Some early mammals liked nothing better than a dinner of dino.

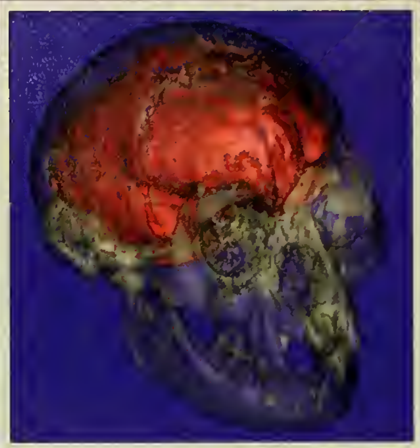
Repenomamus could have been either a scavenger or a predator, the investigators suggest. But given the paucity of modern-day mammalian scavengers (hyenas do it the most), the mammal mavens among us may be justified if we imagine *Repenomamus* on the hunt for wee live reptiles. (*Nature* 433:149–52, 2005)

—*S.R.*

Why Scramble a Good Design?

70,000,000 B.C. — Rotten eggs are bad enough when they come from chickens, so imagine the smell of a 70-million-year-old dinosaur egg. But a team of paleontologists led by Mary H. Schweitzer of North Carolina State University in Raleigh was not about to let the "petroliferous odour" keep them from examining the shells of a few astonishingly well preserved eggs deposited by the giant Argentinian dinos known as titanosaurs.

Ancient floods deposited silty mud around some clutches of the eggs, fossilizing them almost instantly. The process left the skeletal remains and even some of the soft tissues of the eggs' ill-fated embryonic contents visible in exquisite detail. Schweitzer and her colleagues were able to investigate not only the details of the eggs' structure, but also their molecular makeup and even the immunological reactions they provoked. Titanosaur eggs, they found, weren't much different from those of their closest living relatives, birds and reptiles. It seems evolution is well acquainted with rule zero of the indolent engineer: If it ain't broke, don't fix it. (*Proceedings of the Royal Society* B, DOI: 10.1098/rspb.2004.2876, 2005) —*Nick W. Atkinson*



Cast of a hobbit-size human brain

Thinker's Brain

16,000 B.C. — *Homo floresiensis*, the miniature human species discovered last October on the Indonesian island of Flores, has been much in the news. Alive as recently as 18,000 years ago, the species was contemporary with our own. And near the skeleton of a three-foot-tall *H. floresiensis* adult female, dubbed Ebu, were clues that she and her ilk had used tools and mastered fire. So Dean Falk, a paleoneurologist at Florida State University in Tallahassee, together with a multidisciplinary team of investigators, decided to see how the *H. floresiensis* brain shaped up.

Because Ebu's braincase was mostly intact, its inner surface retained an imprint of the shape of the brain as well as the positions of major blood vessels. Falk and her colleagues analyzed CT scans of the skull and used some fancy software to create a digital 3-D picture of the interior of the braincase, and they made a latex "endocast" of the organ that once occupied it. They then compared the endocast with those of apes; human forerunners, including *H. erectus*; normal modern females; a pathologically small-brained modern human; and a pygmy.

Ebu's chimp-size brain was most similar to the brains of *H. erectus* and normal *H. sapiens*. Tellingly, a structure called the lunate sulcus was pushed toward the back of her brain, as it is in *H. sapiens*'s, leaving more space for areas involved in advanced association, forward planning, and problem solving. (*Science* DOI: 10.1126/science.1109727, 2005) —*S.R.*

("Samplings" continues on page 24.)

LETTERS

(Continued from page 9)
tubes, the water evaporates into spaces within the trees' leaves . . . ." The xylem tubes, however, are not open. They end blindly in the leaf, surrounded by chlorenchyma cells. The cell walls in the xylem and chlorenchyma cells have pores only a few nanometers wide. Water reaches the intercellular spaces in the leaves through these pores.

The water forms menisci, or curved surfaces, at the openings of the pores in the cell wall. It is from those menisci that the water in the xylem tubes hangs. Because the menisci are so small, they can stand the pull created by a hundred-meter-high column of water and prevent air from entering the column.

Halvard Baugerød
Norwegian University of Life Sciences
Ås, Norway

Cloud Nine

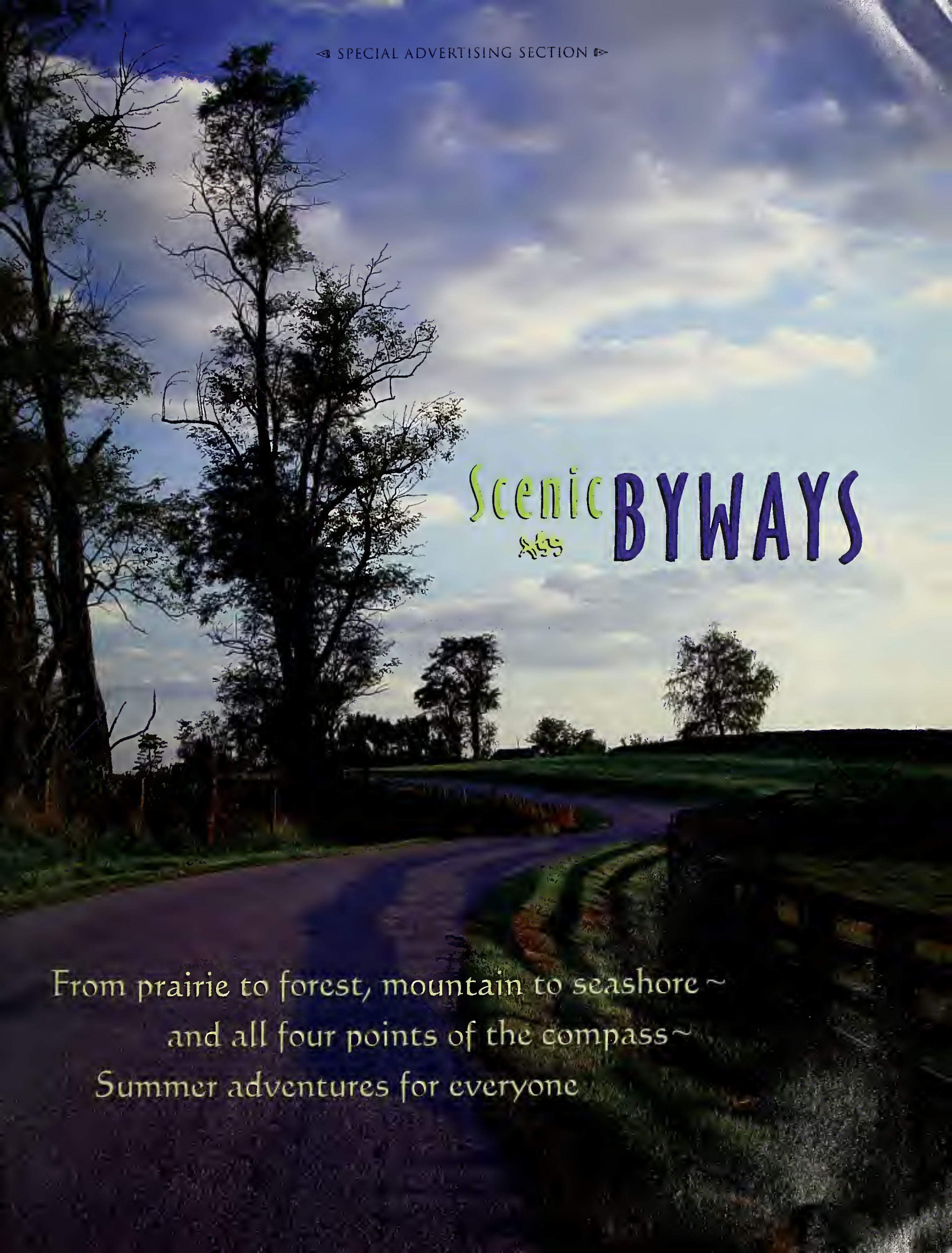
Having just read "Send In the Clouds," [12/04–1/05] by Neil deGrasse Tyson, I knew it was time to send a long-overdue letter. Mr. Tyson writes the most informative and easy to understand column I have ever read on a subject that should be almost impossible to fathom to a layperson like myself. Thank you, Mr. Tyson, for always teaching me something with your incredible monthly columns.

Jeanne Riggall
Atlanta, Georgia

Amendment

Robert H. Mohlenbrock's statement in "Peak Experience" [3/05] that there are no representatives of the burseraceous plants in temperate North America was incorrect. Plants in this genus, such as *Bursera microphylla* (also known as the elephant tree), occur in California and Arizona, as well as other places in the United States.

Natural History *welcomes correspondence from readers* (nhmag@naturalhistorymag.com). *All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*



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Philippe Delisle

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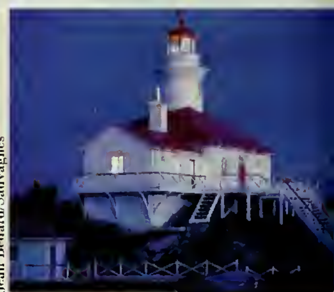
Philippe Delisle



Jean Bédard/Sauvagiles

Pierre Rambaud/Le Cyclope

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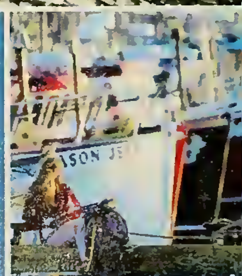

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LE QUÉBEC MARITIME

Nova Scotia

Scenery ~ and More ~ in Nova Scotia

Nowhere on earth are the tides higher — or swifter — than in Nova Scotia's Minas Basin, on the Bay of Fundy's eastern extremity. And no time's better than summer to experience this gift of nature. Hikers who make the two-hour trek to Cape Split, a narrow grassland lined by jagged cliffs overlooking the Bay, are rewarded by the sight of a turbulent tide rushing over ocean ridges below . . . then pausing before ebbing in the opposite direction.

On the Parrsboro shore, the site of the biggest fossil find in North America, beachcombers gather semi-precious agates and sparkling amethysts at low tide. Not surprisingly, Parrsboro's Nova Scotia Gem and Mineral Show draws visitors from around the world each August. Serious dinosaur fans will delight in a visit to nearby Joggins Area Fossil Cliff, an internationally recognized palaeontological site with an abundance of 100-million-year-old fossilized plants and dinosaur bones.

For inspiring and diverse land and seascapes—plus whale and bald eagle sightings—the rugged coastline-hugging Cabot Trail is one of the world's most scenic drives. Along the way, stop at Cape Breton Highlands National Park, one of Canada's most exceptional wilderness and hiking regions, for pristine landscapes and a bit of moose-spotting. Water sports enthusiasts can sail the gentle, fog-free coves and wooded shore of Bras d'Or Lakes, or scuba dive to discover unique sinkholes rich in ecological diversity. A visit to Christie Brook and Falls near Bible Hill in the East District offers a perfect picnic or swimming spot, with its waterfall dropping to a crystal-clear swimming hole surrounded by shallow caverns and looming cliffs.

Top: Whales off the coast; above: Cabot Trail; left: Bay of Fundy

Summer in Nova Scotia offers sports and nature lovers a wide variety of activities to choose from. At Kejimkujik National Park, a natural Historic Site of Canada, 91 kilometers of trail wind through untouched forests, rivers and lakes. Do bring extra film for a visit to Peggy's Cove, surrounded by spectacular glacial deposits of barren rock and granite boulders, to capture the view... and the Nova Scotia spirit.

Pennsylvania

The Great Pennsylvania Wilds

When summer comes to Pennsylvania, urban pleasures take a backseat to an unlimited number of outdoor adventures. Gaze at stars, gaze at elk—or both. Camp in wilderness glens, fish in rushing streams, hike or bike far from city cares . . . or spend days exploring forests and nature preserves untouched by time.

With more than 2 million acres of rambling rivers, scenic streams and wild forest, the Pennsylvania Wilds are a natural treasure—and home to the largest free-roaming elk herd in the northeast. Elk-watching central is the town of Benezette, with a herd of 800 . . . and counting (not to mention courting, particularly in late summer and early fall). Last year saw the inauguration of the Elk Scenic Drive, a 127-mile corridor winding through three state forests and three state game lands. A large portion of the Elk Scenic Drive includes two official Scenic Byways: Route 144 through Sproul State Forest and Route 120 from Renovo to Driftwood.

One of America's most picturesque highways is Route 6, stretching more than 400 miles across northern Pennsylvania. For stargazers, Cherry Springs State Park is home to the darkest skies in the northeastern United States. The 46-acre Park, located within the Susquehannock State Forest, has a 360-degree view of the sky and zero light pollution for optimum viewing of stars and planets. Cherry Springs has been designated by astronomers as the northeast's only Official Dark Sky Park.

Route 6 is also a key route for those who want to swim, water ski or boat on 13-mile Lake Wallenpaupack; hike, bike or take in the views at the Delaware Water Gap National Recreation Area or visit breathtaking Pine Creek Gorge, a spectacular site 50 miles long and 1,400-feet deep. Hike the 42-mile Pine Creek Rail Trail, fish for trout, raft the rapids, canoe or simply soak up the scenery. Route 6 will also take you to the 500,000 wilderness acres of the Allegheny National Forest, with more than 1,000 miles of trails for hiking, biking or horseback riding.

Top to bottom: Free-roaming elk dot the valleys and moutains of Benezette. Warm summer days attract hikers, bikers and kayakers in Pine Creek Gorge. Cherry Springs State Park's dark skies provide a canvas for nature's light shows.

You just can't make a wrong turn in Pennsylvania.
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New York State

Commemorating the War That Launched a Revolution

When the French and Indian War began 250 years ago, few could predict its powerful historical significance. Today, the five-year conflict is acknowledged to have established the British colonial dominance on the East Coast of America, setting the scene for the Revolutionary War to come, and altering the history of this country and the world in its wake.

New York State will be commemorating the 250th anniversary with a comprehensive series of historic battle reenactments at pivotal sites and communities across the state from 2005 to 2010. History buffs will have a significant number of festivals, reenactments, 18th-century encampments and educational programs to choose from, all held in some of the nation's most scenic settings.

The landscape is little changed from 1754, when a young George Washington, serving under the British flag, was sent to evict the French from frontier territories. His failure to do so ignited a war, which quickly spread out across the colonies and into Canada, between France, Britain, and the American Indian nations that were struggling to preserve control of their lands. As a result, the ultimate fate of North America was decided and seeds planted for the American Revolution.

New York's unprecedeted series of reenactments and encampments will begin in June with the Grand Encampment of the French and Indian War in Fort Ticonderoga, a large-scale two-day reenactment with military camps, settlers, drills and battles. In July, another encampment will recreate the 1759 Siege of Fort Niagara in Youngstown, featuring children's activities along with battle demonstrations and artillery demos. In August, a battle reenactment will be held at the Old Fort Ontario State Historic Site in Oswego to commemorate the founding of Fort Ontario in 1755. There will be full-scale British, Colonial, French and Native American military camps with demonstrations of camp life and 18th century merchants. And a September highlight will be a reenactment of the 250th anniversary of the Battle of Lake George at Lake George Battlefield Park.

Photos courtesy of Fort Ticonderoga

Top: Members of the British Inniskilling Regiment fire into the opposing French forces at Fort Ticonderoga's Grand Encampment of the French and Indian War; above: In a field overlooking Lake Champlain, battles occur each day between British and French forces during Fort Ticonderoga's Grand Encampment of the French and Indian War

For a full listing of New York State commemorative activities, contact **www.iloveny.com**.

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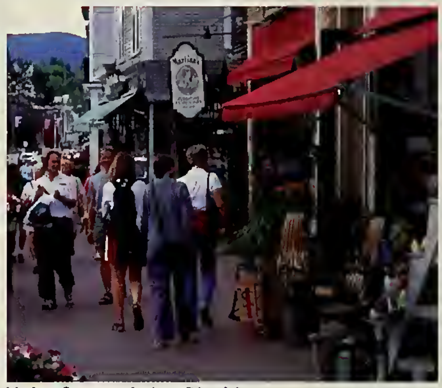
Lake Placid

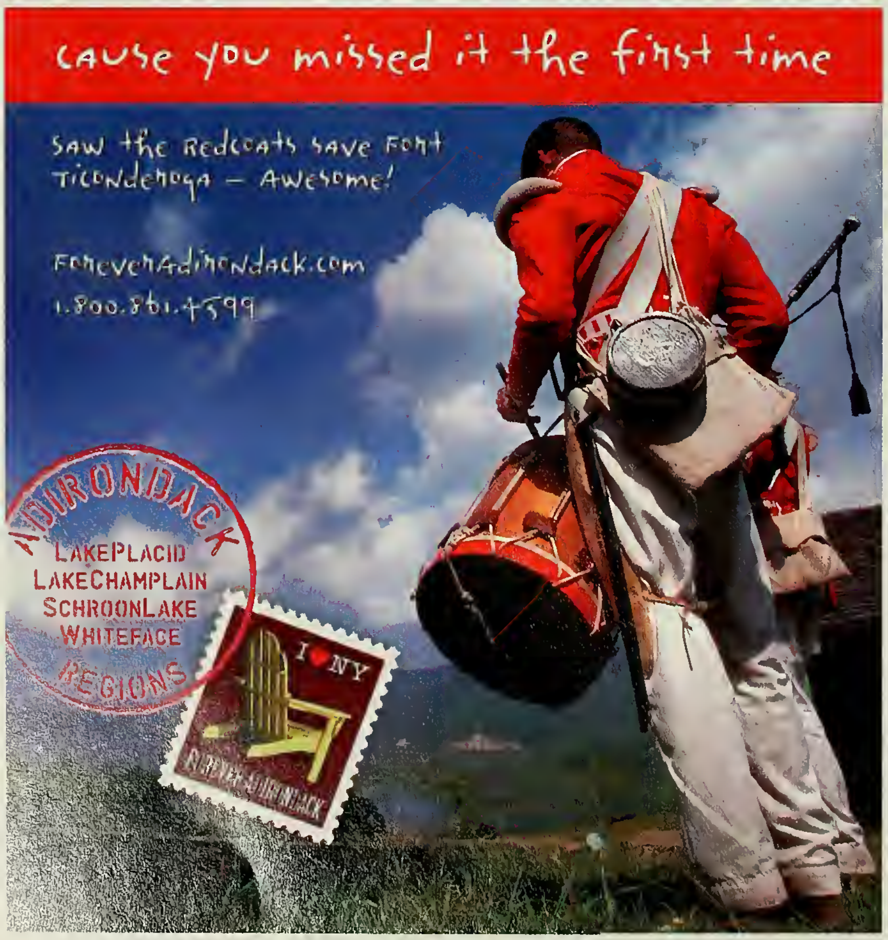
Lake Placid Summer: Scenery, Sports and History

Overlook of Lake Placid



Main Street, Lake Placid

Sports fans know Lake Placid as the site of the Winter Olympic Games in 1932 and 1980—only one of three towns worldwide to have hosted two Winter Olympics. But savvy oudoors lovers know Lake Placid and Essex County as key destinations for summer fun, with glorious mountain and water views providing the backdrop for a plethora of al fresco activities.



Home to the majority of the Adirondack High Peaks, Essex County boasts three don't-miss scenic drives—the 170-mile Olympic Trail, from Great Lake Ontario to Lake Placid and Lake Champlain; the Route 73 Byway, which winds past the Adirondack's highest peaks and some of its most picturesque waters; and the Whiteface Mountain Veterans' Memorial Highway, a spectacular mountaintop drive.

In Lake Placid, summer pasttimes include antiquing, visits to the Winter Olympic Museum, historic sites, and scenic boat tours of the lake. Founded in 1765 and with one of the finest collections of Federal and Greek Revival architecture in New York, Essex Village is listed on the National Register of Historic Places, with well-preserved 19th century homes, inns and shops.

Summer is hiking time in the region. Popular trails include High Falls Gorge with the Ausable River's 600 feet of cascading waterfalls, Hurricane Mountain's exceptional views of Lake Champlain and the High Peaks with Mount Marcy, at 5,344 feet it's New York's highest peak. Gentle rambles or challenging terrain—take your pick!

Nebraska

Nebraska Rocks!

Courthouse and Jail Rocks near Bridgeport

Witness an ancient mystery at Hudson-Meng Bison Bonebed

Nearly 65 million years ago, the land now known as Nebraska rolled beneath a giant inland sea, leaving a legacy of silt, sand, fossils, and extraordinary land formations. Today, these otherworldly outcroppings reveal astonishing cross sections of Great Plains geological history.

Take a trip to the panhandle of Nebraska to experience rugged buttes, badlands, and spires. Here you'll find Chimney Rock—the most mentioned geological formation in pioneer journals—as well as Courthouse and Jail Rocks. In the northern part of the panhandle, be sure to see the lunar-like landscape at Toadstool Park.

Called the Pompeii of prehistoric animals by *National Geographic*, Ashfall Fossil Beds State Historical Park near Royal features ancient rhinos and tiny ancestral horses engulfed by volcanic ash 12 million years ago.

You can also tour Hudson-Meng Bison Bonebed near Crawford, where 600 bison perished 10,000 years ago. Or visit Agate Fossil Beds National Monument near Harrison, where you'll find Miocene paleontology exhibits and American Indian artifacts.

Lincoln's University of Nebraska State Museum of Natural History features one of the world's premier collections of fossil elephants. You'll also experience a hands-on discovery center, Nebraska fossils, American Indian and African exhibits, dinosaurs, and wildlife dioramas.

Whether the outcroppings of today catch your eye or the fossilized reminders of yesterday tickle your fancy, Nebraska rocks!

Time Probes

Wear and Tear

A.D. 1000 — For millions of years before the invention of bulldozers, ox-pulled ploughs, rotary tillers, and steam shovels, Earth's skin was eroded at a slow, steady pace by wind, water, and natural chemical change. Now that people have taken over the planet, the pace has picked up alarmingly.

Human activity has become the prime agent of erosion.

According to Bruce H. Wilkinson, a geologist at the University of Michigan in Ann Arbor, agricultural and construction activity is now eroding rock, soil, and sediment at about fifteen times the overall rate of erosion caused by natural processes. Across the globe, farming now erodes soil about twenty-eight times faster than the combined effects of all natural processes during the past 500 million years. Wilkinson calculates that, on its own, weathering by wind, water, and chemistry stripped away nearly eighty feet of land surface, on average, every million years. Enter *Homo sapiens*, and the ground becomes festooned with farms, orchards, pastures, houses, public buildings, roads, canals, parking lots, airports, and on and on. If you imagine all the human-caused denudation spread equally across all the ice-free land on Earth, you're looking at an average net loss of 1,200 feet per million years. At that rate, the lost rock and soil would fill up the Grand Canyon in about half a century.

Toward the end of the first millennium A.D., Wilkinson estimates, people surpassed nature as the major force shaping Earth's surface. Soil, in particular, is now being lost more rapidly than it is being formed. In fact, the great disparity between the rates of natural and human erosion may make current agricultural practices unsustainable. (*Geology* 33:161–64, 2005) —*Dave Forest*

Not Jurassic Park?

68,000,000 B.C. — Intentionally breaking bones isn't standard operating procedure for a paleontologist. But there was no other way to get the thighbone of a recently excavated 68-million-year-old *Tyrannosaurus rex* fossil from a remote part of Montana to a laboratory. So John R. Horner of the Montana State University–Bozeman and his colleagues, who discovered the specimen in 2003, gave in to the inevitable—and now they're thrilled they did.

Fossils form gradually, as minerals from soil, rocks, and water replace the chemical constituents of long-dead bodies. The result is a rock-solid copy—except when it isn't, as Horner, Mary H. Schweitzer, and two other paleontologists were startled to find.

Under Schweitzer's supervision, the fossilized femur was given a soaking to remove the minerals. Astonishingly, the investigators saw translucent blood vessels waving in the acid bath. Soft tissue, still flexible, had been preserved in the thick bone. And some of the vessels retained cell-like structures, complete with what looked very much like cell nuclei.

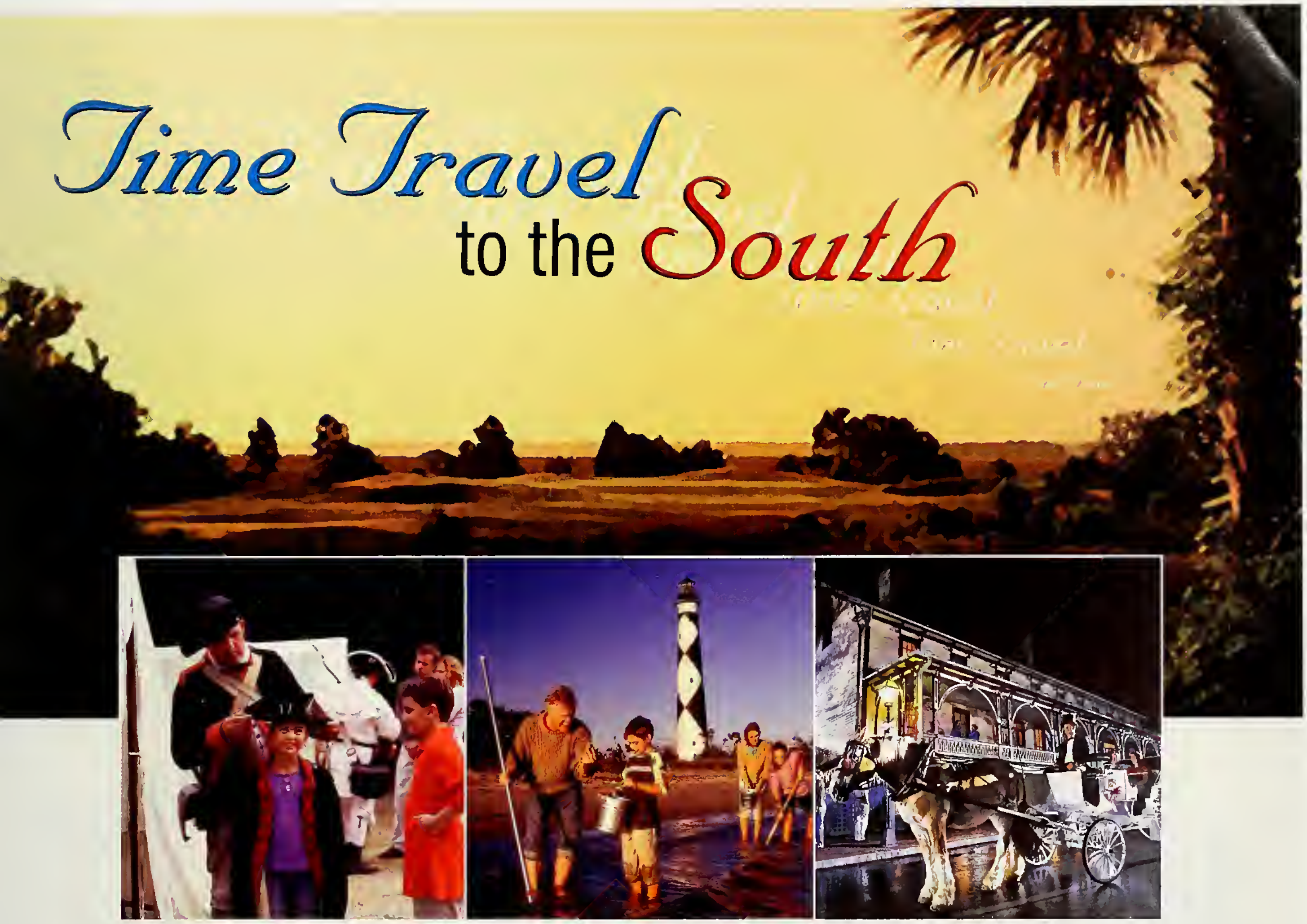
Have the investigators come across a new kind of molecule-swapping process? Might some of the original molecules (proteins, even DNA) be intact? Ongoing tests will tell. (*Science* 307:1952–55, 2005) —*S.R.*

Rosy Past

11,000,000,000 B.C. — In the universe, as in Rome, ancient history is all around us. The cosmic microwave background, which formed as soon as the young universe had cooled down enough for electrons and protons to bind, bathes us all in radiation that left its source almost 14 billion years ago. The light of distant galaxies, "redshifted" by the expansion of the universe since the big bang, shows the galaxies as they were many billions of years ago. In fact, if you're looking for old, look for red: it signals that the light source is very distant and very ancient.

Christopher R. Mullis, an astronomer at the University of Michigan in Ann Arbor, and his colleagues have been following the motto "The redder the better." Searching telescopic archives for as-yet-unstudied diffuse X-ray smears (rather than points) populated by ruddy blobs, they came up with a list of candidates, booked some time on the European Southern Observatory's Very Large Telescope in northern Chile, and presto! they discovered the most distant massive object ever observed. It's a colossal, fully formed, 2-billion-year-old galaxy cluster lying 9 billion light-years from Earth. Add its age to its distance, and you're looking at a galaxy cluster that formed 11 billion years ago, less than 3 billion years after the big bang. Apparently the young universe grew up much more quickly than cosmologists had thought it could. P.S. The new cluster has as much mass as several thousand Milky Ways. (*The Astrophysical Journal*, arxiv.org/abs/astro-ph/0503004, 2005) —*T.J. Kelleher*

Galaxy clusters matured surprisingly early in cosmic history.



This year take a trip through time when you visit the many unique historical attractions throughout the Southeast.

From mountains to sea, the South is rich in history and culture. It's not surprising, given that this region is home to the earliest European settlements in the country, with a heritage that stretches back centuries into Native American and prehistoric past.

Pick any period of our past and Virginia offers a variety of fascinating historic attractions. From Williamsburg, Yorktown and the birth of our nation to Richmond, Danville and the re-enactments of the Civil War – from the days of Daniel Boone and the Wilderness Trail in Southwest Virginia to remembering the fallen at D-Day – Virginia's attractions span America's history.

Just to the south, North Carolina serves up culture and history with its own friendly flair. Whether visiting lighthouses along its beautiful coast or traveling the scenic Blue Ridge Parkway, you'll find yourself slowing down just a bit. And after all, isn't that part of what a getaway is all about?

Could You Have Survived?

In celebration of the 400th anniversary of the first English-speaking settlement in the New World, Virginia launched an interactive game that challenges players to survive the Jamestown Settlement of 1607.

Since only 12 percent of the original settlers survived, the game promises to be challenging. Test yourself at **www.Jamestown1607.org**

Clockwise From Top: Many points of historic interest dot the landscape of South Carolina's Lowcountry; Jonesborough, Tennessee, a National Trust for Historic Preservation 2005 Distinctive Destination; Cape Lookout Lighthouse along North Carolina's Crystal Coast; Yorktown, Virginia brings history to life.

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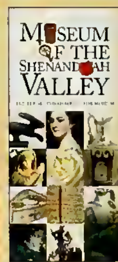

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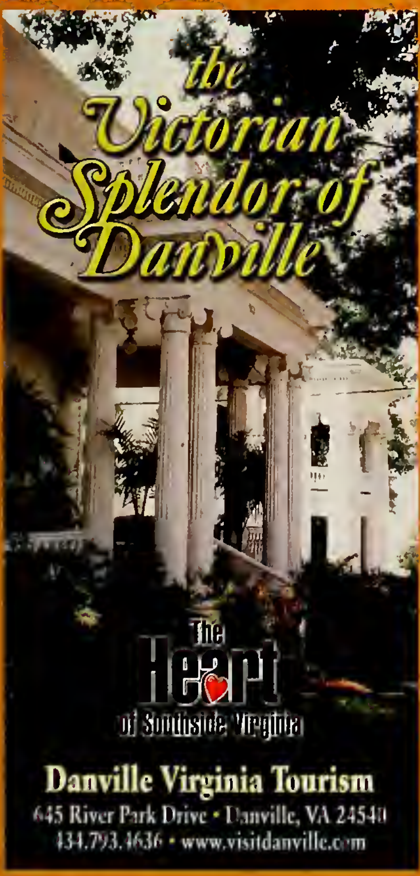

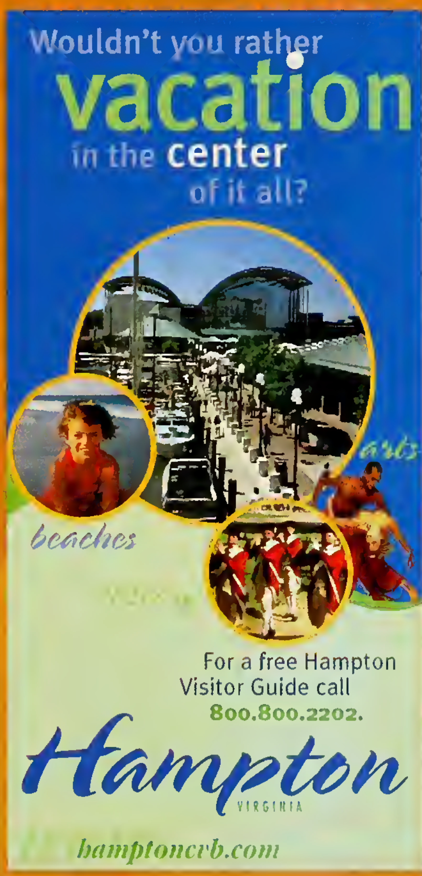


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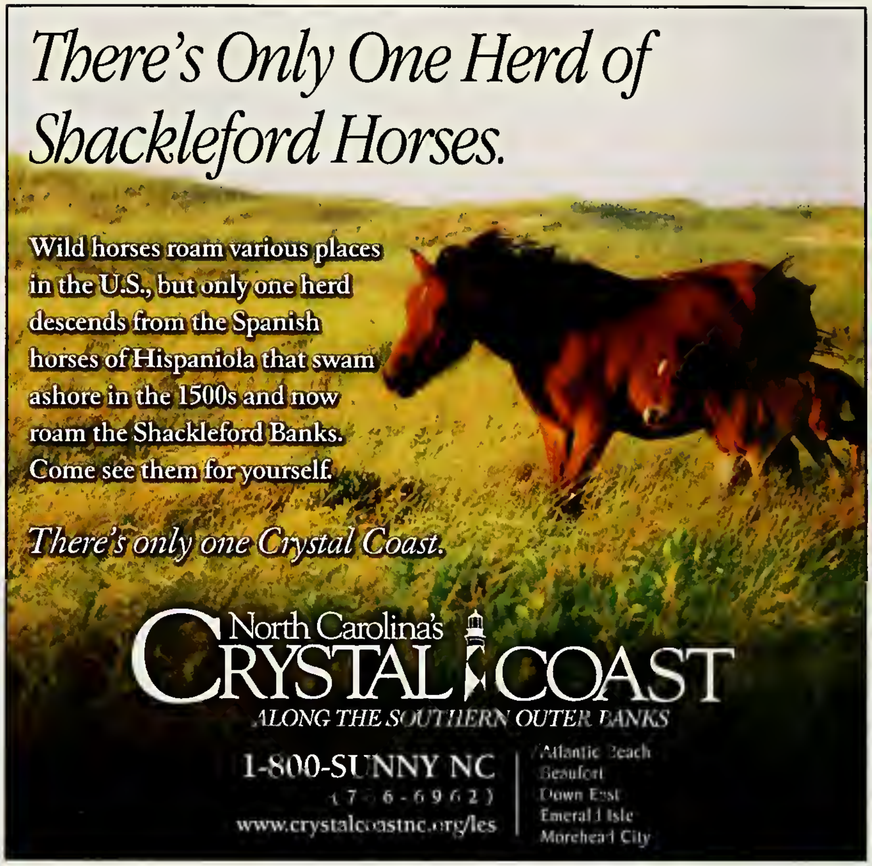
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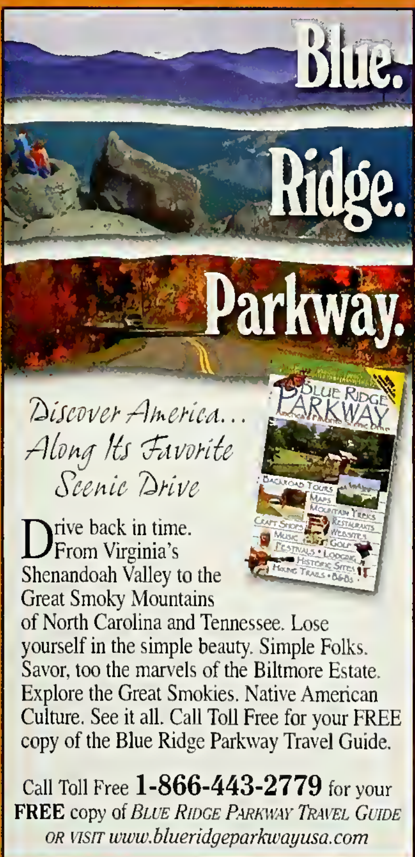
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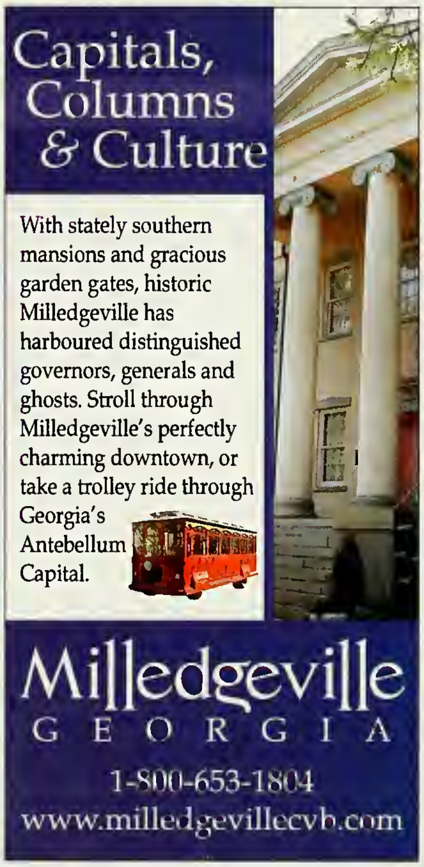
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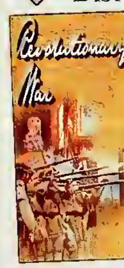

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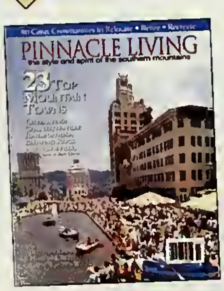

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UNIVERSE

Knock 'Em Dead

How does one extinguish life on Earth? Let me count the ways.

By Neil deGrasse Tyson

Ever since dinosaur bones were discovered, scientists have proffered no end of explanations for the disappearance of the hapless critters. Maybe a torrid climate dried up the available sources of water, some say. Maybe volcanoes covered the land in lava, poisoned the air, and brought on an ice age. Maybe too many early mammals dined on too many dino eggs, or the meat-eating dinosaurs ate up all the vegetarian ones. Maybe the need to find water led to massive migrations that spread diseases. Maybe the real problem was a reconfiguration of landmasses, caused by tectonic shifts. All these crises have one thing in common: the scientists who came up with them were well trained in the art of looking down.

Other scientists, however, trained in the art of looking up, began to make connections between Earth's surface features and the visits of vagabonds from outer space. Maybe meteor impacts generated some of those features, such as a bowl-shaped depression nearly a mile wide in the Arizona desert. In the 1950s at the big bowl, the American geologist Eugene M. Shoemaker and his associates discovered a kind of rock that forms only under extremely high pressure—the kind of pressure only a meteor can deliver. Geologists could finally agree that an impact caused the bowl (now called Meteor Crater). Shoemaker's discovery also resurrected the nineteenth-century concept of catastrophism—the idea that changes to our planet's skin can be caused by brief, powerful, destructive events.

Once the gates of speculation opened, people began to wonder whether the dinosaurs might have disappeared at the hands of a similar, but bigger, assault. Meet iridium: a metal rare on Earth but common in metallic meteorites, and conspicuous in a 65-million-year-old layer of clay that occurs at scores of sites around the world. That clay, dating to about the same time as the dinos checked out, marks the crime scene: the end of the Cretaceous. Now meet Chicxulub Crater, a 120-mile-wide depression at the edge of Mexico's Yucatán Peninsula. It, too, is about 65 million years old.

Case closed? Perhaps not.

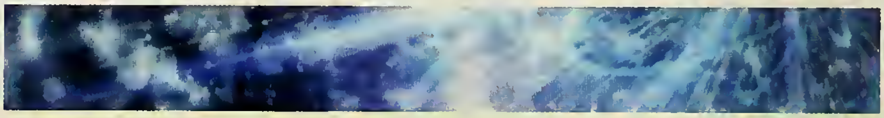
Scientific inquiry shouldn't stop just because a reasonable explanation has apparently been found. Some paleontologists and geologists remain skeptical about assigning Chicxulub the lion's share—or even a substantial share—of responsibility for the dinos' departure. Some think Chicxulub may have significantly predated the extinction. Furthermore, Earth was volcanically busy at about that time. Plus, other waves of extinction have swept across Earth without leaving craters and rare cosmic metals as calling cards. And not all bad things that arrive from space leave a crater. Some explode in mid-air and never make it to Earth's surface.

So, besides impacts, what else might a restless cosmos have in store for us? What else could the universe send our way that might swiftly unravel the patterns of life on Earth?

Several sweeping episodes of mass extinction have punctuated the past half-billion years on Earth. The biggest are the Ordovician, about 440 million years ago; the Devonian, about 370 million; the Permian, about 250 million; the Triassic, about 210 million; and, of course, the Cretaceous, about 65 million. Lesser extinction episodes have taken place as well, at timescales of tens of millions of years.

Some investigators pointed out that, on average, an episode of note takes place every 25 million years or so. People who spend most of their time looking up are comfortable with phenomena that repeat at long intervals, and so astrophysicists decided it was our turn to name some killers.

Let's give the Sun a dim and distant companion star, a few up-lookers said in the 1980s. Let's declare its orbital period to be about 25 million years and its orbit to be extremely elongated, so that it spends most of its time too far from Earth to be detected. This companion would discombobulate the Sun's distant reservoir of comets whenever it passed through their neighborhood. Legions of comets would jiggle loose from their stately orbits in the outer solar system, and the rate of impacts on Earth's surface would vastly increase.



In 7 billion years the Milky Way and the Andromeda Galaxy may collide, causing a cosmic train wreck.

Therein was the genesis of Nemesis, the name given to this hypothetical killer star. Subsequent analyses of the extinction episodes have convinced most experts that the average time between catastrophes varies too greatly to signify anything truly periodic. But for a few years the story was big news.

Periodicity wasn't the only intriguing idea about death from outer space. Pandemics were another. The late English astrophysicist Sir Fred Hoyle and his longtime collaborator Chandra Wickramasinghe, now at Cardiff University in Wales, pondered whether Earth might occasionally pass through an interstellar cloud laden with microorganisms, or be on the receiving end of similarly endowed dust from a passing comet. Such an encounter might give rise to a fast-spreading illness, they suggested. Worse yet, some of the giant clouds or dust trails might be real killers—bearing viruses with the power to infect and destroy a wide range of species. Problem is, it's not clear how an interstellar cloud could manufacture and carry something as complex as a virus.

You want more? Astrophysicists have imagined a nearly endless spectrum of awesome catastrophes. Right now, for instance, the Milky Way Galaxy and the Andromeda Galaxy, a near twin of ours 2.4 million light-years up the road, are falling toward each other. In about 7 billion years they may collide, causing the cosmic equivalent of a train wreck. Gas clouds would slam into one another; stars would be cast hither and yon. If another star swung close enough to confound our gravitational allegiance to the Sun, our planet could get flung out of the solar system, leaving us homeless in the dark.

That would be bad.

Two billion years before that hap-

pens, however, the Sun itself will swell up and die of natural causes, engulfing the inner planets—including Earth—and vaporizing all their material contents.

That would be worse.

And if an interloping black hole comes too close to us, it will dine on the entire planet, first crumbling the solid Earth into a rubble pile by virtue of its unstoppable tidal forces. The remains would then be extruded though the fabric of space-time, descending as a long string of atoms through the black hole's event horizon, down to its singularity.

But Earth's geologic record never mentions any early close encounters with a black hole—no crumbling, no eating. And given the number of neighborhood black holes and their rate of formation, I'd say we have more pressing issues of survival before us.

How about getting fried by waves of high-energy electromagnetic radiation and particles, spewed across space by an exploding star?

Most stars die a peaceful death, gently shedding their outer gases into interstellar space. But one in a thousand—the star whose mass is greater than about seven or eight times that of the Sun—dies in a violent, dazzling explosion called a supernova. If we found ourselves within thirty light-years of one of those, a lethal dose of cosmic rays—high-energy particles that shoot across space at almost the speed of light—would come our way.

The first casualties would be ozone molecules. Stratospheric ozone (O_3) normally absorbs damaging ultraviolet radiation from the Sun. In so doing, the radiation breaks the ozone molecule apart into oxygen (O) and molecular oxygen (O_2). The newly freed oxygen atoms can then join forces with other oxygen molecules, yielding ozone once again. On a normal day, solar ultraviolet rays destroy Earth's ozone at the same rate as the ozone gets replenished. But if there were an overwhelming high-energy assault on our stratosphere, the ozone would be destroyed too fast—leaving us in desperate need of sunblock.

Once the first wave of cosmic rays took out our defensive ozone, the Sun's ultraviolet would sail clear down to Earth's surface, splitting oxygen and nitrogen molecules as it went. For the birds, mammals, and other residents of Earth's surface and airspace, that would be bad news indeed. Free oxygen atoms and free nitrogen atoms would readily combine. One product would be nitrogen dioxide, a component of smog—which would darken the atmosphere and cause the temperature to plummet. A new ice age might dawn even as the ultraviolet rays slowly sterilized Earth's surface.

But the ultraviolet blasted in every direction by a supernova is just a mosquito bite compared to the gamma rays let loose from a hypernova.

At least once a day, a brief burst of gamma rays—the highest of high-energy radiation—unleashes the energy of a thousand supernovas somewhere in the cosmos. Gamma-ray bursts were accidentally discovered in the 1960s by U.S. Air Force satellites, launched to detect radiation from any clandestine nuclear-weapons tests the Soviet Union might have conducted in violation of the 1963 Limited Test Ban Treaty. What the satellites found instead were signals from the universe itself.

At first nobody knew what the bursts were or how far away they took place. Instead of clustering along the plane of the Milky Way's main disk of stars and gas, they came from every direction on the sky—in other words, from the entire cosmos. Yet surely they had to be happening nearby, at least within a galactic diameter or so from us. Otherwise, how was it possible to account for all the energy they registered here on Earth?

In 1997 an observation made by an orbiting Italian X-ray telescope settled the argument: gamma-ray bursts are extremely distant extragalactic events, perhaps signaling the explosion of a single supermassive star and the attendant

(Continued on page 70)

NATURALIST AT LARGE

Bringing Up Baby

The evidence mounts that some dinosaurs were attentive parents.

By David J. Varricchio

Troodon, a six-foot-long carnivorous dinosaur, broods its clutch of eggs. The artist's reconstruction is based on excavations of fossils in Montana, dating from about 75 million years ago. The eggs in the nest are half buried, a pattern intermediate to that of Troodon's closest living relatives: crocodilians bury their eggs completely, whereas nearly all birds leave them exposed.

In Montana, the summer of 1993 barely existed. It snowed in June and August, and in between there was plenty of cold rain. On ground normally baked hard and dry by the summer sun, I had my first and only badland encounters with salamanders and turtles. For me and my colleagues from Montana State University–Bozeman, the rain also made a mess of our paleontological pursuits, turning the mudstone we were quarrying into its gloppy namesake and preventing glue from holding fossil fragments together. Finally, kept from digging, we prospected for new fossils.

As I picked my way along a relatively firm sandstone ledge, surveying the slippery mudstone, a wet, shiny fossil grabbed my attention. From my fossil-hunting experience in the preceding four summers, I knew it belonged to *Troodon formosus*, a six-foot-long member of the group of dinosaurs, mainly carnivorous, known as theropods. The theropods include such charismatic extinct animals as *Tyrannosaurus rex*, as well as the only surviving dinosaurs—the birds. This *Troodon* was an adult whose bones were still partly articulated, or joined together, a prize compared to the scattered and jumbled remains we were used to finding.

But an even bigger prize was in store. As soon as the rains subsided, we began digging. Beneath the right leg of the animal lay a clutch of at least eight eggs. Was this juxtaposition purely accidental, a result of the vagaries of fossil deposition? Or was it significant? The eggs were of a type ascribed, in the literature of the time, not to *Troodon*, but to a somewhat smaller, herbivorous dinosaur, *Orodromeus*. That identification had been based on the only clutch of such eggs ever found with embryonic remains. (Fossilized embryos are rarely discovered, because their bones only begin to ossify late in development.) Was our *Troodon* caught in the act of raiding an *Orodromeus* nest? Or could the earlier clutch have been misidentified—in which case our find would reflect a parent looking after its own eggs? We could only wonder.

Meanwhile, more than 8,000 miles away in Mongolia, another egg surprise was cooking. Back in the 1920s, explorers from the American Museum of Natural History, in New York City, had discovered clutches of fossil eggs in the Gobi Desert. The explorers had attributed them to the herbivorous dinosaur *Protoceratops*, the most common species in the fossil beds. Their prospecting later turned up a carnivorous theropod dinosaur on top of a clutch of the same eggs, and—drawing what seemed to be the obvious conclusion—they had named it *Oviraptor*, "egg stealer." Now, in 1993, on a new American Museum expedition, paleontologist Mark A. Norell was discovering that both of the previous conclusions were wrong.

As any aficionado of dinosaurs has heard by now, what Norell and company found was a fossil embryo preserved in a supposed *Protoceratops* egg—except that the embryo was an *Oviraptor*. The original identification of the eggs was incorrect. Moreover, poor *Oviraptor*, maligned as an egg stealer, was apparently brooding its own nest, as subsequent discoveries by American Museum and Sino-Canadian expeditions have confirmed. Clearly these dinosaurs, at least, cared for their eggs.

The new find in the Gobi, and the subsequent rehabilitation of *Oviraptor's* image, encouraged me to take a closer look at our own *Troodon* fossil for clues of parental care. As I've pursued that whodunit, new material that may demonstrate parental care in yet other fossil dinosaurs has come to light. Paleontologists have long attributed the evolutionary successes of mammals to a variety of features, but a critically important one has been parental care. After all, the name of the group comes from the mammary glands, the organ virtually synonymous with parental care. But the new dinosaur discoveries suggest that perhaps it's time we stopped looking down our mammalian noses at the creatures that didn't survive the Cretaceous mass extinction.

As early as 1979, John R. ("Jack") Horner, also of Montana State University–Bozeman, proposed the radical idea that some dinosaurs not only attended their eggs but cared for their young as well. In western Montana, along the Rocky Mountain Front, Horner's team had uncovered grapefruit-size eggs and two groups of young of a new herbivorous species of hadrosaur, or duck-billed dinosaur, which they named *Maiasaura*. The fossilized young were contained in bowl-shaped sedimentary structures, which he interpreted as nests. One of the groups was intermixed with the fossils of broken eggshells. Judging by the size of the animals—only eighteen inches long—compared with the eggs, these *Maiasaura* offspring had been either embryos close to hatching or newly hatched young. The young in the second group were substantially older individuals, each about three feet long.

Horner concluded that these *Maiasaura* young had remained nest-bound and dependent on adults for food. His argument was supported by what he found when he looked at the fossils under the microscope. The ends of the limb bones had been cartilaginous at the time of death. Such immature limbs would have been too weak for the young animals to have run about on their own. Similar growth patterns occur in the nest-bound young of some birds.

Horner argued that dinosaurs were not the cold-blooded (in the emotional as well as thermal sense), uncaring parents they had previously been assumed to be. But his break with orthodoxy meant that his evidence would be disputed. At the time, paleontologists were stuck in a reptilian perspective on dinosaurs. Few had considered that dinosaur reproduction might better reflect that of crocodilians and birds, the extinct dinosaurs' closest living relatives.

Both crocodilians and birds exhibit fairly extensive parental care. Crocodilians guard their nests, help their young to hatch, and even protect them during early development. Many familiar birds, such as the backyard robin, feed their young. There is also a wide range of birds, from chickens to ostriches, whose young are able to feed on their own as soon as they are hatched, but which still depend on their parents for protection.

By the early 1990s, Horner's ideas had gained a more receptive audience. When the news broke about *Oviraptor* and its misidentified eggs, our suspicions about our own fossil grew. Step one was to reevaluate the identification of the eggs. Fortunately, during the previous summers we had amassed the largest known sample of *Troodon* remains anywhere, from a rich bone bed discovered by Horner [*see "The Birthday Site," by David J. Varricchio, April 1997*]. Armed with this new material, we examined the original embryos.

The *Orodromeus* identification had indeed been mistaken: our eggs belonged to *Troodon*. In hindsight, several factors had contributed to the earlier error. One was the prevalence of *Orodromeus* fossils near the eggs that contained the embryos (a false lead, as in the case of *Protoceratops* and *Oviraptor*). Another factor was the earlier paucity of good *Troodon* material for comparison with the embryos. And finally, because the embryos had poorly developed teeth, they lacked the most characteristic *Troodon* feature—teeth with unusually large and distinctive serrations.

Another piece of the *Troodon* puzzle fell into place the following summer. In western Montana, about seventy miles south of our 1993 *Troodon* find, we came upon a complete clutch of twenty-four *Troodon* eggs. The eggs rested nearly vertically in the ground, the upper portions within a soft mudstone and the bottoms within soil that over the ages had hardened into a limestone. Our awls and ice picks easily stripped away the mudstone but were completely ineffectual against the limestone. After we worked around the eggs, we were left with a shallow bowl of limestone with a raised rim—the remains of a *Troodon* nest built some 75 million years ago. The structure suggests an open nest with the upper parts of the eggs exposed, and brooding by an attending adult [*see illustration on opposite page*].

The fossil eggs rested upright, half buried in a shallow depression— a nest built 75 million years ago.

A couple of complete clutches and a dozen partial ones are now known for *Troodon*. The half-buried eggs, and those of *Oviraptor* as well (also now known to be half buried), are good evidence that the egg-laying behavior of these dinosaurs was innovative. To this day, many reptiles bury their eggs,

Artist's reconstruction, above, of a nighttime family gathering of Psittacosaurus, *based on what appears to be a fossil nest, left. Discovered in Liaoning Province, northeastern China, the yard-wide nest contains the remains of an adult (its back half largely lost to erosion) and thirty-four juveniles. Apparently the group was killed rapidly and buried in place. The unusually well-preserved fossils show that this herbivorous dinosaur protected its young after hatching, as do crocodilians and birds.*

whereas nearly all birds leave them exposed. The theropods seem to have been pointing the way toward the present-day behavior of birds. *Troodon*'s eggs also had a large end and a small end, as do the eggs of modern birds. Research I undertook with Frankie D. Jackson of Montana State University–Bozeman, who specializes in the study of eggs and nest sites, shows that these extinct theropod egg shells were nearly indistinguishable at the microscopic level from those of modern birds.

Curiously, the eggs in the clutches occur in pairs, as do eggs in some other theropod clutches, suggesting the female laid two eggs at each sitting. Modern birds also lay intermittently, but because they only have one functional ovary and oviduct, they lay just one egg at a time. In contrast, modern turtles and crocodilians lay all their eggs in one bout. The paired eggs suggest that these dinosaurs retained two functioning ovaries and oviducts, each producing a single egg at a time.

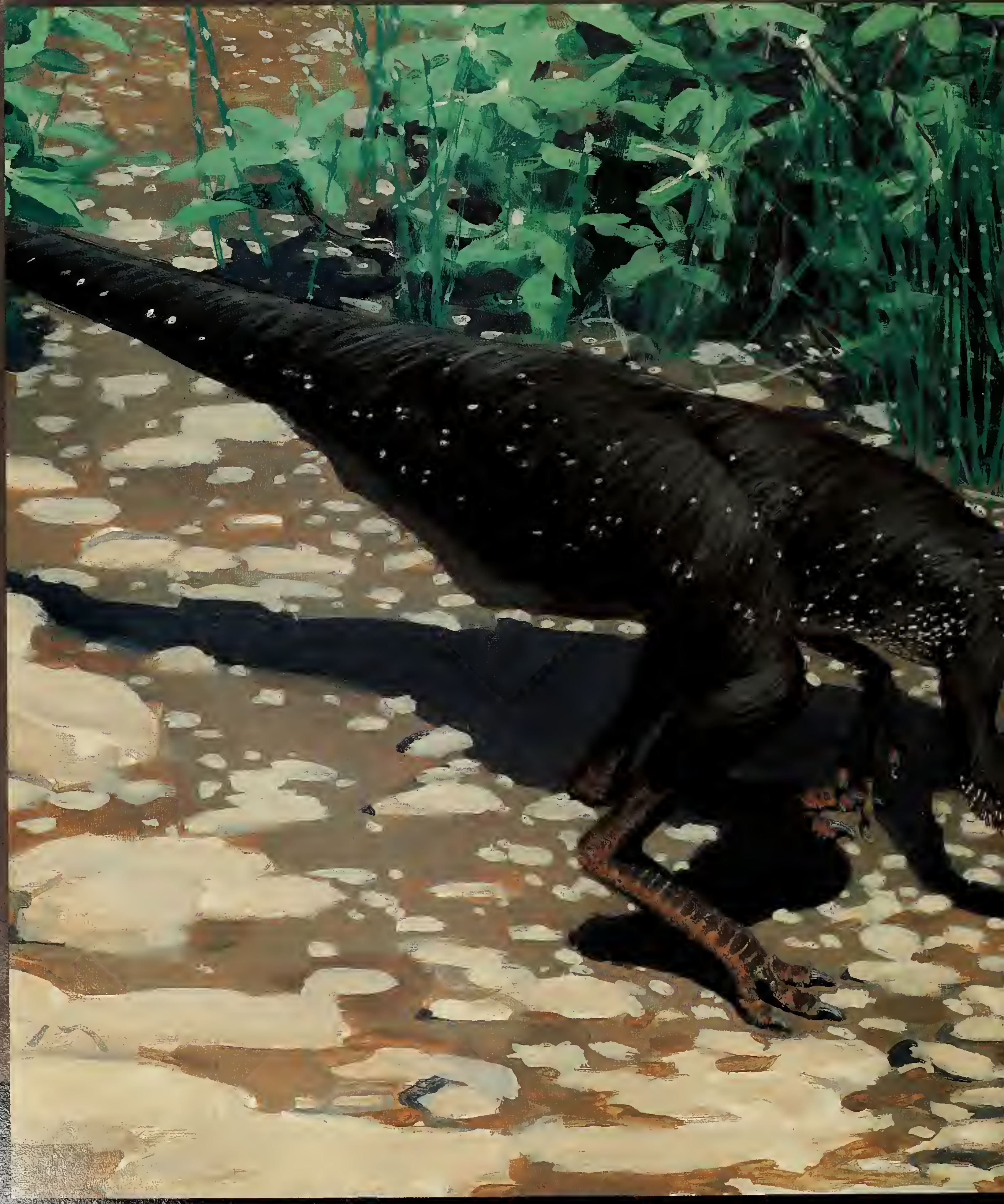
Yet there is no hard evidence that the theropods cared for their hatchlings. The bones of their embryos, in contrast to those of Horner's *Maiasaura* hatchlings, appear well ossified, indicating that the theropod young came into the world ready to forage for themselves.

A new case for parental care of young dinosaurs, including their feeding, comes from the paleontologist Robert T. Bakker, who is legendary for his provocative ideas. Bakker recently examined some sites in Wyoming that include isolated bones of large herbivorous dinosaurs, as well as the shed teeth of both small and large individuals of the carnivorous theropod *Allosaurus*. His conclusion: The sites were the lairs of *Allosaurus*, places to which adults brought food to feed their offspring. I find his arguments intriguing but not convincing. First, these "lairs" occur in what would have been exposed floodplains. Second, Bakker maintains that the bones and teeth were in place before they were covered with the sediments that now entomb them. A more standard explanation, though, seems sufficient: water simply carried and deposited the fossils and sediments together.

A much more convincing find, from Liaoning Province in northeastern China, presses the point of parental care much more effectively. In 2003 I had the good fortune to be asked by Timothy Huang of Paleoworld-Taiwan and Liu Jinyuan and Gao Chunling of the Dalian Natural History Museum, in Dalian, China, to take part in describing an exceptional specimen.

The specimen includes the partial remains of a single adult *Psittacosaurus* surrounded by thirty-four young, each about nine inches long and most of them complete, their skeletons articu-

(Continued on page 67)



NATURAL HISTORY
MAY 2005

The Varieties of Tyrannosaurs

Knowledge about the most fearsome dinosaurs and their relatives is finally measuring up to the animals' fame.

By Mark A. Norell and Xu Xing

Dilong paradoxus, a feathered tyrannosaur, is shown in an artist's reconstruction. Although no one knows what patterns existed on the dinosaur's feathered coat, the artist has depicted them as speckled, based on patterning found in many living birds. The plants shown in the background, Tyrmia acrodonta (with large leaves) and Equisetites longevaginatus (with reedy stalks), are commonly found near Dilong fossils.

A hundred years ago, Henry Fairfield Osborn, a vertebrate paleontologist and curator at the American Museum of Natural History, reintroduced the world to one of the most spectacular animals ever to have trod Earth: *Tyrannosaurus rex*. The specimen Osborn described had been collected by the legendary fossil collector Barnum Brown in the badlands of eastern Montana in 1902. During his career, Brown collected several other tyrannosaurs—that is, *T. rex* and its closest relatives. In the October 1915 issue of the *American Museum Journal* (as *Natural History* was once known) Brown called *T. rex* "the very embodiment of dynamic animal force." Visitors to the museum's fourth-floor fossil halls can still see what Brown means. The *T. rex* skeleton reconstructed from Osborn's and Brown's efforts has become a New York City icon—an image permanently etched in the mind of many a young visitor to the galleries of the museum.

Fossil of Dilong found in the Yixian Formation preserves traces of the animal's feathery coat, seen here along with part of two vertebrae from the animal's tail. The feathers were about an inch long.

In the hundred years since the discovery, *T. rex* has become the most famous dinosaur of them all. Its name has been borrowed to name rock bands and to pitch products such as motorcycles and a new superhighway in Denver, and its body has inspired both Godzilla and Barney—making it, in two senses perhaps, the most terrifying mega-villain in contemporary culture. A frenzy of collection has accompa-

Juvenile Tyrannosaurus rex *bears a coat of feathers predicted to be characteristic of the species at a young age. If tyrannosaurs were endothermic, or "warm-blooded," feathers could have been important as insulation for smaller animals, including the immature* T. rex. *As* T. rex *grew, however, its size alone would have kept it warm, without an insulating coat. The dinosaur would have shed its feathers.*

nied *Tyrannosaurus*'s recent cultural ascendancy. More specimens of the animals have been discovered in the past decade than were found in the preceding nine. Together those finds comprise a sample so good that paleontologists are testing hypotheses about tyrannosaur biology with real data, rather than relying on mere conjecture.

As a consequence, dinosaur paleontology has changed dramatically since the days of Osborn and Brown, particularly in the past twenty years. Compare a book on dinosaurs published before 1990 with a modern textbook on an existing group, say, mammals or reptiles. The textbook would include chapters on the systematics (evolutionary relationships) and classification of the various groups of animals, their life histories, soft-part anatomy, sociobiology, biomechanics, diet, geographic distribution, and feeding. The older dinosaur book would largely end after chapter one—systematics and classification. But times have changed. Ignorance about so much of a tyrannosaur's life has given way to ever-improving ideas of how tyrannosaurs grew, how they moved and behaved, and what they looked like—the discovery that some even had feathers is particularly surprising. The book of the tyrannosaurs is not yet etched in stone—unlike the fossils from which it ultimately comes—but it is becoming ever more complete.

Tyrannosaurlike dinosaurs begin appearing in the fossil record about 145 million years ago, near the boundary between the Jurassic and Cretaceous. The group lasted nearly 80 million years, finally disappearing 64.5 million years ago. At least six well-established tyrannosaur species are known, as well as several other species thought to be either closely related to the main group or part of the group itself.

The earliest bona fide tyrannosaur is *Dilong paradoxus.* It was discovered last year in Liaoning Province in northeastern China, in rocks about 128 million years old. *Dilong* had features common to many more primitive theropods—the group of dinosaurs most closely related to birds [*see "Bird's-eye View," by Matthew T. Carrano and Patrick M. O'Connor, page 42*]—such as a hand with three fingers (most tyrannosaurs' hands had just two fingers) and a relatively small body (it was just five feet long). But *Dilong* also had skeletal features, skull openings, and teeth that were characteristic of tyrannosaurs. In particular, the teeth at the front of its snout had D-shaped cross sections.

Larger tyrannosaurs, as long as twenty feet, appeared just a few million years later: *Alectrosaurus* roamed what is now China and Mongolia. *Eotyrannus* (which was probably, though not certainly, a tyrannosaur) hunted on what is now the Isle of Wight in the English Channel.

Throughout the Late Cretaceous, tyrannosaurs diversified into several species, all with large heads, powerful bodies, and two-fingered hands. Tyrannosaurs lived throughout the Northern Hemisphere, but they are best known from Asia and North America. Two species, *Tyrannosaurus,* in North America, and *Tarbosaurus,* in Asia, were so closely related that they constitute strong evidence for a Beringian land bridge joining the two continents in Late Cretaceous times. North America, though, was home to the greatest tyrannosaur diversity; here *Albertosaurus, Daspletosaurus, Dryptosaurus, Gorgosaurus,* and *Tyrannosaurus*—as well as the recently discovered *Appalachiosaurus*—lived at the top of the food chain in Late Cretaceous communities.

For much of the twentieth century tyrannosaurs were portrayed as lizardlike or crocodilelike, sometimes with hides covered in tubercles and scaly outgrowths like the ones on a large iguana. But new fossil discoveries suggest a more birdlike appearance. Tyrannosaurs shared a number of characteristics with birds, including hollow bones, feet with three primary toes that all pointed forward, and a wishbone. And in late 2004, when the first specimens of

Dilong were described, they corroborated a hypothesis that at least some tyrannosaurs had what might be the most superficially obvious bird trait of them all: feathers.

Investigators from the Institute of Vertebrate Paleontology and Paleoanthropology, in Beijing, were digging in the Yixian (pronounced *E-she-an*) Formation in northeastern China's Liaoning Province. The rocks of the Yixian, which have yielded many of the exquisite feathered dinosaurs described in the past decade, were formed between 135 million and 128 million years ago. The younger of those sediments, laid down at the bottoms of ponds and lakes, are called paper shales because their layers are paper-thin. Thanks to the oxygen-poor conditions of the lake bottoms, and to the fine grain of the original sediments, the paper shales often preserve soft tissues of plants and animals.

Soft parts are uncommon finds in the fossil record. Among the tissues preserved in the paper shales are delicate feathers, flower parts, hair, insect wings, and scales. The fossils are smashed flat, however, and the anatomical intricacies of the skeleton are often distorted or even destroyed.

Surrounding the tyrannosaur were the unmistakable traces of feathers.

Fortunately, the Yixian Formation has given up other treasures. The lower, older rocks are made up of coarsely grained sediments that contain a high percentage of volcanic ash. Those coarse sediments do not preserve soft tissues, but they do preserve specimens in three dimensions, and some of the specimens appear to have been buried alive by the ash. The ashen deposits have yielded spectacular specimens, including groups of baby *Psittacosaurus* [*see "Bringing Up Baby," by David J. Varricchio, page 30*]; a mammal called *Repenomamus,* whose last meal, a young *Psittacosaurus,* fossilized inside it; and an array of other mammals and theropods, including the most complete specimen of *Dilong* found to date.

Much of that specimen's skeleton was preserved, making it ideal for comparison with other fossils. One of us (Xu) noted a similarity between the new specimen and an extremely fragmentary animal collected years earlier from the Yixian's younger paper shales. Although that specimen was only a few bones spread on several broken slabs of rock, enough was present to confirm a hunch that it too was a *Dilong.*

What made that realization exciting was what surrounded some of the skull bones and segments of the tail on the fragmentary specimen: the unmistakable traces of a body covering [*see photograph on page 35*]. The covering looks like a thin film of dark streaks, all running at oblique angles to the skeletal elements. The structures, which are branched and about an inch long, are similar to the coverings of *Sinosauropteryx,* the first feathered dinosaur that was not a bird to be discovered.

The discovery of the first feathered dinosaurs in the late 1990s caused quite a stir. By now paleontologists have firmly established that many theropod dinosaurs had feathers. They range from simple structures, such as the ones on Sinosauropteryx and Dilong, to feathers just like those of a modern bird, which occur on Caudipteryx and several other species.

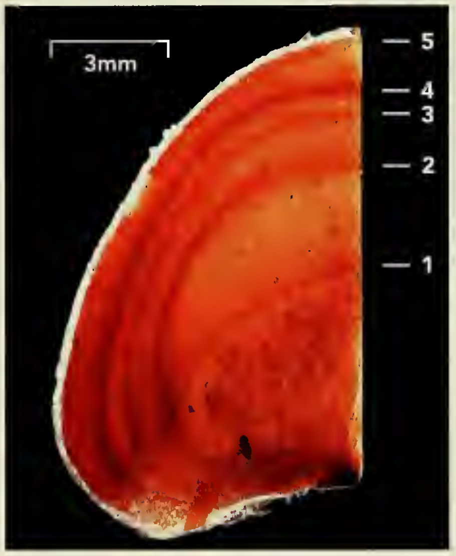
Feathers likely evolved in multiple stages, beginning as hollow, hairlike structures that may have served as insulation. Indeed, feathers insulate birds to this day, and a covering of feathers may have been a factor in the origin of endothermy (warm-bloodedness) in dinosaurs—especially the ones closely related to birds. Subsequently those primitive feathers specialized and diversified into a range of types. Some dinosaurs are known to have had long tail plumes and large feathers on the backs of their hands—not for flight, but perhaps for display of some kind. Eventually, though, evolution co-opted the feathers for flight.

Although it was a little surprising to discover that *Dilong* had feathers, it was far less surprising that the feathers were of the primitive type. After all, the theropod dinosaurs that have feathers similar to those of modern birds are much more closely related to birds than tyrannosaurs are.

In spite of the downy feathers cloaking the earliest tyrannosaurs, probably not all tyrannosaurs would have been giant fuzz balls from hell. The larger an endothermic animal, the more heat it generates relative to the surface area of its body. Thus, mammals such as elephants and rhinoceroses have just a sparse coat of hair, because they need to radiate excess heat efficiently. A full-grown *T. rex* would have weighed about the same as a large African elephant, and so it is unlikely that the dinosaur would have benefited from extensive insulation. If *T. rex* was endothermic, though, a recently hatched *T. rex*, weighing only a few pounds, would be predicted to have been covered in insulating feathers, which were then shed as the animal grew [*see illustration on opposite page*].

As the tyrannosaurs' physical appearance has become clearer, so have the growth patterns and life histories of the animals. *Dilong,* the smallest form, was also the most primitive. *Alectrosaurus*, another early tyrannosaur, was bigger but still not gigantic. *Albertosaurus, Daspletosaurus*, and *Tarbosaurus*, which appeared in the fossil record at the end of the Cretaceous, all weighed in excess of 3,000 pounds and measured more than twenty-five feet long. *T. rex*, at more than 12,000 pounds, forty feet long, and fifteen feet high, was, of course, the biggest of them all.

What kind of growth pattern led to *T. rex*'s massive size? One possibility is that it grew at the same rate as its smaller ancestors, but just kept growing for a longer time. Or perhaps it grew for the same length of time as its relatives, but faster. A third possibility is that it began life in a large egg—after all, an ostrich egg is twenty-four times larger than a chicken egg. There are physical limits to the size of eggs, however, which make it highly unlikely that *T. rex*'s eggs were much larger than those of *Albertosaurus*.



Fibula of the tyrannosaur Gorgosaurus shows how the animal grew during its five-year life. Each line in the bone, like a tree ring, records the annual growth. The fibula is unusual in that it never hollows, as do most bones in a tyrannosaur. The bone enables paleontologists to study the entire growth history of an animal.

Fortunately, fossils record dinosaur growth. Many vertebrates, including dinosaurs, leave annual rings in their bones as they grow. By examining the cross sections of bones microscopically, paleontologists can determine how much the bones grew each year, as well as the age of an animal at death. But applying the technique is complicated somewhat by the fact that most of the weight-bearing bones in tyrannosaurs are hollow. The hollow cavities were formed as the animal matured and grew to adulthood, erasing the early growth rings. Some bones, however, remained solid for life. One is the fibula, a small bone on the outside of the leg. That bone grows through accretion, and is not extensively remodeled as the animal matures. The adult fibula even contains the embryonic fibula—so the bone captures the entire life history of the animal.

Gregory M. Erickson of Florida State University in Tallahassee and a group of colleagues, which included one of us (Norell), determined that advanced tyrannosaurs all reached maturity in about twenty years. The oldest of the seven *T. rex* specimens the team surveyed was twenty-eight when it died and weighed about 13,000 pounds. The smallest specimen was a two-year-old that weighed about sixty-five pounds. In the intervening years, *T. rex* must have grown at a fantastic rate. During the five-year phase of its most rapid growth, a *T. rex* would have gained at least five pounds every day.

To reach even the half-ton sizes of the smaller tyrannosaurs, an animal would have to consume a great deal of food. Little is known, though, of how or what tyrannosaurs ate. Everything from scavenging to aggressive predation has been proposed. Yet some clues to their diet do exist. A few bones of plant-eating dinosaurs such as *Edmontosaurus* and *Triceratops* have bite marks that seem to correspond to the serration pattern of tyrannosaur teeth. It cannot be determined, however, whether those animals were alive or dead at the time of the bite.

Other evidence comes from a coprolite—fossilized dung—from southern Saskatchewan that seems to have come out of a tyrannosaur. An analysis of the dung by Karen Chin, now at the University of Colorado Museum in Boulder, and her colleagues initially found small digested bones, confirming little more than what all schoolchildren already know: *T. rex* ate meat. More careful analysis indicated that the bones came from juvenile herbivorous dinosaurs. Certainly juvenile animals are a common prey of large carnivores today, and it is no surprise that similar patterns should have played out in the past.

Skeletons reveal more than just how fast tyrannosaurs grew, however, or even what they ate. Many tyrannosaur skeletons display bones that have broken and healed; that is certainly the case with several ribs of the specimen at the American Museum. "Sue," a *T. rex* at the Field Museum in Chicago, shows similar rib injuries, and it has leg injuries as well. Many *T. rex* specimens, as well as other tyrannosaurs such as *Albertosaurus*, also have pathologies of the skull and vertebral column.

Perhaps the most illuminating injuries occur on the teeth and snout. Many tyrannosaurs have multiple bite marks on the muzzle and nicks on the sides of the teeth. Such wounds might have come from nuzzling or other face-to-face contact, perhaps in battles for territory or mates. It is impossible to say whether some of the scars and broken bones resulted from hunting or from roughness associated with mating. But there is no doubt that the injuries were painful, and that the animals lived a hard-knock life—and that the pain could have made a six-ton, forty-foot *T. rex* extremely cranky.

Popular images often portray tyrannosaurs as solitary animals, or speedy, or both. Arguably the best evidence for such behavior is trackways, which are essentially snapshots of individual events. Trackways have indicated herding in sauropods, preserved the moment of a kill, and even suggested that some theropod dinosaurs hunted in packs. Unfortunately, only a couple of tyrannosaur trackways have been recovered, and some are not particularly informative.

Other evidence, though, suggests tyrannosaurs were gregarious. For example, some tyrannosaur excavations have yielded multiple individuals. One of those is a quarry that Barnum Brown excavated in the Red Deer River area of what is now Dinosaur Provincial Park in Alberta, Canada. The quarry was re-excavated by Philip J. Currie of the Royal Tyrrell Museum of Paleontology in Drumheller, Alberta. Currie's analysis of collections both old and new showed that several *Albertosaurus* individuals of various ages and sizes were preserved together. Because no other dinosaur species were preserved with those animals, Currie surmised that they died at the same time, perhaps while crossing a dangerous river. Although the find is not definitive evidence for pack behavior, it and other similar depositions of multiple tyrannosaurs are at least highly suggestive that such behavior took place.

As for the speed of tyrannosaurs, some fantastic claims have suggested the huge animals could reach sprinterlike speeds. But those claims fail to take account of some basic issues in the physics of movement of large animals. John R. Hutchinson, now at the University of London's Royal Veterinary College, and his colleagues digitally modeled the hind limb and hips of a *T. rex* [*see "A Weighty Matter," by Adam Summers, June 2002*]. By varying the controllable factors in the model such as posture and the total weight of the animal, Hutchinson was able to calculate how big the muscles of the hind limb must have been for the animal to move at various speeds.

His simulations clearly showed that *T. rex* adults could never have run much faster than twenty-five miles an hour. Going faster would have tied up such a high percentage of the total body mass in the hind-limb muscles that the rest of the animal would have been emaciated.

Skulls of mature Dilong (left) and T. rex (above), pictured at the same scale, show obvious similarities, and one salient difference: size. Analysis of tyrannosaur growth patterns revealed that the group's various species, all quite similar in size in youth, each undergo a growth spurt during which growth rates vary widely. The result was an enormous range in size.

In fact, the fastest runners were probably juvenile *T. rex*'s and other smaller tyrannosaurs. That suggests the various tyrannosaur species would have exploited different prey in areas where they lived together—just as cheetahs, leopards, and lions do in Africa today. The speed analysis also suggests that *T. rex* and other big species would have gone from speedy youth to lumbering adulthood.

The book of the tyrannosaurs is still, slowly, being written. The tyrannosaurs of 2005 are quite different from the ones familiar to Osborn and Brown. No longer just large, imperious lizards, they represent an evolutionary explosion of diversity—some feathered, some not, some faster than others, but all capable of wreaking havoc—culminating in some of the most magnificent animals ever to walk the Earth. Both of us look forward eagerly to adding more to every chapter. □

All in the Family

A cladogram shows how dinosaurs are related to each other—and how the birds fit in.

By Thomas R. Holtz Jr. ~ Illustrations by Roberto Osti

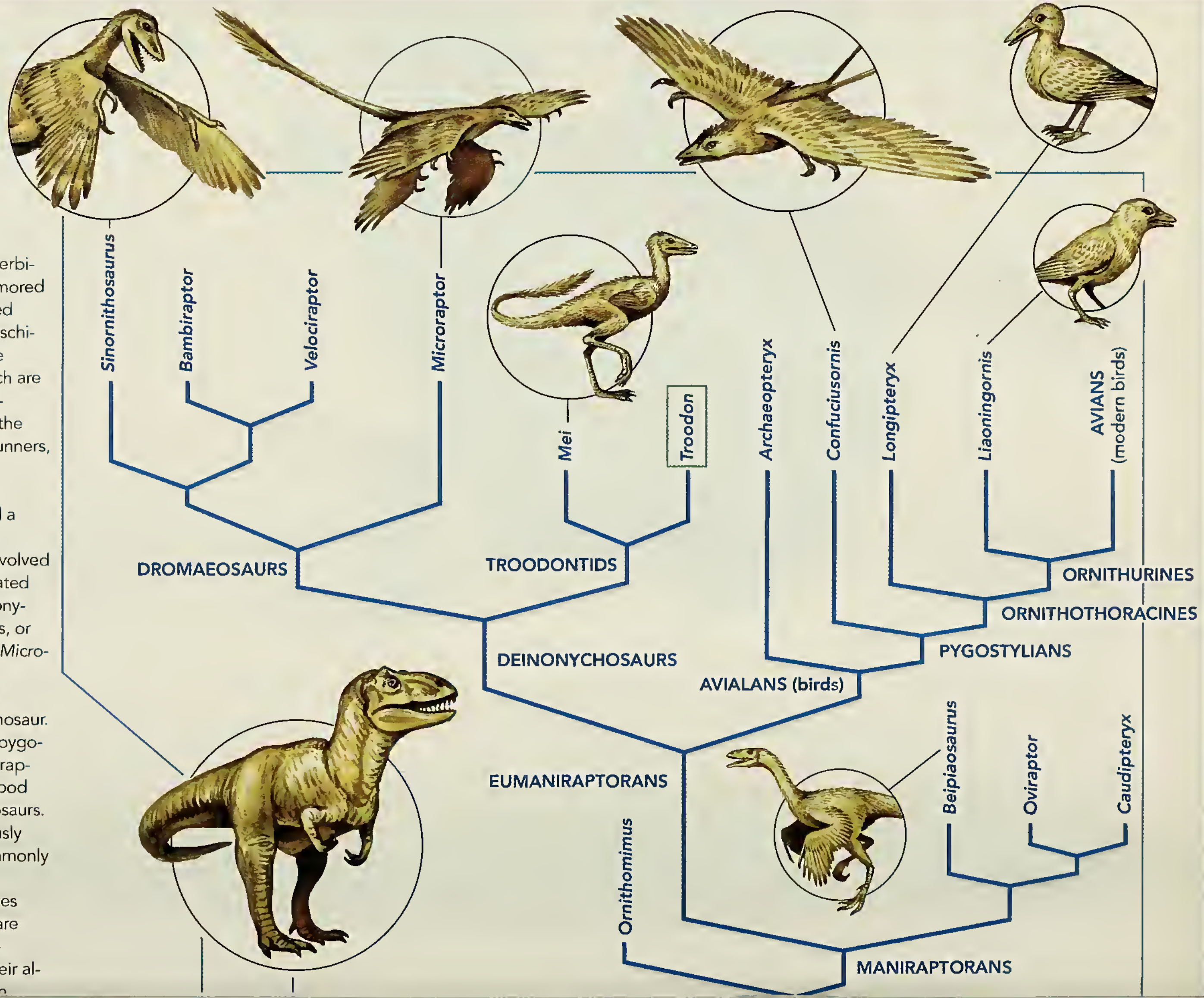
The evolutionary relations—the pattern of common ancestry—among the various dinosaur groups mentioned in this issue are mapped out on this "family tree," known as a cladogram. Biologists create cladograms on the basis of the way specialized characteristics are distributed among the species being examined.

Dinosaurs are divided into two major groups. The ornithischians ("bird-hipped" dinosaurs) are herbivores, and include the plated *Stegosaurus*, the armored *Ankylosaurus*, horned ceratopsians, and duck-billed hadrosaurids. The second major group is the saurischians ("lizard-hipped" dinosaurs). One branch of the saurischians is the sauropodomorphs, among which are the gigantic long-necked plant eaters, such as *Apatosaurus* and *Brachiosaurus*. The other branch is the theropods, all of which were initially carnivorous runners, such as *Coelophysis* and *Allosaurus*.

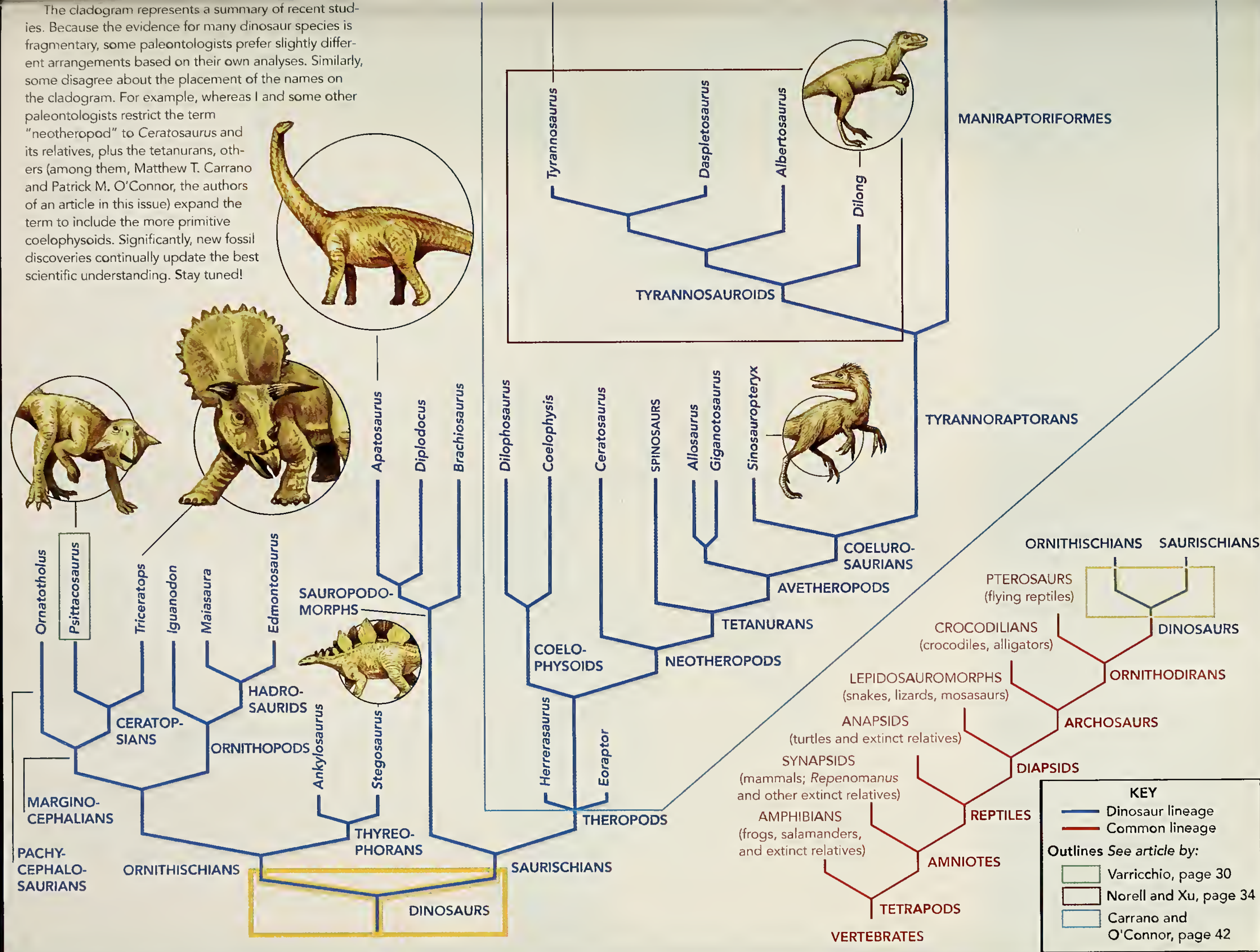
Recent discoveries in China reveal that a major branch of theropods, the coelurosaurians, evolved a downy covering of "protofeathers." Among the coelurosaurians, the subgroup of maniraptorans evolved true broad feathers on their limbs. Two closely related specialized groups of maniraptorans are the deinonychosaurs (*Velociraptor* and its kin) and the avialians, or birds. Indeed, primitive deinonychosaurs (such as *Microraptor* and *Mei*) and primitive birds (such as *Archaeopteryx*) are anatomically exceedingly similar.

As the cladogram shows, birds are a kind of dinosaur. Specifically, they are ornithurine ornithothoracine pygostylian avialan eumaniraptoran maniraptoran maniraptoriform tyrannoraptoran coelurosaurian avetheropod tetanuran neotheropod theropod saurischian dinosaurs. Ironically, although birds are dinosaurs and obviously have bird hips, they are not part of the group commonly called bird-hipped dinosaurs!

In the broader context of four-limbed vertebrates [see small *cladogram at bottom right*], dinosaurs are grouped together with the flying pterosaurs as ornithodirans; ornithodirans and crocodilians and their allies are grouped together as archosaurs; and so on



The cladogram represents a summary of recent studies. Because the evidence for many dinosaur species is fragmentary, some paleontologists prefer slightly different arrangements based on their own analyses. Similarly, some disagree about the placement of the names on the cladogram. For example, whereas I and some other paleontologists restrict the term "neotheropod" to *Ceratosaurus* and its relatives, plus the tetanurans, others (among them, Matthew T. Carrano and Patrick M. O'Connor, the authors of an article in this issue) expand the term to include the more primitive coelophysoids. Significantly, new fossil discoveries continually update the best scientific understanding. Stay tuned!



Bird's-eye View

By Matthew T. Carrano and Patrick M. O'Connor

The array of the dinosaurs that flourished during the Mesozoic era was as dazzling as any bestiary ever imagined; not even medieval fantasies of griffins and unicorns could compete with the fabulous record of fossils in rock. Yet with a single exception, the entire dinosaur lineage was obliterated 65 million years ago. The sole dinosaurian representatives to survive the cataclysm were the birds, a group that has since radiated into virtually every environment on the planet.

The suggestion of an evolutionary link between dinosaurs and birds originated with several late-nineteenth-century biologists, most notably Darwin's friend Thomas Henry Huxley. At first welcomed, the hypothesis was later disregarded by most biologists and treated with skepticism through much of the twentieth century. But in the past three decades, the hypothesis has roared back to life, with almost overwhelming support. The latest evidence for the link has come from the spectacular recent discoveries of a number of feathered dinosaurs in China.

To many a casual eye, the case is made by the presence of feathers on the fossils. But feathers only highlight one of the most visible similarities between the two groups. Biologists classify birds among the dinosaurs not only because both groups have (or had) feathers, but also because they share a suite of other, characteristic anatomical traits. One of those important traits is the "pneumaticity" of the skeleton: certain dinosaurs possessed bones riddled with air pockets, which during life were linked with the pulmonary, or breathing, system of the animal. Much the same is the case with many birds today.

The classification of birds as dinosaurs also implies that many other so-called avian features are better thought of as dinosaurian. And similar anatomies could imply that the bodies of birds and dinosaurs functioned similarly. Moreover, one may also learn a great deal about dinosaur biology by contrasting their features with the anatomical and biomechanical characteristics of other, more distantly related vertebrates. It is the birds, though, that have carried the torch of dinosaurian biological heritage from the Mesozoic through global calamity to the present day. Modern paleontologists, in large part by the light of that torch, are elucidating the paleobiological characteristics of those long-dead, long-buried, long-obscured animals.

To understand what one can learn about dinosaurs from the study of birds, it is useful to sketch how the two groups are related. A discipline of biology known as cladistics, or phylogenetic systematics, investigates the evolutionary relationships among organisms by charting their anatomical similarities. Cladistic hypotheses about such interrelations often take the form of a branching diagram called a cladogram. Each junction on the cladogram indicates an evolutionary event that split one lineage into two. Each of the two descendant lineages shares one or more features inherited from the ancestor at the most recent junction, and those shared features define different groups. To examine the relations within and between groups of organisms is also to chronicle the sequence by which those groups' features evolved.

According to the leading cladistic hypotheses, birds are descended from within the group of theropod dinosaurs. Theropods are quite familiar to most people, if not necessarily by that name: members include giant *Tyrannosaurus,* sickle-clawed *Velociraptor,* and birdlike *Ornithomimus.* Theropods such as *Herrerasaurus,* from the Middle Triassic are among the earliest known dinosaurs. [*For a summary chart of geologic periods, see "Up Front," page 6.*]

Theropods, like birds, were bipedal animals. All of them share several key features: thin-walled bones, a foot with three main toes, and a joint in the lower jaw. Early theropods split into two groups, the herrerasaur-like primitive theropods, and a group called the neotheropods, which included most of the familiar predatory dinosaurs [*see the branch of the illustration on pages 40 and 41 outlined in blue*]. Early neotheropods, known as the coelophysoids, were common in the Late Triassic and Early Jurassic.

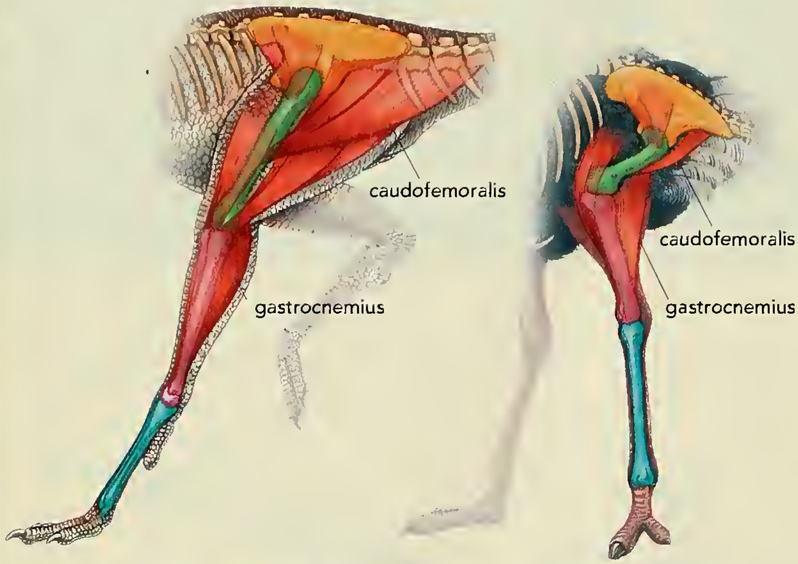
As the neotheropods emerged as a separate group, they shared an important "birdlike" trait—the fur-

Because modern dinosaurs are flying all around us, examining them closely can offer new insights into the lives of their fossilized ancestors.

Theropod dinosaurs, represented here by an artist's reconstruction of Ornithomimus (left), are thought to comprise the group from which modern-day birds, including the ostrich (right), descended. Because common descent implies shared anatomical characteristics, comparisons of theropod and bird anatomies can provide new insights into dinosaur biology. Two particularly fruitful comparisons—of the muscles and bones of the legs, and of the animals' "pneumatized" bones—have revealed much about theropod locomotion and the theropod pulmonary system.

maniraptorans (to which *Velociraptor* and many other dinosaur species belonged)—show the greatest affinities with birds. Some early forms, including primitive tyrannosaurs, had a downy covering on the skin, possibly either for insulation or for display [*see "The Varieties of Tyrannosaurs," by Mark A. Norell and Xu Xing, page 34*]. Other species had distinct feathers covering nearly the entire body. Maniraptorans also had a specialized shoulder blade and a unique, curved bone in the wrist, which enabled the hand to move in just one plane. The motion was similar to wing folding in modern birds.

Finally, with just a few additional modifications—such as the lengthening of the forearm and hand—the last living subgroup of the maniraptorans appeared: the true birds.



Ornithomimus, like nearly all theropods and birds, walked on its hind legs, but comparing the anatomy of the two groups shows their methods of walking differed. Theropods (left) had large caudofemoralis muscles, which attached to their long tails and provided power that caused much of the movement of each step to occur at the hip. Ostriches (right) and the other birds have reduced tails and correspondingly diminutive caudofemoralis muscles. But birds, for their size, have proportionately larger muscles, such as the gastrocnemius, in the lower leg than theropods did; most movement during a bird's step takes place at the knee.

cula, often (in birds) called the wishbone. The furcula is formed by the fused left and right clavicles, and in modern birds it acts as a spring between the powerful flapping wings. Clearly, though, the furcula did not function in that capacity in the earliest neotheropods. Although its original role remains unclear, it may have helped neotheropods control their forelimbs.

By the end of the Early Jurassic the theropods split again, giving rise to the ceratosaurs (a group that includes *Ceratosaurus)* and tetanurans (a diverse group that includes *Allosaurus, Spinosaurus, Tyrannosaurus, Velociraptor,* and a number of others). The tetanurans are named for their tails, which were less flexible than those of their forebears. Like the hand of a modern bird, the tetanuran hand had only three fingers; the tetanurans' wrist was more specialized, and their entire forelimb more birdlike, than the corresponding anatomy of any of the earlier theropods.

Around the same time the allosaurs appeared, another subgroup of the tetanurans, the coelurosaurs, also branched off. Coelurosaurs included both large species, such as *Tyrannosaurus rex,* and small ones, some not much bigger than a chicken. The coelurosaurs—particularly their subgroup known as

The hypothesized interrelations expressed by a cladogram can guide paleontologists to specific evolutionary patterns that can shed light on other aspects of dinosaurian biology. For example, how did dinosaurs move? Living animals, of course, confront the same laws of physics as the dinosaurs did. By studying the biomechanics of locomotion in living animals, then, dinosaur biologists can focus more precisely on what the fossil evidence can convey.

Early theropod locomotion was not particularly specialized—theropods were, in general, neither runners nor plodders, neither climbers nor diggers nor swimmers; more likely, they were jacks of many of those trades, but masters of none. Their most notable attribute was an inherited one: bipedalism. The original dinosaurs walked on two legs, making the group an oddity in the history of vertebrates. In spite of their shared bipedalism, various theropod groups did become more specialized in their locomotion, as their skeletons attest. Comparing their bones with those of modern animals can help show how differences in anatomy translate into differences in behavior.

Among living groups, the distal—that is, distant from the body's center—segments of limbs are relatively long (compared with the rest of the body) in fast runners such as ostriches and cheetahs, and in long-distance runners such as wildebeest and caribou. Animals with relatively short distal bones, such as elephants and hippopotamuses, have more columnar legs and do little running. Between those extremes is a near-continuum of variation. The proportions of the distal limb bones in theropods were generally intermediate between the extremes of cheetah and elephant.

Another mammalian tendency is that large species typically have relatively short limbs and small species relatively long ones. The same pattern held in theropods. Some large theropods, such as spinosaurs and allosaurs, had lionlike limbs—perhaps because they hunted by stealth or covered relatively little ground in their roamings. Other species bucked the trend, though. Tyrannosaurs had a runner's limbs, despite their enormous size—indicating that they were probably adapted to running relatively fast or far.

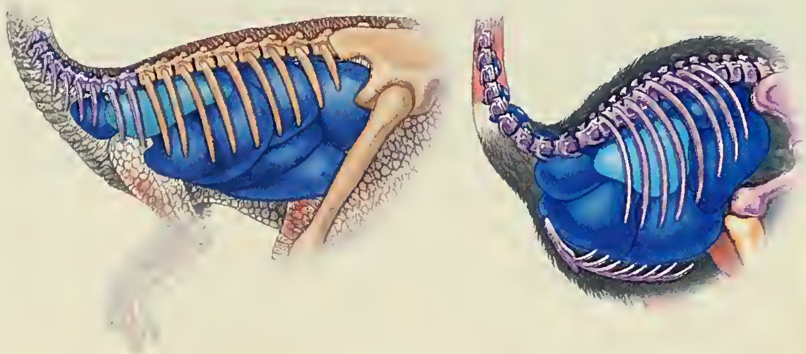
Another way to examine theropod biomechanics is to reconstruct the musculature of the limbs. Muscle-attachment marks on fossilized theropod bones can be compared to similar marks on the dinosaur's nearest living relatives: the crocodilians—whose ancestors were quadrupedal—and the birds.

The hind-limb muscles of birds are well adapted for bipedal motion. The muscle arrangement at the hip and knee maximizes stability, yet gives the leg the ability to make wide swings fore and aft. But bipedalism in birds is a highly specialized form of bipedal motion; the large tails of birds' ancestors, which in crocodilians still anchor the leg muscles, have mostly vanished in birds. Hence, in birds, the muscles attached to the tail are also small [*see illustration on opposite page*]. Birds walk in a crouched posture, moving the knee more than the hip—what biologists sometimes call "Groucho running," after Groucho Marx.

An analysis of theropod fossils shows that the animal had birdlike limb muscles early in their evolution. That was certainly the case by the time the coelophysoids appeared, and perhaps even by the time of *Herrerasaurus*. The repositioning of the muscles changed the way theropods walked: they began moving their legs as birds do—in one plane, fore and aft—rather than as crocodiles do, waddling from side to side.

In later theropods, such as allosaurs and tyrannosaurs, several new muscle attachments appeared, which occur in birds but not in crocodilians or earlier theropods. Yet despite the rearrangement of the attachments of some leg muscles, most theropods still retained substantial attachments of the leg muscles to the tail. The Mesozoic world was probably not full of Groucho-running theropods. Rather, the leg muscles attached to the tail would have caused the upper part of the limb to move at the hip.

Although great size, as well as a great range of body sizes, are among the most familiar qualities of dinosaurs, the early theropods were both small and fairly uniform. *Eoraptor*, one of the earliest theropods, was perhaps three feet long and weighed about twenty-five pounds, more or less the dimensions of a medium-size dog. Yet even that animal was much larger than its nearest ancestors. Further change came quickly. By the Late Triassic, the dominant predators were coelophysoid theropods, a group ranging from the nine-foot-long *Syntarsus* to the fifteen-foot-long *Gojirasaurus*. But the first large theropods, animals more than thirty feet long and weighing between two and three tons, appeared during the Late Jurassic. The true giants did not arrive until the middle of the Cretaceous period. The carcharodontosaurs were among the largest terrestrial predators that ever lived, some reaching as much as forty feet long and weighing four tons. The spinosaurs were contemporary to the carcharodontosaurs, and similar in size. The giant tyrannosaurs appeared in the latest part of the Cretaceous, reaching or exceeding the carcharodontosaurs in size.



Skeletons of theropod dinosaurs and most modern birds are perforated by their pulmonary systems, a condition known as pneumaticity. Pneumatic bones (purple) have holes in them to accommodate air sacs (blue) extending from the lungs (light blue). In birds, most air sacs serve as bellows to ventilate the lungs. Ornithomimus (left) had pneumatic bones only in the vertebrae and in small ribs in the neck, whereas the ostrich (right) has air-filled bones throughout much of its body. The pneumaticity of bones may have evolved as a means of reducing their density, thereby allowing theropods to grow larger without a commensurate increase in body mass. The artist's reconstruction of the air sacs in the dinosaur outside its bones is based on the positions of air sacs in birds.

What is interesting is not so much the absolute size of those giant predators but that at least three lineages of theropods independently evolved to almost exactly the same size. Something, it would seem, made such a size advantageous. Or perhaps something structural or ecological made any larger size a real disadvantage.

Body size affects nearly every aspect of organismal biology. The basic physics of size dictates an animal's structure and function in a number of predictable ways. For example, when an animal doubles its linear dimensions, its volume increases eightfold. Hence processes that depend on volume, such as maintaining body temperature, are highly sensitive to changes in body size. Other physiological processes that depend on surface areas—gas exchange across a membrane, for instance—are intermediately affected by changes in body size. One consequence of those geometric relationships is that the larger the animal, the harder it becomes to adjust its body temperature. Body temperature is regulated through the body's surface area, but heat is stored in the body's volume.

To some degree, most living reptiles rely on the external environment for controlling body temperature; thus, reptiles are called ectothermic, or, somewhat erroneously, "cold-blooded." Birds, however, can fine-tune their body temperatures internally, a condition referred to as endothermy, or, also somewhat erroneously, "warm-bloodedness." But the apparent dichotomy between endothermy and ectothermy is misleading; rather, there is a broad spectrum of metabolic types, many of which are directly correlated with the anatomical form and function of the breathing apparatus.

Lightweight bones made giant dinosaurs possible. Birds owe their bones to that earlier evolution.

Many reptiles have relatively simple lungs. As they expand or contract, air flows in and out of them through the same channels, just as it does in people. But the configuration of the internal cavity of the reptilian lung varies from species to species. In a few species, including some lizards, each lung is a simple sac, and gases are exchanged only around its edges. In other species, such as monitor lizards and crocodilians, the lungs are partitioned into chambers made up of an intricate net of support structures. The network provides a larger surface area, which enables higher rates of gas exchange than do the edges of a simple, saclike lung.

Modern birds have modified the basic reptilian design in such a way as to increase lung partitioning, and, consequently, the surface area for gas exchange. But unlike the reptilian lung, the avian lung changes very little in size during ventilation. Instead, birds have flexible air sacs (usually nine in number) that act as bellows to move air through the lungs. Although the air sacs are connected to the lungs, they do not take part directly in gas exchange. Furthermore, in some parts of the bird lung, air flows almost continually in just one direction. Those specializations enable birds to exchange gases efficiently enough to sustain high metabolic rates and regulate their temperatures internally.

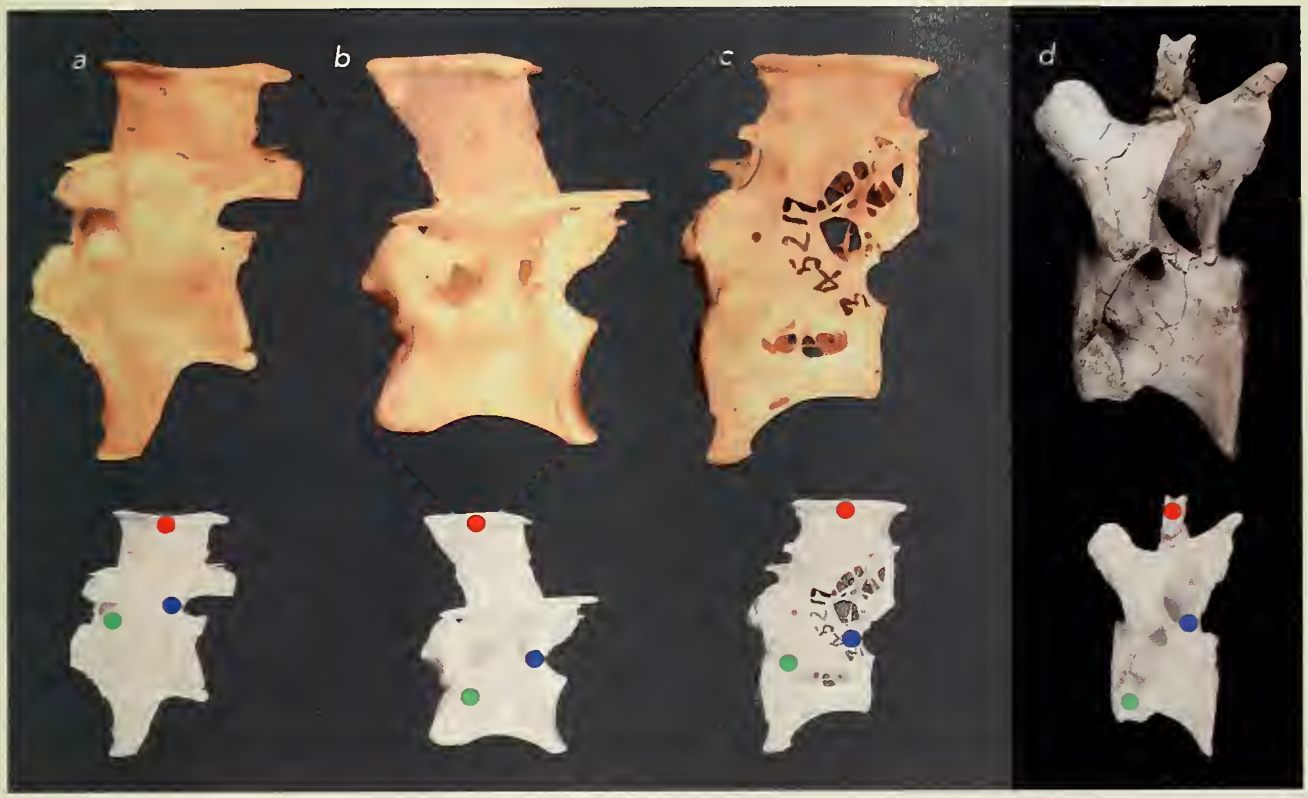
Although avian lungs and air sacs are made of soft tissues, they have important connections with the skeleton. Extensions from the air sacs physically invade the skeleton, a process known as pneumatization. The result can be dramatic. Imagine walking down the windpipe of a bird, into its lungs, and then on into the skeleton, including the backbone and limbs—within the pulmonary system. That's some fantastic voyage!

No other living animals have pneumatic bones like those of birds, but substantial evidence suggests that theropods, along with the flying pterosaurs and sauropod dinosaurs, had at least a superficially similar pulmonary system. Like birds, those animals had holes in the outer surfaces of many of their bones. The holes were connected to large, air-filled chambers within the bones.

Even in birds, though, the function of pneumatic bones remains unclear. No gases are exchanged within the bones, nor do the air-filled chambers in the bones help move air through the lung—bone, after all, is not a flexible bellows. One plausible idea is that pneumatic bones might have evolved because they replaced heavy (and metabolically expensive) bone marrow with air. Pneumatic bones enable a bird (or a dinosaur) to expand its overall body size without a commensurate increase in weight.

In spite of the uncertain role of pneumatic bones, their presence in theropods suggests that at least some theropods had air sacs similar to those observed in birds. Without additional evidence, though, it is probably idle to speculate any further about how theropods breathed. Nevertheless, the historical perspective provided by theropod pneumaticity may be the key to understanding the origin of air-filled, lightweight bones in birds.

Ornithologists have long sought to explain pneumatic bones in birds as an adaptation to some aspect of their lifestyle, such as the great benefit they offer for energy savings in flying. Pneumaticity clearly originated much earlier in avian history, but perhaps for a similar reason—that is, its adaptive value in relaxing the constraints on the size of theropods. One point corroborating that idea is that many of the largest theropods, such as carcharodontosaurs and tyrannosaurs, often had the most extreme pneumaticity. Many of the smaller theropods, in contrast, only pneumatized certain regions of the vertebral column.



Vertebrae (top row) in three species of bird—penguin (a), owl (b), and screamer bird (c)—show varying degrees of pneumaticity. (The more air sacs in the bone, the greater its pneumaticity.) The theropod dinosaur vertebra (d) exhibits similar pneumatic openings. Large birds such as screamers likely possess such heavily pneumatized bones to reduce body weight, whereas penguins and other diving birds have no pneumatization in order to reduce their buoyancy. Medium-size birds such as owls have intermediate levels of pneumaticity. The colored circles in the line drawings (bottom row) correspond, by color, to identical anatomical structures in each bone.

Similar patterns of pneumaticity occur in birds: among flying birds, at least, the larger the bird, the more extensive its pneumaticity. Certain large-bodied flying birds, such as bustards, pelicans, and vultures, pneumatize virtually the entire skeleton, out to the tips of the wings. Many medium-size and small birds, such as ducks, pheasants, and songbirds, only pneumatize the vertebrae and limb bones closest to the lung and air sacs. Some interesting exceptions to the correlation between body size and pneumaticity occur in birds that dive underwater to feed, such as grebes, loons, and penguins. Those birds have eliminated bony pneumaticity altogether, so as to reduce their buoyancy when they dive.

The broad variation in skeletal pneumaticity among birds suggests that interactions between the pulmonary and skeletal systems alter drastically in response to a variety of physical and environmental pressures. Could similar variations in pneumaticity reflect the various physical and ecological factors theropods had to confront? With birds as a model, paleontologists should be able to frame and test hypotheses that can begin to answer that question.

Using living animals as "model organisms" for understanding dinosaur biology offers many advantages over traditional methods of paleontology. But paleobiologists must also remain cautious when making inferences related to the activities of long-dead animals. For example, as tempting as it is to read "bird" into every dinosaurian trait, it is just as important to acknowledge the limits of current knowledge, and the fact that the dinosaurs maintained their own evolutionary trajectory; they likely possessed an amalgam of traits present in modern birds and their reptilian relatives.

Ideally, paleontology integrates multiple lines of evidence, from a variety of living and extinct animals, to assess the full biological potential of long-extinct groups. That approach is not without its limits. Nevertheless, by seeking novel ways to integrate the vast array of biological subdisciplines, paleobiologists are beginning to put a modern face on some very old "terrible lizards." Those complementary studies will ultimately provide the most rigorous assessment of how dinosaurs actually lived. □

Dinosaur Disputes

In the social arena, controversies are fed by opinion and ideology. Uncomfortable facts are routinely ignored. Among scientists—ideally, at least—controversies must be grounded in facts. But merely piling up facts doesn't close a case. It's how the facts fit together that counts. That's the role of a theory: to make sense of disparate facts.

Theories excite scientists, because theories make predictions: new evidence, if it is relevant at all, should conform to the theory. If it does not, the theory must be revised.

Ever since the first discoveries of dinosaur bones, theories about the animals—how they lived and died, how their bodies functioned, why they grew so large and had such strange armament, how they were related to other animals—have occupied some of the best scientific minds.

Some of those theories have emerged as mainstream scientific thinking—most paleontologists espouse them more or less whole, though dissenting voices are usually around to highlight their imperfections. Other theories, on topics that still lack decisive evidence, remain vigorously competitive.

For this special issue, Natural History *invited eleven leading investigators to present their views about four of the most important controversies in dinosaur paleontology. In some cases, the mainstream contender has proceeded with certainty, emboldened by the weight of the evidence. The challenger has largely been content poking holes in the theory. In other cases, the positions staked out are complementary.*

All the participants, of course, anticipate further discoveries that will confirm, once and for all, their own theoretical predictions.

What Good Was All the Headgear?

For Decoration

By Mark B. Goodwin

After prospecting for several hours one hot, dusty afternoon in the summer of 1983, I noticed a round, cracked, softball-size, and honey-colored fossil emerging from the badlands around the Judith River Formation in Montana. I was about to uncover the best pachycephalosaur ("thick-headed lizard") skull yet found, buried in the bed of an ancient stream that had meandered across a broad coastal plain 78 million years ago.

Pachycephalosaurs first gained notoriety when the science-fiction writer L. Sprague de Camp characterized them as "bonehead" dinosaurs with a fondness for using the "bulge" of "solid bone" on top of their brains to "butt each other with these heads in fighting over the females."

In pachycephalosaurs, the bones at the top of the skull do indeed unite to form a conspicuous round (and quite solid) dome, surrounded by clusters of bony horns, nodes, and tubercles. Some specimens even sport multiple pairs of horns, between four and six inches long. Needless to say, all this headgear is prominently featured when charging pachycephalosaurs are portrayed. But did these dinosaurs really butt heads?

My colleague John R. ("Jack") Horner, of Montana State University–Bozeman, and I tested the head-butting hypothesis on some thirty pachycephalosaur domes and skulls. We examined micron-thin sections of bone from the insides of the skulls under the microscope, and imaged the skulls with high-resolution computer tomography. Both juvenile and subadult pachycephalosaur domes turned out to be highly porous and filled with spaces for blood vessels, showing that the bone tissue was fast-growing and well nourished.

For decades paleontologists had as-

For Defense

By Catherine A. Forster and Andrew A. Farke

When fossil ceratopsians, or horned dinosaurs, were first discovered in the American West in the 1870s, the enormous spikes, horns, and neck shields that sprouted from the creatures' humongous skulls instantly captivated the public and paleontologists alike. Speculation about the purpose of these bizarre cranial appendages quickly followed. Paleontologists suggested that the long horns were used defensively, to "impale the enemy." Even today this idea makes perfect intuitive sense. Any animal fairly bristling with long, pointed horns and spikes simply looks ready to fend off any and all would-be predators. More recently, paleontologists have suggested that other dinosaurs, notably the dome-headed pachycephalosaurs, also used their cranial appendages defensively.

Pointy headgear certainly plays a role in the defensive strategies of many modern animals. For example, the horned lizard *Phrynosoma mcalli* apparently uses the horns on its head to deter the shrike, a bird fond of impaling lizards on thorns or barbed wire for later consumption [*see "The Natural Moment," March 2005*]. Longer horns make a lizard less likely to end up as a shrike's meal. Much larger animals adopt a similar defensive strategy: some unfortunate visitors to Yellowstone National Park have experienced the use of horns by bison firsthand.

But paleontologists early on recognized that defense may not have been the sole function of cranial "weaponry." In 1907 J.B. Hatcher and colleagues charmingly informed their sumed that what they called "radiating structures" in the dome could resist compression, giving the animals a biomechanical advantage in head-butting. Our microscopic examinations proved instead that the structures were transitory, a product of the growth of the dome. Remarkably, they were absent in the skulls of adults—precisely the individuals that would have engaged in head-butting. And in the fossils we examined, we saw no evidence of fractures, healed wounds, or specialized adaptations for managing the forces generated by head-butting, such as the adaptations that occur in bighorn sheep.

So if the elaborate cranial dome was not for head-butting, what was its function? We think the "bulge of solid bone" and accompanying cranial protuberances were chiefly ornamental. They enabled individuals within a species to recognize each other and communicate, the way African antelope such as hartebeest, impala, and wildebeest do when they display their elaborate horns. If the modern animals are good models, most encounters among head-butting dinosaurs would have been ritualized displays of intimidation, aggression, and submission.

Two male Centrosauruses cross horns in a fictionalized encounter. Was dinosaur headgear like theirs primarily for defense against predators or for combat over mates? Was it primarily for display? Or was it some combination thereof?

Our microanalysis yielded another noteworthy discovery: collagen fibers that typically anchor tendon and ligaments to bone lay within and just below the surface of the dome. The finding indicates that the skull had an external covering, most likely of hard keratin, similar to the bills of modern birds. Many birds display brightly colored keratin on their heads to communicate with other members of their species. The domed skulls of pachycephalosaurs may likewise have been vibrantly colored to indicate sexual maturity, attract a mate, or warn an adversary.

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readers that "*Triceratops* was extremely deficient mentally" and likely quite docile, except during the breeding season, when "combats between rival males . . . must have been prompted and carried out by blind, unreasoning instinct."

The "mate competition" hypothesis is borne out by research showing that the cranial headgear of most modern animals evolved not only for defense against predators, but also for ritualized jousting or just plain "showing off" among members of their own species. Male bighorn sheep with the largest horns, for instance, have the highest social rank and are more likely to mate. Similar patterns hold for many horned or antlered mammals, including African antelope, deer, and pronghorn. Among reptiles, the male Jackson's chameleon (which looks like a miniature *Triceratops* with three horns and a bony frill, or ruff, over its neck) also engages in horn-to-horn combat with other males of its kind.

Actual evidence of horn use in ceratopsians is circumstantial. On some *Triceratops* fossils, both on the face and on the frill (the only plate extending back over its neck), there are healed puncture wounds. Some paleontologists interpret the wounds as evidence of combat with members of the same species. Other skulls show that ceratopsians underwent rapid evolutionary change and that, in particular, the size and shape of their horns and frills responded to shifting circumstances with great plasticity. Those findings suggest that natural selection focused on diversifying the cranial appendages for use in relations with other members of the same species. Beyond that, comparison to modern animals is all paleontologists have to go on to infer ceratopsian behavior.

Ultimately, dinosaurs probably used their cranial appendages in whatever way they were needed. The pattern is well demonstrated in deer: even though antlers function primarily for display and for combat with rivals, they can also be used with deadly efficiency against predators. *Triceratops* likely used its horns to impress mates, shoo off rivals, or argue for territorial ownership. But it's hard to imagine that such deadly weaponry wasn't aimed at a menacing *Tyrannosaurus* when the need arose. If you've got it, use it!

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BUTTING HEADS

Were Dinosaurs "Cold-" or "Warm-blooded"?

"Cold-blooded"

By John A. Ruben and Willem J. Hillenius

Endothermy, or warm-bloodedness, in birds and mammals results from high rates of internal heat production, even while at rest. In the wild, metabolic rates in birds and mammals are about twenty times higher than they are in reptiles. These elevated metabolic rates also require accelerated rates of oxygen consumption and lung ventilation.

Endothermy is a highly specialized physiological strategy, whose evolutionary history, until recently, was elusive: no fossilized structures could unambiguously and exclusively prove endothermy. For example, one might think that skeletal growth rates would be higher for an endothermic animal than for an ectothermic, or cold-blooded, one. Perhaps, too, the higher growth rates would become apparent in the bone microstructure. But both those tests are inconclusive, and, in any case, those features are not causally linked to the metabolic rates of birds or mammals. Even the possible presence of feathers in some dinosaurs is not a certain indicator of endothermy: many modern birds occasionally regulate their body temperatures ectothermically.

The entire study of metabolism in fossilized animals changed recently, with the realization of the importance of respiratory turbinates, the scroll-like structures in the nasal cavities of all terrestrial birds and mammals. Because turbinates reduce respiratory water and heat loss, they are tightly linked to high rates of lung ventilation in these terrestrial endotherms. In contrast, all living ectotherms lack respiratory turbinates. Thus the study of turbinates can open a window onto the metabolism of dinosaurs and their close relatives, the earliest birds.

Turbinates are delicate, and so they themselves are often not preserved in fossils. But their existence can be inferred in another way. We found that living endotherms have much wider nasal chambers than living ectotherms do, probably to compensate for the turbinates' extra resistance to air flow.

Multiple lines of evidence indicate that dinosaurs had relatively narrow, ectotherm-like nasal passages. When we examined several specimens, including the theropod *Nanotyrannus*, via computed tomography (CT), we could find no evidence of respiratory turbinates. In all dinosaur specimens the nasal passages are surprisingly narrow, with little room for an elaborate complex of respiratory turbinates, and proportionately nearly identical to those of extant ectotherms. The CT scans also revealed that most of the space in the animals' snouts was taken up by large, air-filled nasal sinuses, which do not function in respiration.

Together, those findings constitute strong evidence that dinosaurs and

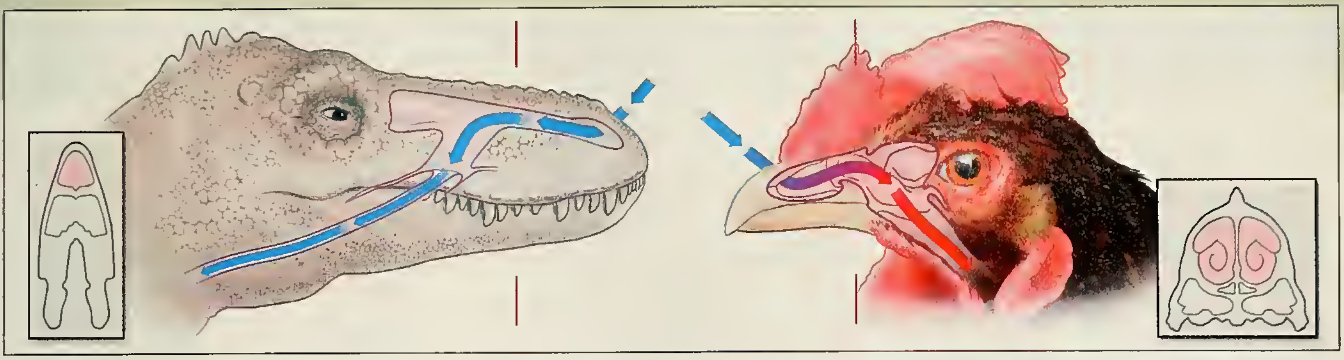
"Warm-blooded"

By Mary Higby Schweitzer

When I was growing up, paleontologists (and virtually everyone else) regarded dinosaurs as slow-moving, stupid, ill-adapted reptiles—in short, ectothermic, or "cold-blooded." Now all that has changed: the dinosaurs' ancestors may have been cold-blooded, but most paleontologists think that, over time, dinosaurs began to exhibit traits that we link with higher metabolic rates. Today they are portrayed as lithe, agile, intelligent animals, able to compete with the best that mammals had to offer—and probably win. The idea that metabolic rates changed over time in this group of animals brings two basic questions to mind: First, why might an animal lineage adopt the strategy of warm-bloodedness, given its steep energy costs? Second, how—since no one can take the temperatures of extinct animals—can paleontologists tell what kind of metabolism was at work in the dinosaurs?

Natural selection favors new adaptations if, by reducing an animal's competition from other organisms for limited resources, or by helping it better survive and thrive in its environment, the animal produces more offspring. Yet, in general, a warm-blooded animal requires about ten to twenty times more food and oxygen (per unit weight, per unit time) than a cold-blooded animal. Those requirements would seem too costly for warm-bloodedness to evolve through natural selection.

Albertosaurus fossil shows the dinosaur's head and neck drawn downward over its back. The pose is struck when the muscles contract at death: the stronger muscles at the back of the neck—which hold the head upright in life—overcome the weaker muscles at the front. The death pose is characteristic of warm-blooded animals, such as birds and mammals. The fossil is in the Royal Tyrrell Museum in Alberta, Canada.



Respiratory turbinates recycle heat and moisture during breathing, and so prevent excessive respiratory dehydration in endotherms. For example, in the chicken (right), cool, dry air (blue arrows) enters the nose. As it passes through the complex of turbinates, it is heated and humidified (red arrows). When the bird exhales, most of the moisture condenses back onto the turbinate surfaces. In contrast, modern ectotherms, such as crocodiles and lizards, lack respiratory turbinates; their ventilation rates are so low that the amount of water lost through breathing is negligible. To make room for the turbinates, endotherms have comparatively spacious nasal cavities (see inset at right). CT scans, however, indicate that dinosaurs such as Nanotyrannus *(left) have very narrow nasal passages (see inset at left), nearly identical to those of modern ectotherms. It therefore appears that dinosaurs, and even early birds, lacked respiratory turbinates, and that their lung ventilation rates and metabolic rates were not as high as those of modern endotherms.*

early birds lacked the high ventilation rates associated with endothermy. The modified, enlarged "modern" avian nasal cavities first appear in certain Late Cretaceous birds, which suggests that endothermy appeared relatively late in the evolution of birds.

The metabolic status of the dinosaurs probably reveals less about their lifestyle than many investigators have supposed. For example, it would be erroneous to conclude from their relatively low metabolic rates that they were sluggish herbivores or "sit-and-wait" predators. Given the mild climates of the Mesozoic, most dinosaurs almost certainly maintained a constant body temperature, whether they were endothermic or not. And even if they were fully ectothermic, there are large, tropical-latitude lizards, such as the Komodo dragon, alive today that demonstrate that ectothermy by no means implies sluggishness. Had dinosaurs possessed the physiological capacities and predatory habits of the Komodo dragon, they might well have maintained large home ranges, actively pursued and killed large prey, and, when cornered, defended themselves fiercely.

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One plausible explanation is that warm-bloodedness reduced competition. If an animal's metabolic rate was just a little bit higher than that of its competitors, maybe it could be active for just a little bit longer, or could move a little bit faster. Maybe it could forage an hour earlier or an hour later than its competitors, or move a little farther from home to find food and water. Maybe, with extra speed, it could hunt prey more effectively. Those advantages would not require a great increase in body temperature (half a degree might suffice). But the benefits might be enough, statistically speaking, to pass on a higher metabolism to offspring. Other factors might then favor yet another slight increase in body temperature. Ever so slowly, the animals in the lineage might approach what biologists consider full-blown endothermy.

The second question is slightly more complicated. By studying living animals, however, we can answer a great many questions about the metabolic rates of extinct animals. Dinosaurs had many characteristics that today occur only in warm-blooded species. Only warm-blooded animals become obligate bipeds—animals that *must* walk on two legs. Only warm-blooded animals have upright posture: legs positioned directly under their bodies, rather than splayed to the sides, as in lizards. Only warm-blooded animals have an insulating body covering, such as hair or feathers. Warm-blooded animals are the only terrestrial creatures that live in large herds or flocks or that migrate long distances.

All those traits occur in dinosaurs. More precisely, some traits (upright posture) occur in all dinosaurs; other traits (feathers) occur only in some. Dinosaurs may not have been as fully warm-blooded as birds or people are, but all the evidence suggests their metabolic rates were substantially higher than those of living crocodiles, lizards, snakes, and turtles.

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BUTTING HEADS

Were Dinosaurs the Victims of a Single Catastrophe?

Yes, and an Asteroid Did the Deed.

By David E. Fastovsky

The idea that a single, spectacular, catastrophic event—an asteroid impact—at the end of the Cretaceous period, 65 million years ago, obliterated all the nonbird dinosaurs (as well as many other organisms) is a simple, attractive scenario. But is it more accurately described as *simplistic*? Since not all life was wiped off our planet, there must have been winners as well as losers in the Cretaceous endgame. Surely survival occurred for better reasons than a mere roll of the cosmic dice!

Yet in the past fifteen years it has become clear that the extinction of the dinosaurs was geologically instantaneous. Geological instantaneity, however, is an inexact quantity. From a vantage point of 65 million years after the event, paleontologists cannot resolve time spans of less than tens of thousands of years: whether the extinction took a minute or many thousands of years may never be known. Still, 10,000-year timescales rule out events that lasted millions of years, and those include a whole class of gradual, earthbound processes.

In three separate studies in western North America (the only place where these issues have been studied), the diversity of dinosaur fossils was carefully recorded, meter by meter, through rocks that record the Cretaceous-Tertiary (K/T) boundary. In each case, paleontologists failed to identify any decrease in dinosaur diversity in the 2 million years or so preceding the boundary. In fact, every published, quantitative, field-based, stratigraphically refined study addressing this question has concluded that dinosaur diversity was unchanged up to the K/T boundary: the final extinction was thus geologically instantaneous.

When it comes to the ecology of survival, paleontologists are in refreshing agreement: your chances of surviving were pretty good if you were small and cold-blooded (correctly termed ectothermic). But your best bet was to be aquatic.

At first blush, those attributes might not seem the ideal armament against incoming asteroids. But they do seem to have been keys to survival. Although the exact effects of large-body impacts on Earth remain

No, It Only Finished Them Off.

By J. David Archibald

Some 65 million years ago, Murphy's Law applied—almost everything that could have gone wrong did: A huge bolide, or asteroid, struck Earth. Globally, the seas receded. Fissures on the Indian subcontinent spewed forth thousands of cubic kilometers of material. All three events took place in rapid succession, toward the end of the Cretaceous period. Each of them is thought to have been the largest event of its kind in the past 250 million years, and each is thought to have played a role in the demise of the nonbird dinosaurs. Each event left obvious physical and chemical proof of its occurrence in the rock record. That much is clear. But how can paleontologists measure the effects of such events on the creatures living at that time?

The most powerful method is simply to read, in the fossil record, which animals survived and which did not. Only western North America, though, preserves a reasonably continuous fossil record of the land and freshwater vertebrates for the last 10 million years of the Cretaceous and on through the Cretaceous-Tertiary (K/T) boundary. In those last 10 million years of the Cretaceous, but well before the K/T-boundary events, the most recent compilations show an unequivocal decline in the diversity of dinosaur species. In fact, before the time of the boundary is reached, between one-third and one-half of all dinosaur species—mostly such relatively common groups as the duck-billed and horned dinosaurs—had already disappeared.

The analysis of the final million years of the Cretaceous is more problematic, because the precision required is far greater than is discernible in the fossil record. A recent study in North Dakota noted little or no change in the vertebrate fauna throughout the thickness of the Hell Creek Formation. Those data were cited to argue that a bolide impact must have suddenly terminated the nonbird dinosaurs at the top of this formation.

Yet in the uppermost five meters of the formation only two dinosaurs could be identified well enough to specify their generic name. What happened to the other eighteen or so nonbird dinosaur species present in the Hell Creek Formation? No one knows whether they survived to the time of the boundary or became extinct thousands of years before it.

Apart from the problems of detecting rates of dinosaur extinction, we can examine the pattern of total vertebrate extinction. Of 107 species of vertebrates known from Hell Creek, about half had disappeared uncertain, there is a general consensus that such impacts probably have two kinds of dire consequences: dust, smoke, and debris in the atmosphere blocking sunlight for several months, and an instantaneous pulse of thermal energy igniting global fires. [*See "Loading the Cannon," by Charles Liu, page 58.*]

For both those effects, being small, ectothermic, and aquatic may have been the secret to survival. For as long as sunlight was blocked, photosynthesis would have ceased, reducing much of Earth's available foodstuffs to detritus. Dinosaurs and other organisms dependent on "primary production"—fresh plants and meat—would have become effectively helpless. But aquatic animals, which tend to feed on detritus, may have been protected. On land, many Cretaceous mammals were likely part of detritus-based food chains. Furthermore, many were small enough to have lived in burrows (as many small mammals do today), and so they could have been protected from the thermal pulse. Finally, in the face of a global heat pulse and fires, small size and aquatic refuge offered nearly ideal shelter in what had become an inhospitable world. In short, the ecology of both winners and losers reflects the imprint of the impact with surprising fidelity.

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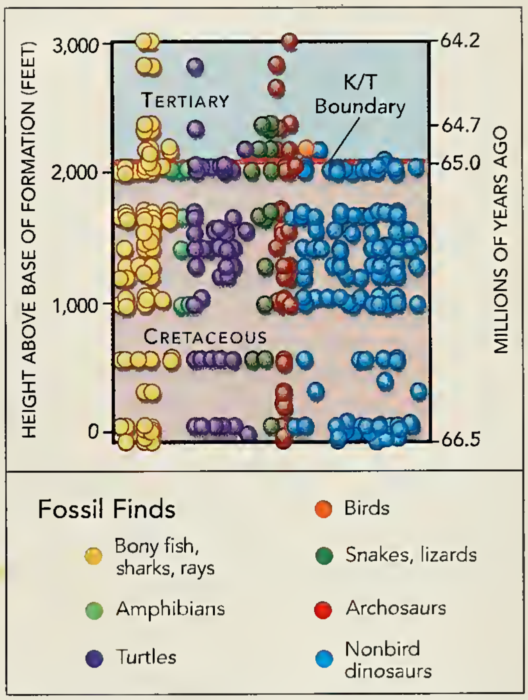

Record of the distribution of fossil vertebrates (colored dots), excluding mammals, is shown for rocks of the Ferris Formation, in south-central Wyoming. The figure shows the approximately 1.5 million years before the Cretaceous-Tertiary (K/T) boundary, 65 million years ago, and 800,000 years after it. The red horizontal line represents a layer of rock more than twenty-six feet thick that includes the boundary. Because that layer is largely devoid of fossils, the exact location of the K/T boundary within those twenty-six feet is uncertain. Nonbird dinosaurs disappear dramatically within the twenty-six-foot-thick layer. The data are from J.A. Lillegraven and J.J. Eberle, Journal of Paleontology *73:691–710, 1999; the figure is based on a graph in D.E. Fastovsky and P.M. Sheehan,* GSA Today *15:3, 4–10, 2005.*

by the time corresponding to the K/T boundary. Of those extinctions, 75 percent are concentrated in just four groups: lizards, marsupials, sharks (and their relatives), and nonbird dinosaurs. The lizards may have faced habitat loss from increasing rainfall in the Hell Creek region near the end of the Cretaceous. As sea levels fell, the Bering land bridge enabled the precursors of modern hoofed mammals to enter North America and outcompete other mammals, notably the marsupials. The sharks, too, lost their habitat as the seas retreated. And the nonbird dinosaurs? With the loss of inland seas, the low coastal plains, from which almost all of the fossils of these animals are known, shrank and fragmented.

Then the bolide struck Earth. Many consequences of this impact have been proposed—global wildfire, extended periods of darkness, sharp temperature increases, tsunamis, and hurricanes. Other suggested effects—notably acid rain and a sharp drop in the temperature—now seem extremely unlikely, given the fossil record. The most recent proposed consequence has been sudden infrared heating. That might explain why large creatures such as dinosaurs died, whereas smaller species survived by taking refuge in holes, crevices, or under a thin layer of water.

Whatever the results of the impact, though, it only finished a job that earthbound factors had already begun. The dinosaurs and other vertebrate species had already become vulnerable to extinction.

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How Did Dinosaurs Begin to Fly?

From the Trees Down

By Sankar Chatterjee and R. Jack Templin

A century-old controversy over whether avian flight began in the trees (trees-down theory) or on the ground (ground-up theory) finally appears to be settled. Hundreds of small, exquisitely preserved feathered theropod dinosaurs were discovered just as they were some 125 million years ago when they were smothered in the "Cretaceous Pompeii" of China. These fossils show various transitional stages—from wingless, tree-dwelling theropods to fully winged, active flyers.

The central theme of the trees-down theory is that gravity was the source of energy: a small climbing dinosaur first parachuted down, then began to stay aloft longer by gliding, and finally acquired powered flight. As those abilities developed, feathers became larger and more specialized, providing greater lift and thrust. In contrast, a theropod struggling toward flight directly from the ground up, without any gliding stage, had gravity working against it.

We developed a computer model to simulate the flight performance of these Chinese theropods and an early bird, *Archaeopteryx*. All these animals had acquired adaptations for quadrupedal climbing similar to those of the modern young hoatzin, a bird native to tropical South America. They were small, with highly recurved claws; their fingers and toes were long for grasping bark; their wrist joints were swiveled so they could flex their hands during climbing; and their stiffened tails supported them as they climbed upward.

At first, small theropods such as *Sinosauropteryx* invaded arboreal habitats to elude predators. Their bodies were covered with downy feathers, which provided insulation in the cooler environment of the trees.

Caudipteryx and *Protarchaeopteryx* typify the next stage in the evolution of flight. Symmetrical contour feathers on their hands and tails provided lift during parachuting, but offered little control over the flight stroke.

Microraptor, which exemplifies the third stage of flight, was a glider; its two sets of wings, one over the other, functioned much like the fixed wings of a biplane. But the creature's most unusual feature was a set of long, asymmetric feathers with hooked barbs on its hind limbs and forelimbs. The leading edge of each long feather was narrower than the trailing edge, which helped streamline the body in flight, and the hooked, interlocking barbs gave strength and flexibility to the feather and prevented air from passing through it in flight.

From the Ground Up

By Luis M. Chiappe

Early on a windy December morning, slightly more than a hundred years ago, the Wright brothers' *Flyer* made a short takeoff run, then took to the air. The airplane was aloft for only 120 feet, but the flight was epoch-making: the first time a powered, heavier-than-air flying machine got off the ground to make a successful, controlled flight.

More than 150 million years earlier, another first took place in aviation: a small dinosaur flapped its feathered arms as it ran, perhaps fleeing a predator. Slowly it rose above the ground, escaping its pursuer, and then lived long enough pass its genes on to the next generation. The era of avian flight had begun.

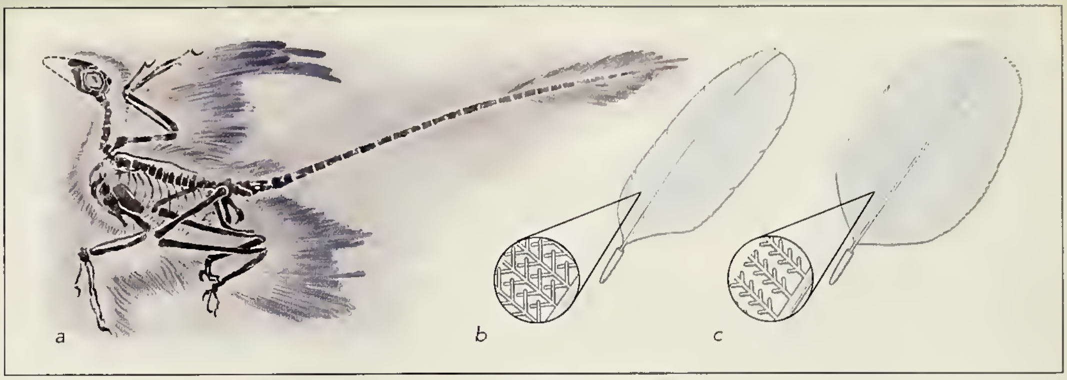
Making such a parallel between the Wright *Flyer* and the first dinosaur flight may seem far-fetched.

Primitive bird—or a theropod dinosaur—could have increased its thrust, or force in the direction of its run, by flapping its wings (a,b). The enhanced thrust would have boosted its running speed and, at the same time, increased its lift, the upward force created by the air moving across the wings. As lift increased, the force between the bird's hind limbs and the ground would have been reduced until it reached zero and the bird took off (d). The bird's center of gravity (red crosshairs) would not move up or down until the bird left the ground, because the vertical components of all the forces would have remained in equilibrium.

But new evidence has given fresh credibility to the idea that flight originated "from the ground up."

Since the late 1800s, two antagonistic theories have competed to explain the onset of avian flight. Some investigators have argued that birds became airborne "from the trees down," as their theropod forerunners mastered tree-climbing, then parachuting and gliding, and finally powered flight. Others have countered that small land-dwelling dinosaurs learned to fly without ever developing arboreal

Such asymmetric feathers are essential for flight—and their presence in a fossil this old contradicts the ground-up theory: *Microraptor* had them even on its metatarsals, or "toes," which would have made running on the ground nearly impossible. Our analysis suggests that *Microraptor* held its hind legs tucked under its body in a Z shape during gliding, which gave the animal a configuration strikingly similar to that of a biplane.



Fossil of Microraptor (a) has preserved traces of the animal's feathers. The long digits and sharp claws of the fore- and hind limbs equipped the animal both for climbing trees and perching in them. The long feathers on its wings and legs had evolved for flight: they were asymmetric, with interlocking barbules (b); less developed feathers, such as the symmetric feathers with noninterlocking barbules (c), cannot sustain flight. The long flight feathers on Microraptor's back legs limited its ability to run in preparation for takeoff; to launch its flight, it would first have had to climb a tree and take off gliding, assisted by gravity.

Sinornithosaurus represents the fourth stage of flight. Its forewings were even larger than *Microraptor*'s, forming, in essence, a gliding monoplane. The feathers on the metatarsals were lost on the back wings.

Finally, *Archaeopteryx* achieved fully powered flight, as its wings became even larger than those of *Sinornithosaurus. Archaeopteryx* retained the hindlimb feathers of the gliders, but the feathers were now much shorter, more like the "trousers" of modern raptors that streamline the legs just before an aerial attack or during a flight with a captive prey. It is intriguing to contemplate that perhaps avian flight, like aircraft evolution, went through a biplane stage before the monoplane was introduced.

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habits: no trees were needed. The fact that gravity-aided flight seems easier to achieve than its opposite has always lent a kind of intuitive advantage to the trees-down theory. Yet neither direct evidence of the hypothetical tree-climbing stage, nor convincing arguments that the meat-eating precursors of birds developed specialized adaptations for climbing or gliding, have ever materialized.

In contrast, the fossil record makes it clear that theropod dinosaurs lived a terrestrial existence. Their long legs and short toes were well suited for running. Fossils of bipedal, bird-like dinosaurs such as the parrot-headed oviraptorids, the lightly built troodontids, and the sickle-toed dromeosaurids have been discovered in positions that indicate they were brooding their eggs, but always in nests on the ground [*see "Bringing Up Baby," by David J. Varricchio, page 30*]. Some of them have been unearthed in dormant poses, indicating they also rested on the ground.

Furthermore, these animals evolved the skeletal framework necessary for flapping their feathered forelimbs—the functional precursors of powered flight. Fossils spanning the evolutionary transition from theropod to bird also detail how the wings of these animals became larger as their bodies became smaller. Aerodynamic studies have documented how, by flapping their wings, the animals could have boosted their running speed. Taken together, the evidence suggests that flight could have evolved as a by-product of wing-assisted running in animals that were becoming lighter even as their wings were becoming bigger.

Does all this evidence prove conclusively that birds evolved their flight from the ground up? With wing-assisted running the theropod forerunners of birds could have ascended inclines, including trees. But if they did, why didn't they take advantage of that more protective environment when they were nesting or resting—that is, when they were most vulnerable to predators?

Theories about the origin of flight will continue to be conjectural. Yet aerodynamics, the potential for locomotion, and the documented habits of birds' predecessors all make the ground-up hypothesis the less conflicted of the two conjectures.

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Tales from the Badlands

By Adrienne Mayor

In art and oral legends, Native Americans recorded their encounters with dinosaur fossils.

Zuni Pueblo, in New Mexico, may be the oldest continuously occupied community in the United States. The town of less than 7,000 is the cultural center of a tribe that can trace its roots back for millennia, a culture informed through and through by the volcanic mountains and deeply eroded canyons of the dramatic landforms all around. The Zuni story of the creation of the world reflects those surroundings.

In Zuni myth, before humans were fully formed, they lived underground, in the dark. When they finally emerged to the surface through a series of caverns, they had to shield their eyes, which, like an owl's, were unused to daylight. The world had been covered with water; it was damp and wracked by earthquakes. The humans lived on an island surrounded by water, preyed upon by strange monsters that rose up from the deep.

Two mythical brothers, twin children of the Sun, realized that the world needed to be dried out and solidified lest the humans succumb to the monsters. Wielding a magic shield, a rainbow, and arrows of cosmic lightning, the two ignited a tremendous conflagration. The fire raged over the face of the earth, scorching it dry and hardening the ground.

But now, on the newly dry land, powerful predatory animals, with their talons and sharp teeth, threatened to multiply and devour the human beings, who were so much weaker. So the two brothers strode across the world, blasting mountain lions and other creatures with lightning. "We have changed you into rock everlasting," they proclaimed, as they struck the animals with their lightning—*thlu!* Yet the petrified creatures retained the heart and "magic breath of prey" that had made them powerful, and they became *we-ma-we,* or fetishes, helpers that would serve people instead of devouring them.

In 1881 the ethnologist Frank Hamilton Cushing heard this ancient epic recited by Zuni priests. He had lived many years among the Zuni, learned their language, and been adopted into the tribe. The priests explained that all kinds of beings were changed to stone when the earth was young. Thus "it happens that we find, here and there throughout the world, their forms, sometimes large like the beings themselves, sometimes shriveled and distorted," the priests told Cushing. "And we often see among the rocks the forms of many beings that live no longer, which shows us that all was different in 'the days of the new.'"

Petroglyph at Cub Creek, near rich bone beds and fossil trackways in Dinosaur National Monument, Utah, is attributed to the Fremont culture (A.D. 700–1200). It depicts large lizardlike creatures approaching a smaller human figure. Many Native American creation myths envision earlier eras in which ancestral people were preyed upon by monsters.

The only other vehicle I saw on the long dirt road to the Hell Creek field camp was a dusty pickup truck carrying a *Triceratops* skull encased in plaster. I was on my way, seven summers ago, to visit a new excavation site in the badlands of eastern Montana. John R. ("Jack") Horner, of Montana State University–Bozeman, and his team were searching for dinosaur bones in the same landscape where the fossil hunter Barnum Brown had discovered *Tyrannosaurus rex* almost a century earlier. The colorfully layered hills and ravines, dotted with sagebrush and home to rattlesnakes, are a vast burial ground of dinosaur species that lived here between 68 million and 65 million years ago, near the end of the age of dinosaurs.

The day was a scorcher, but we happily climbed hills, scrabbled down clay cliffs, and walked along dry alkali washes, scanning constantly for bits of bone and tooth, until every canteen was empty. Everyone in our group found at least one piece of dinosaur bone or tooth. Among the prospectors was Joseph Johnston,

Native American petroglyph, or rock carving, was made by chipping away the dark, weathered surface of a sandstone boulder in Petrified Forest National Park, New Mexico. Believed to be between 650 and 1,000 years old, the image appears to show an enormous bird that has seized a person. Great birds of prey, such as giant condors and teratorns, may have once co-existed with people in the region, but legends about the great birds were most likely sparked by the discovery of their fossils or mummified remains. In other locales, dinosaur tracks and the bones of pterosaurs—the large flying reptiles that were contemporaries of the dinosaurs—may have helped confirm belief in the gigantic Thunderbird, which wielded lightning.

the director of *Jurassic Park III* (Horner was the paleontological consultant for the movie series). Johnston pulled from his pocket a five-inch-long, black fang, the point and serrated edges still razor sharp. It was so obviously the tooth of a terrible predator that we were all struck silent by the reality of dinosaurs.

"We often see among the rocks the forms of many beings that live no longer."

Around the campfire that night, as we watched the black skies for falling stars and satellites, the talk drifted to the people who had known these fossil-rich badlands better than anyone else ever would: the Blackfeet, Crow, and Sioux. Long before the arrival of Europeans, Native Americans had been the first to experience the thrill of discovery that we had felt today.

Suddenly we all were wondering out loud: What did Native Americans think of these bizarre skeletons mysteriously turned to stone? How did they explain the bones, claws, and teeth of gigantic creatures that no one had ever seen alive? Did they speculate about what could have destroyed such monsters? Growing up in South Dakota, I had read Sioux myths about Thunderbirds fighting Water Monsters. Now I was curious to know whether those stories had been woven around the skeletons of dinosaurs and other giant reptiles that people had observed weathering out of the badlands. The questions kept me awake in my tent late into the night, and by morning I had decided to learn about the paleontological knowledge of the First Americans. My goal became to recover, from their oral legends, as many details as possible about their early fossil discoveries and insights.

Three-toed dinosaur footprint is highlighted in Arizona stone after a rain. Historical records show that Native Americans often commented on the resemblance between such tracks and those of birds. Current paleontological thinking is that the living birds are a branch of an important group of bipedal dinosaurs known as the theropods.

Of course, many fantastic creatures of myth are purely imaginary or symbolic, and their origins and meaning may have nothing to do with paleontology. It's also true that as information is passed down over generations and across cultures, important details can be garbled, misinterpreted, or omitted. Old traditions may even become intertwined with new layers of modern knowledge about dinosaurs or extinct mammals. In addition, many Native American groups have migrated far from their original homelands or been displaced from them; the creation myths their forebears carried with them may not accord with the new surroundings.

But many examples of fossil legends survive, such as the epic Zuni tale recorded by Cushing. Some of the traditional concepts even anticipate modern theories of geologic ages and ancient life-forms, telling of the relations among species, changes over time, and great extinctions in the deep past.

In the northeastern U.S., the fossils of Pleistocene mastodons, oversize buffalo and bears, and even rare dinosaur bones were the inspiration for exciting tales of giant creatures among the Iroquois, Delaware (Lenape), and other Indian nations. Fossilized footprints of dinosaurs, known to the Iroquois as *uki* prints, also drew intense interest. (*Uki* refers to the powers of the sky, such as thunder and lightning).

A legend recounted by Richard C. Adams, a Delaware born in 1864, attempted to explain the presence of dinosaur footprints embedded in rock. "When the world was young," wrote Adams,

> there lived in this country many huge Monsters, some who dwelt in the sea, some who roved over the land, and some who lived on land and in the water. The grandfather of these Monsters was greater than them all . . . and preyed upon every living creature . . . and he was a terror to all living things.

When this stupendous monster crossed the mountains, Adams added, "He made tracks on the stones, and in many places his tracks can be found today."

The Delaware legend accounts for observed fossil evidence, most likely the tracks left by extinct theropod dinosaurs (theropods are a group that includes such carnivores as *T. rex* as well as modern-day birds). Giant theropod tracks abound in Maryland, New Jersey, and eastern Pennsylvania. When I visited local dinosaur museums on my travels between 1998 and 2004, I was amused to notice how much the Delaware vision of the "greatest monster that terrorized all other creatures," written sometime between 1887 and 1905, resembles this typical description from a small-town dinosaur display: "65 million years ago lived the greatest, most powerful predator ever to walk the Earth. The great *Tyrannosaurus rex* feared nothing."

Few dinosaur skeletons, however, are preserved in the eastern half of the U.S. or on the West Coast. In other regions, however—the arid Southwest (New Mexico and Arizona), the Great Basin (Utah and Nevada), the Rocky Mountains of Colorado, and the badlands of Montana and the Dako-

Members of the Hopi Snake Society, photographed in the early years of the twentieth century, perform a ritual rain dance, invoking the assistance of a kachina, or deified ancestral spirit. One of the emblems on their kilts bears a striking resemblance to a fossil dinosaur track, such as the one in the photograph on the opposite page. The Hopi may have attributed the track to the kachina.

tas—dinosaur fossils are abundant. There mountain building and the deposit of sediments favored the preservation of Triassic, Jurassic, and Cretaceous fossils, and the fossil beds have been uplifted and then dramatically carved and eroded by water and wind.

In Cretaceous times, between 145 million and 65 million years ago, the lands of the Southwest lay along the fluctuating western shore of a shallow inland sea that bisected North America. Stone ammonites, clams, fish, oysters, and other marine fossils bear silent witness to those ancient times. The flooded land in the Zuni creation myth shows the Zuni recognized that a sea had once covered their desert. Volcanic evidence, such as burned rocks and hardened lava flows—and perhaps even an oral tradition of eyewitness accounts of eruptions—supported another part of the Zuni creation myth: that a great conflagration had dried out the young earth, enabling human beings to survive.

Modern Zuni fetishes, small carved stone animals with inlaid hearts, are well-known tourist commodities. But traditionally, the most valued personal fetishes were small rocks or fossils that resembled some animal form. Most treasured of all were the ones that needed little or no carving to bring out the animal likeness. As Cushing had noted, the heart and breath—the soul—of every once-dangerous predator or monster remained in its *we-ma-we,* or fetish, even though its body had been turned to stone. Such predator fetishes were used mostly as hunting charms, because the breath of a predator, derived from its heart, was believed to be the force that overpowered the hearts of game animals.

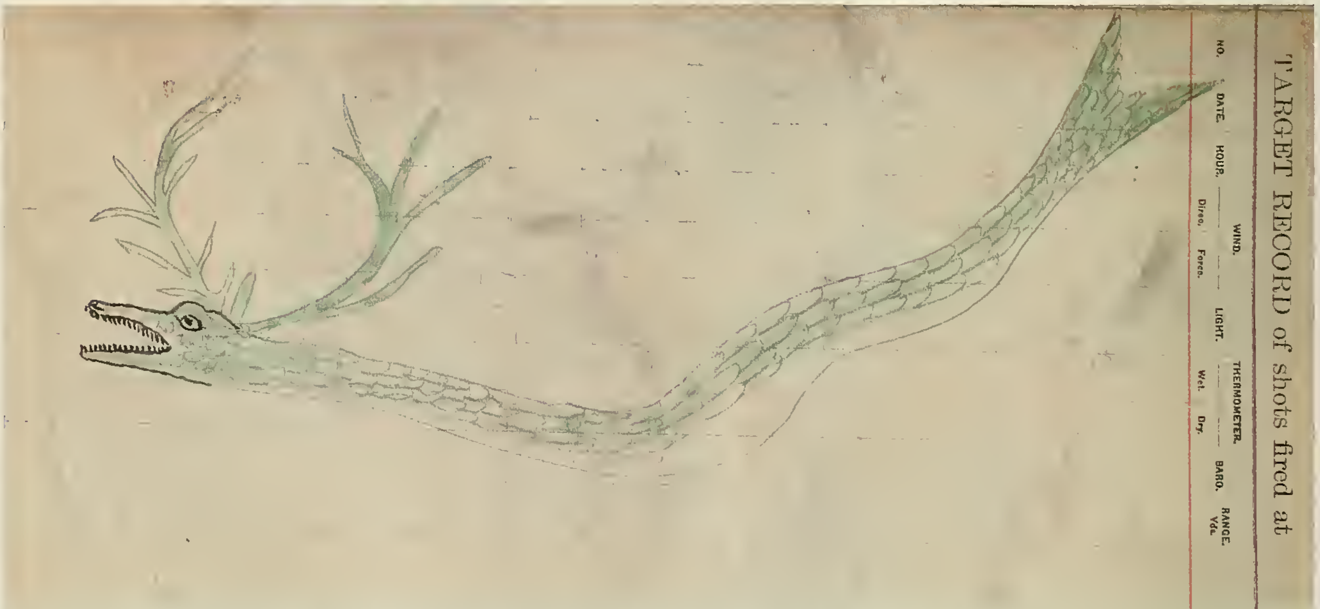
When the elders among the Zuni spoke of finding the forms of many beings no longer alive—"sometimes large like the beings themselves"—they were describing the skeletons of dinosaurs and other extinct creatures. Fossil skeletons may have been the original *we-ma-we,* but claws, teeth, and smaller fossil bones, along with animal-shaped concretions, were more easily carried as amulets. Recent Zuni carvers, aware of the connections between fossils and fetishes, have even begun to make small fetishes in the shapes of dinosaurs.

The Navajo of New Mexico and Arizona are close neighbors of the Zuni and share some similar legends. Yet, as many paleontologists have noted, they shun fossils because of their connection with death. In the 1930s, during the construction of a dam on their reservation, Navajo workers refused to continue after enormous bones were exposed by the horse-drawn scrapers. "*Chindee*," they whispered. "Ghost." Around the same time, the geologist Baylor Brooks learned from some Navajo that the bones of immense dinosaurs and marine reptiles were considered to be the remains of the monster Yeitso. The giant's ghost was said to haunt the bone beds.

In Navajo creation myth, the present world emerged out of a series of past worlds—the number varies—that were destroyed long ago. People escaped from each world, bringing a token from the previous era. The earlier worlds, wet and muddy, were dominated by monsters, which had been created before people were and which pursued them as prey. Salvation came, in the Navajo myth, when the Sun gave special lightning bolts to the twin sons of Changing Woman, enabling them to become the heroic Monster Slayers.

The first, most dreaded monster overcome by the twins was Yeitso. The bones of the monster were all around: large fossils of dinosaurs or marine reptiles, as well as immense petrified logs (which can resemble bones). Yeitso was also described as covered with flinty scales, an image that recalls the distinctive remains of Triassic amphibians, phytosaurs, and armored dinosaurs covered with bony scales or scutes. And indeed, like the dinosaur bones and petrified logs, fossilized scutes or plates of armored dinosaurs and other species are conspicuous in the desert. Water monsters, born of rock in the first world, were also subdued by the Monster Slayers but were allowed to live because they promised to keep springs and rivers flowing. Like the water monsters of many other Native American myths, they were imagined to have peculiar, elongated bodies and horns like a buffalo's.

Footprints in stone are plentiful in the Southwest and the Great Basin, and they, too, have attracted the attention of many Native American tribes for centuries. The three-toed tracks of extinct theropods bear a striking resemblance to those of their living relatives, the birds. A dinosaur trackway near Cameron, Arizona, for instance, was known to the Navajo as the Place with Bird Tracks. Representations both of birds and of three-toed dinosaur tracks sometimes occur in ancient rock carvings or rock paintings that are near dinosaur trackways.



Sketch of a water monster, known as Tenocouny or Zemoguani, was made by the Kiowa artist Silverhorn ca. 1891–94. The tribe, which inhabited the southern Plains, would have encountered the shells and other fossils of marine creatures, evidence that in ages past the region was flooded by a sea. Among the most impressive fossils that erode out of the landscape are those of mosasaurs—sinuous, toothed, predatory reptiles that grew thirty or more feet long.

For example, near a track site at Flag Point, Vermilion Cliffs, in the Grand Staircase–Escalante National Monument, Utah, are several representations of birds, painted onto the rock near what looks like an image of the footprint of a three-toed dinosaur. Tracks whose fossil name is *Eubrontes* (precisely which dinosaur made them is not known) are prominent in the area, and so the footprint image is probably a rendering of such a track. The rock paintings are attributed to artists of the Anasazi culture, who made them sometime between A.D. 1000 and 1200.

Perhaps even older are rock carvings at Cub Creek, in Dinosaur National Monument, Utah. One set of petroglyphs depicts lizards carved in various sizes, some as long as six feet, approaching a human figure only about a foot tall [*see photograph on page 57*]. The carvings have been attributed to the Fremont culture, which flourished between A.D. 700 and 1200.

In Arizona, members of the Hopi Snake Society incorporated three-toed tracks into the kilts worn in the traditional snake dance. This ritual is performed with live rattlesnakes, because the snakes are supposed to relay the need for rain to the proper kachina, or ancestral spirit. The rain-making spirit is envisioned as a giant underground serpent called Palulukon. Artifacts and photographs show that the design on the kilts has been in use for at least a century, and it cannot be known for certain what inspired them. The design has sometimes been said to represent duck or frog prints, but bears a striking resemblance to dinosaur tracks. According to one account, recorded in the early 1960s, the large, three-toed fossil tracks impressed in local rocks were believed to have been made by the kachina who sends the rain. Interestingly, the tracks are most noticeable after they become filled with rainwater. [*See photographs on pages 58–59.*]

The inland sea that covered Kansas and Nebraska during the Cretaceous period kept those lands off limits to dinosaurs. But within the Niobrara Formation, which forms chalk bluffs along the Solomon and Smoky Hill rivers in Kansas, are the petrified remains of a variety of marine creatures. Skeletons of enormous eel-like mosasaurs, long-necked plesiosaurs, and huge sea turtles inhabit the chalk, along with palm-size shark teeth and countless seashells. The Yale paleontologist Othniel C. Marsh, who explored the Smoky Hill River drainage in the 1870s, discovered *Pteranodon* skeletons with wingspans of twenty feet, the first flying reptiles known in the New World, as well as the fossils of giant diving birds.

But as with the dinosaur discoveries elsewhere in the Americas, indigenous people were on the ground first. Many stories in the Great Plains tell of battles between sky or thunder beings and water monsters. With the striking remains of giant creatures lying all about, it seems only a short imaginative step to the idea of such a primal conflict. Skeletons of the toothed *Hesperornis*, a great diving bird, have even been found inside skeletons of Cretaceous water monsters.

When the Sioux resided in the Great Lakes area, in what is now Minnesota, they described the ancient beings they called Unktehi as large, horned, mammal-like creatures that lived underwater. The description was probably based on the bones and tusks of mammoths and mastodons that eroded out of lakes and rivers. In the mid-1700s, however, some bands of Sioux acquired horses and began to move west, into what is now North and South Dakota, Nebraska, and eastern Wyoming and Montana. As they migrated into the badlands of the Dakotas, they began to encounter the fossil skeletons of large marine reptiles. And with those encounters, the western Sioux came to visualize the Unktehi as immense reptiles or serpents with legs, though the creatures retained their horns. Interestingly, a sketch by the late-nineteenth-century Kiowa artist Silverhorn depicts a mythical Plains water monster as a long, scaly serpent with a toothy crocodilian head, much like the skull of a mosasaur, but topped with branching antlers [*see illustration on opposite page*].

The Navajo refused to work on a dam after enormous bones were exposed. "Ghost," they whispered.

The Unktehi's foes were the Wakinyan, or Thunderbirds. In the Great Lakes region the extinct inspiration for the Thunderbirds could have included giant condors and Ice Age teratorns, with wingspans of twelve to seventeen feet (memories of the living animals could even have been preserved in some oral traditions). Sioux who traveled in the Dakotas and Nebraska, however, would have encountered *Pteranodon* and *Hesperornis* fossils. Legends of enormous birds in the badlands could also have grown out of encounters with the remains of *Diatryma*, a predatory flightless bird of the Eocene epoch (between 56 million and 34 million years ago).

Of course, no one can ever be sure just what role the remains of extinct winged or beaked creatures might have played in creating the mythology. Much of the lore about Thunderbirds—that they wielded lightning bolts, for instance—was the product of storytelling imagination. But the task of mining tales and myths for these and other links to the physical fossils is far from complete. Although some legends may have been irretrievably lost, others may be recorded in obscure documents or still survive as oral traditions, to be shared when someone asks the right questions. □

This article was adapted from Adrienne Mayor's book Fossil Legends of the First Americans, *which is being published this month by Princeton University Press.*

A Dinosaur Lover's Bookshelf

With so much out there, how is a dinophile to choose?

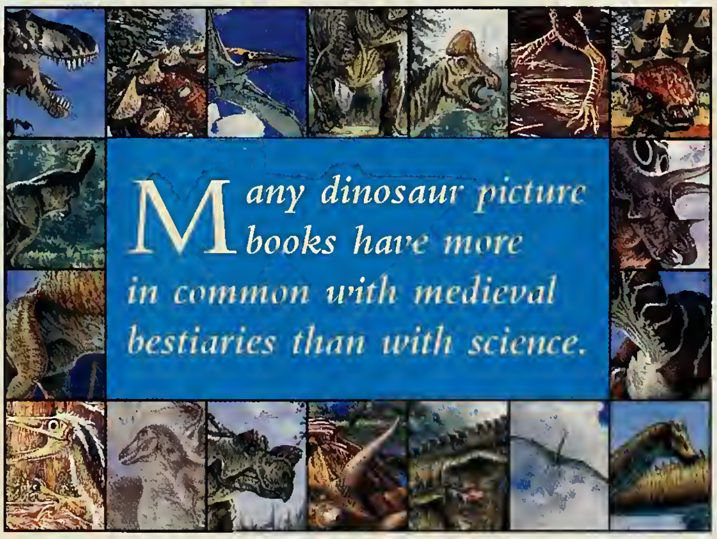
By Thomas R. Holtz Jr.

A persistent problem for the dinosaur fan, and no less for the parents thereof, is the search for the perfect dinosaur book. What the reader is looking for is a work that is textually and visually accurate, up to date, and comprehensive.

The trouble is, no dinosaur book is going to get it all right, or have all the latest information. Dinosaur paleontology, like any other growing science, is a rapidly evolving field—as the articles in this issue, and the current dinosaur exhibition at the American Museum of Natural History, can attest. Investigators are describing new species all the time; a total of more than fifty new species of Mesozoic dinosaurs were named in 2003 and 2004 alone. New techniques of analysis are continually uncovering previously unrecognized details about the internal anatomy and growth patterns of dinosaurs. And finds of spectacularly well-preserved specimens are revealing unknown and unsuspected features of species first described many years ago: long tail quills on the horned dinosaur *Psittacosaurus,* for instance, were never dreamed of until a specimen clearly showing that feature was unearthed recently in China.

What all this means is that important descriptive details in dinosaur studies can change in less time than it takes to get a book from its author's hands onto the shelves of a bookshop. What is a discerning reader to do?

Luckily, there are signposts that point to the titles you can trust. The most significant discovery in dinosaur paleontology in recent decades, for example, is that birds are the direct descendants



of dinosaurs—in other words, following modern conventions of classification, birds are the only living members of Dinosauria. A good book will recognize this discovery.

Another indicator that a work on dinosaurs is reliable and modern is the way it treats the question of scaly skin. Until the late 1990s it would have been acceptable, at least within permissibly cautious bounds, to depict the hides of deinonychosaurs (the "raptor" dinosaurs, small to medium-size bipedal predators such as *Troodon* and *Velociraptor*) as scaly. But recent finds in northeastern China, coupled with improved knowledge about the evolutionary relations between advanced carnivorous dinosaurs and birds, demonstrate that deinonychosaurs were feathered. Depicting a *Troodon* or a *Velociraptor* without feathers, therefore, would simply be antiscientific.

Paleoart is, admittedly, a difficult enterprise: after all, its subject matter is long dead, and science can never expect to know very much about the creatures' external surfaces or, for that matter, any of their other perishable features. Nevertheless, there is one inviolate rule of dinosaur restoration: if the known fossil skeleton conflicts with the shape of the reconstruction, the reconstruction must be wrong. That rule gives the casual reader at least a fighting chance of separating the wheat from the chaff: distinguishing books that depict restorations consistent with fossil specimens from books that have more in common with medieval bestiaries, conjured from rumor and imagination alone. One reliable clue that a book belongs to the former group is the inclusion of drawings or photographs of the fossil skeletons on which the restorations are based.

The popularity of dinosaurs, particularly among children, tends to make people forget that paleontology is a science. It's obvious when you think about it that understanding the research in the field requires a substantial amount of background knowledge. But, equally obviously, most of the people who produce movies, TV documentaries, and popular books about dinosaurs do not have such specialized knowledge. That line of thinking leads to a few more clues for choosing a dinosaur book: What is the expertise of the author? What subject is the focus of the text?

The discriminating reader will look for a book written either by, or at least in collaboration with, a paleontologist. That isn't to say that paleontologists always provide the most accurate or most entertaining information. But if you or your offspring are keen to find out about dinosaur science, you'll be better off relying on expert knowledge, or at least on well-informed opinion.

Of course, children love to master the blizzard of available trivial facts about dinosaurs—their height and weight, the pronunciation of their names—and publishers exploit that hunger for surface knowledge. But paleontologists know that, ultimately, the science of dinosaurs is all about methodology. The subject matter of the best dinosaur books will follow suit. Look for texts that explain how paleontologists discover fossils, interpret anatomy, and frame hypotheses about evolution and behavior. Check to see whether the artist has sought to make a lifelike restoration, based on a collaboration with a scientist.

Most of all, look for some hints about what is not known. A good book will explain that some of the most prominent physical details of a picture—the color of a dinosaur's scales or feathers, for instance, not to mention many aspects of dinosaur behavior—cannot be confirmed in the fossil record. Does the book make it clear that such things are still matters of pure speculation?

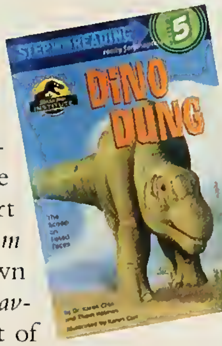
Although few books will meet all those standards, many of those mentioned below deal at least in part with the analytical side of paleontology. In selecting them, I've avoided coffee-table varieties with the format "dinosaurs from *A* to *Z*." Although some dino books are excellent examples of that genre, the selections that follow—which range from books for the very young to volumes for professionals in the field—comprise a variety of fresh approaches to the study of the "fearfully great lizards."

While I'm on the subject of the work of scientists in the field, a disclaimer is in order. The world of dinosaur paleontology is not only fast changing, but also rather small. There are only a hundred or so of us dinosaur paleontologists, and the community of paleoartists is even smaller. Together we represent a close-knit community. So I want to make it clear to the reader that I have previously worked, and am currently working, with some of the scientists, authors, and artists represented in the books reviewed, and have written chapters, in fact, for two of the volumes discussed below: *Dinosaurs: the Science Behind the Stories* and *The Dinosauria.*

For Young Readers

Dino Dung: The Scoop on Fossil Feces, *by Karen Chin and Thom Holmes; illustrated by Karen Carr (Random House Step Into Reading, 2005; $3.99)*

In the past several years the Step Into Reading imprint has released a number of children's books about specific subtopics in dinosaur studies, written by subject experts. Previous works include the paleontologist Robert T. Bakker's *Maximum* Triceratops, and my own T. rex: *Hunter or Scavenger?* The most recent of them, and a splendid point of entry for the ten-year-old in all of us, is *Dino Dung,* an up-to-date book on dinosaur paleontology.



Karen Chin, a paleontologist and the co-author of this newest member of the series, is the leading expert on dinosaur coprolites, or fossilized feces. Karen Carr, the illustrator, is one of the more subdued paleoartists working today. Unlike the images of artists such as Luis V. Rey and Michael W. Skrepnick, Carr's dinosaurs don't seem to be hurrying off somewhere; they're just causally going about the business of contributing to the fossil-fecal record.

Chin and Thom Holmes, a science writer, also tell the tale of how coprolite studies began: how, in the early 1800s, the English vicar and paleontologist William Buckland discovered fossilized hyena dung in Britain, then carried out comparative analyses of fresh droppings from zoo-kept hyenas. Chin and Holmes go on to tell us how feces can be preserved, and what kinds of information can be retrieved from these often-overlooked, and generally underappreciated, leftovers of the ancient world. Chin's presentations at technical conferences are notorious for including at least one bad pun, and she doesn't disappoint her fans here: one chapter is titled, "The Scat with Nine Lives."

Dinosaurs! *by Robert T. Bakker; illustrated by Luis V. Rey (Random House, 2005; $8.99)*

This book combines the talents of two of the more imaginative (some might say "controversial") workers in dinosaur studies. Robert Bakker, whose curriculum includes stints at both Harvard and Yale, as well as the Tate Geological Museum in Casper, Wyoming, was the enfant terrible of the dinosaur renaissance in the 1970s, when his research, combined with similar studies by his colleagues, laid to rest the mid-century vision of dinosaurs as inept, maladapted failures. Rey's dinosaur reconstructions (digitally superimposed for this book onto scenic background photographs) are so brilliantly colored they are almost garish, and the figures are probably the most dynamically posed of any in the tradition of paleoart. Yet despite the bold effects, the results are surprisingly mainstream, in the best sense of the word. That is to say, few dinosaur paleontologists today would find the information and reconstructions in *Dinosaurs!* at all unreasonable (except perhaps for the imaginative colors). If you are looking for a short, colorful, easy-to-read overview of the new understanding of dinosaurian diversity, this book will serve as an excellent introduction for young readers.

I Like Dinosaurs! *by Michael W. Skrepnick, a series for children ages six through eight (Enslow Publishers, Inc., $21.26 each)*
Diplodocus: ***Gigantic Long-Necked Dinosaur*** *(2005)*
Sinosauropteryx: ***Mysterious Feathered Dinosaur*** *(to appear in June 2005)*
Triceratops: ***Mighty Three-Horned Dinosaur*** *(2005)*
Tyrannosaurus rex: ***Fierce King of the Dinosaurs*** *(2005)*

Everything paleontologists know about dinosaurs is ultimately based on fossil discoveries, a concept this new series conveys to children in a sparse but visually inviting manner. Each volume features a single, famous dinosaur species (though often with some mention of related forms). Michael Skrepnick provides a short passage about the scenes depicted—only about thirty words per page. His paintings and drawings, combined with photographs from the field and from museum exhibits, support the brief accounts of the various species, their probable habits, and the way paleontologists have applied the available fossil evidence.

For Intermediate Readers

The Dinosaur Library, *by Thom Holmes and Laurie Holmes, illustrated by Michael William Skrepnick (Enslow Publishers, Inc.; $26.60 each)*
Armored, Plated, and Bone-Headed Dinosaurs *(2002)*
Baby Dinosaurs: Eggs, Nests, and Recent Discoveries *(2003)*
Gigantic Long-Necked Plant-Eating Dinosaurs *(2001)*
Great Dinosaur Expeditions and Discoveries *(2003)*
Feathered Dinosaurs *(2002)*
Horned Dinosaurs *(2001)*
Meat-Eating Dinosaurs *(2001)*
Peaceful Plant-Eating Dinosaurs *(2001)*
Prehistoric Flying Reptiles *(2003)*

This series occupies an intriguing literary niche between a primer for beginners and a book for adults. In some sense, the Holmeses, a husband-and-wife team of natural history writers, have produced a collection of books that is more deserving of the name "encyclopedia" than many single-volume texts in the *A*-to-*Z* format. Taken together, the books represent a relatively comprehensive survey of the major groupings within the Dinosauria. Individual volumes also touch on some related issues, such as dinosaur nesting behavior and field paleontology.

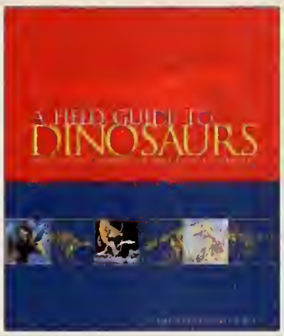
The taxonomic books—the ones focusing on particular dinosaur clades (groups of species that include all the descendants of one common ancestor)—all share the same structure. An opening story focuses on the life of a particular individual dinosaur. Introductory matter discusses dinosaur origins and diversity. Then several chapters cover the anatomy, physiology, and feeding habits of the group in question, and its probable extinction scenario. For a series aimed at young audiences, *The Dinosaur*

Library is unusual in including footnotes that refer to primary literature in the field. The series also gives separate chronological and geographic listings of important discoveries.

Dinosaurs as Living Animals

How to Keep Dinosaurs, *by Robert Mash (Weidenfeld & Nicolson, 2003; $14.99)*
A Field Guide to Dinosaurs: The Essential Handbook for Travelers in the Mesozoic, *by Henry Gee, illustrated by Luis V. Rey (Barron's, 2003; $24.95)*

These two books present rather different takes on dinosaurs as living animals. Mash, a zoologist who heads the biology department at a prestigious English secondary school, has revised and updated a highly amusing book that first appeared in 1983. Adopting the conceit that some dinosaur and reptile genera of the ancient world are still with us, *How to Keep Dinosaurs* provides the would-be saurian-pet owner with details of how to feed, house, raise, and train creatures that range from the diminutive pterosaur *Anurognathus* to the enormous *Brachiosaurus.*



Icons at the entries for each animal signal various aspects of dinosaur care in amiably wacky ways: the diet icon begets "fussy eater," "will eat other pets"; behavior evokes "worryingly clever," "iffy with babies"; practical considerations prompt "messy moulter" "government license necessary." Etymological readings of dinosaurs' genus names are also a source of unsuspected humor. Some are accurate derivations with humorous interpretations: *Ornitholestes,* literally "bird robber," is so named "for a tendency to break into poultry farms." Others are amusingly skewed: *Dicraeosaurus* (properly "bifurcated lizard") has become "two-meat-tray lizard," in reference "to the amount of meat a hunter can expect to get as his share of a carcass: this dinosaur is a popular diet item in Tanzania."

The new edition includes many recently named species, and several of these are appropriately feathered. But, in general, the science in this book is vintage 1980s. Many illustrations (superimposed onto photographs of contemporary domestic settings) are repeated from the original edition.

Whereas Mash brings dinosaurs from the ancient world into modern life, Henry Gee, a senior editor for paleontology at the journal *Nature,* takes us back to the world of the Mesozoic. Gee's work, perhaps not surprisingly, is far better informed than Mash's is about current dinosaur research. And for Gee, dinosaurs also become jumping-off points for addressing such general biological issues as mating displays, growth patterns, and symbiotic relations.

Luis Rey's illustrations are done both in black-and-white and in brilliant (sometimes Day-Glo) colors. Particularly dramatic are his "fish-eye lens" paintings, which lead to some unfamiliar (and sometimes disturbing) perspectives, even for familiar dinosaurs such as *Diplodocus.*

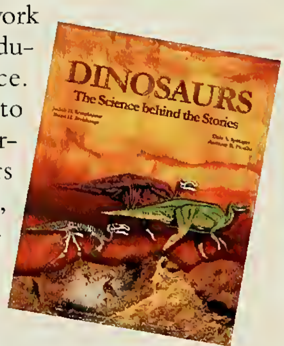
Gee warns that readers who believe what they see in his book do so at their own risk. And it's true that the casual reader might not be certain how much of the information is based on new discoveries, how much on reasonable speculation, and how much comes out of Gee's and Rey's fertile imaginations.

But aside from the bright palate and the odd perspectives, the expert quickly recognizes that Rey's drawings, at least, are based on the latest paleontological data, and are probably more accurate than the typical popular images we're all accustomed to. Still, I wonder if some readers think that the supposed Arctic carnivore *Tyrannosaurus helcaraxae,* for instance, is already known to science?

Transition to the Technical

Dinosaurs: The Science Behind the Stories, *edited by Judith G. Scotchmoor, Dale A. Springer, Brent H. Breithaupt, and Anthony R. Fiorillo (American Geological Institute, 2002; $29.95)*

How do we know what we know about dinosaurs? In this book, dinosaur paleontologists, geologists, and paleoartists explain their work to a general, educated audience. Don't expect to see lots of different dinosaurs fully restored, or an alphabetical listing of major species. But if you are interested in such topics as how dinosaur fossils are found and collected, what fossil trackways can tell us about dinosaur locomotion, how evolutionary interrelations of dinosaur groups are reconstructed, or how science can infer various modes of behavior—this volume is an excellent gateway to the primary technical literature.



Technical Literature

Feathered Dragons: Studies in the Transition from Dinosaurs to Birds, *edited by Philip J. Currie, Eva B. Koppelhus, Martin A. Shugar, and Joanna L. Wright (Indiana University Press, 2004; $49.95)*
The Carnivorous Dinosaurs, *edited by Kenneth Carpenter (Indiana University Press, to appear in July 2005; $49.95)*
Thunder-Lizards: The Sauropodomorph Dinosaurs, *edited by Virginia Tidwell and Kenneth Carpenter (Indiana University Press, to appear in July 2005; $59.95)*

These three volumes are the latest additions to the Indiana University Press series *Life of the Past,* which aims to publish peer-reviewed scientific literature on various topics in paleontology. The series is intended to reach a wider readership than the traditional scholarly journals do.

The Dinosauria, *Second Edition, edited by David B. Weishampel, Peter Dodson, and Halska Osmólska (University of California Press, 2004; $95.00)*

The Dinosauria is the primary professional reference for dinosaur paleontology. Well-worn copies of the first edition, conceived in 1984 and published in 1990, still occupy the desks of curators, fossil preparators, graduate students, paleoartists, and professors, not to mention the shelves of university and museum libraries.

But the discipline has grown substantially in the past fifteen years, and the new *Dinosauria* is a more than adequate update of the original. The number of contributors has grown from twenty-three to forty-three; many were still graduate students when the original was first published. The new edition also includes, significantly, a chapter on birds of the Mesozoic, thereby officially recognizing that Aves belongs to the larger grouping, Dinosauria.

Comprising more than 800 pages, this work is the ultimate reference on dinosaurs, detailing the adaptations, anatomy, diversity, and inferred habits represented on the many branches of the dinosaur family tree. One long chapter examines the occurrence of dinosaur fossils (bones, eggs, and footprints) around the globe. Concluding chapters discuss topics such as dinosaur physiology and extinction. The massive bibliography is the most comprehensive single source of guidance to the professional dinosaur literature ever published.

So this book is a must for the serious student of dinosaur research. But unless you have already mastered vertebrate anatomy, Mesozoic stratigraphy, and phylogenetic analysis, it's probably not the place to begin. □

Dino Web Digs

By Robert Anderson

Most children these days go through a "dinosaur phase," and my son was no exception. Before his interest subsided, he'd consumed just about everything he could get his hands on about the geologic age of the dinosaurs. He's moved on now, but every once in a while, I catch him pulling out one of his dinosaur tomes. It's a reminder that our fascination with these animals never quite goes extinct.

An enduring Internet favorite on the subject for both my son and me is the site of the Museum of Paleontology at the University of California, Berkeley (www.ucmp.berkeley.edu). From the subtopics displayed on the home page menu, select "paleoportal.org" to access "The Paleontology Portal," which gathers many resources into a single informational Web site. The subject headings on the left side of the page direct you to information about ancient fossil flora and fauna, cross-indexed for various geologic time periods and for various locations around the United States.

If you want to go directly to dinosaurs, however, you can begin at a page (www.ucmp.berkeley.edu/diapsids/dinosaur.html) that opens with an evocative illustration by paleoartist Michael W. Skrepnick [*see "A Dinosaur Lover's Bookshelf" page 62*]. You'll also find some dinosaur history in unusual formats at this page. For example, scroll down to "UCMP Special Exhibit: *Dilophosaurus!*" (or go to www.ucmp.berkeley.edu/dilophosaur/intro.html) to find a guided tour led by the late Sam Welles, the Berkeley paleontologist who was the first to discover a *Dilophosaurus* fossil.

If you're looking for a good site for younger children, try "Zoom Dinosaurs" (www.enchantedlearning.com/subjects/dinosaurs), an online hypertext book. The San Diego Natural History Museum also has an appealing dinosaur page for kids, called "Dinosaur Dig" (www.sdnhm.org/kids/dinosaur/index.html).

For more mature dinosaur enthusiasts, especially the ones who enjoy the occasional fossil-hunting field trip, "Dino Russ's Lair" (www.isgs.uiuc.edu/dinos/dinos_home.html) offers a wealth of useful tips and Web links. Click on the icon for "Dinosaur Sites to Visit." I learned, for example, that the Isle of Wight, in the English Channel, is the best place to find dinosaur remains in Europe—a new species comes to light there roughly every three years.

Around the world, new dinosaur finds are cropping up all the time, and many innovative exhibits are launched to showcase them. Opening this month, for example, at the American Museum of Natural History in New York City, is an exhibit that addresses some of the most current thinking about dinosaur biology. Check out one of the highlights of the Web site (www.amnh.org/dinosaurs) by choosing "Behind the Scenes Gallery" from the yellow menu bar: you'll find out how museum preparators re-created the prehistoric environment of a forest in ancient China for a spectacular, 700-square-foot walk-through diorama.

Budding paleontologists will naturally be drawn to other museum Web sites. At the Smithsonian Institution's National Museum of Natural History in Washington, D.C., curators have gone to extraordinary lengths to modernize a *Triceratops* skeleton (www.mnh.si.edu/highlight/triceratops). Scroll down the page and click in the box beside "Scanning the Bones" to access two brief but fascinating QuickTime movies that recreate the animal's gait.

The way dinosaurs moved and behaved fascinates almost everyone, but the push to bring the creatures to life has come mainly from movies and TV programs. At a Discovery Channel Web page called "dinosaur guide" (dsc.discovery.com/guides/dinosaur/dinosaur.html), under the heading "Walking With Dinosaurs" in the blue menu box, check out "Dinos: How Do We Know?"

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(Continued from page 32)

lated and essentially upright. The animals crowd into a shallow bowl-shaped depression less than a yard across [*see lower illustration on page 32*]. The excellent preservation of the skeletons indicates that the animals were buried rapidly and rules out the possibility that they were somehow swept together by the elements. But could such a large group have been a mother and her brood?

No one yet knows enough about *Psittacosaurus* reproduction, such as egg, clutch, and hatchling size, to say for sure. If this dinosaur had small eggs, a brood of thirty-four may have been a reasonable possibility. Yet several other circumstances might account for the apparently large number of young. Perhaps one male protected the eggs laid by his multiple female partners. Or perhaps the young from various females were typically gathered after hatching to form crèches, requiring fewer adults to watch over them.

Psittacosaurus and Horner's *Maiasaura* provide the best evidence to date for the parental care of hatchlings and young among extinct dinosaurs. Another good candidate is *Protoceratops,* for which groups of small young have been found, but so far without an attending adult. All three are herbivorous dinosaurs. Although some extinct carnivorous theropods brooded their eggs, as do their relatives the birds, there is sparse evidence that such theropods minded or fed their young. It's conceivable that the contrast reflects a difference in the creatures' ecological niches. But with so little hard evidence, it's better not to jump to any conclusions.

Paleontologists have learned that they must take care to understand extinct species on their own terms. What no one disputes, though, is that reproductive strategies are directly linked to evolutionary success. Parental care in its various forms may have been among the key adaptations that enabled these remarkable species, now reduced to fossils, to have prevailed for so long. □

Loading the Cannon

How do asteroids from the belt between Jupiter and Mars get into near-Earth orbits?

By Charles Liu

Sixty-five million years ago the Mesozoic era ended with a bang. An asteroid several miles across slammed into our planet, just off what is now the northern coast of Mexico's Yucatán Peninsula. The energy released by the collision—far greater than the combined explosive power of all the nuclear warheads on Earth—caused a global environmental catastrophe: firestorms, choking clouds, acid rain, and more. The impact coincided with a mass extinction that wiped out the nonbird dinosaurs and led, eventually, to the rise of mammals as the dominant large fauna.

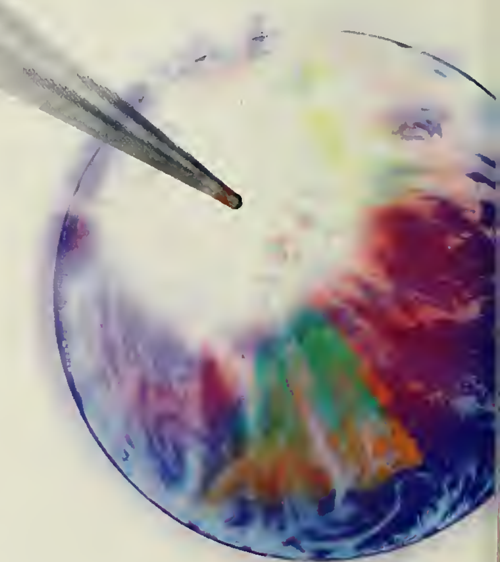
Before that asteroid swung into "death star" mode, it was the kind of body planetary astronomers would call a near-Earth object, or NEO—a chunk of metal, rock, or ice orbiting the Sun, whose orbit happens to intersect the orbit of Earth. Astronomers have already discovered more than 3,200 NEOs, 700 of which are more than a kilometer across—large enough to threaten humanity if just one made a direct hit. Perhaps thousands more NEOs of that size remain undiscovered.

None of the NEOs discovered so far is predicted to hit Earth in the foreseeable future. Long-term, though, even if astronomers plotted all the orbits NEOs are tracing today, they couldn't predict all the potential large impacts. That's because the orbits of the vast majority of NEOs are unstable; after a few million years the objects generally swoop in too close to a planet or the Sun. When they do, the larger body's gravity acts either like a slingshot, swinging them around so fast that they get flung out of their Earth-crossing orbits, or like a vacuum cleaner, dragging them to oblivion on the surface of the larger body. All of the NEOs around when the dinosaurs met their demise are probably long gone.

But NEOs are still abundant, so how does their population get replenished? According to the most widely accepted hypothesis, most NEOs arrive in our local neighborhood from the main asteroid belt, a zone of rocky bodies between the orbits of Mars and Jupiter. Now a research team led by Simone Marchi, an astronomer at the University of Padua, Italy, has found supporting evidence for that hypothesis. Vesta, the third largest asteroid in the solar system, lies in the main asteroid belt, nearly 130 million miles farther from the Sun than Earth does. Yet fragments of Vesta have been found scattered throughout the solar system. Marchi's analysis shows that among those fragments of Vesta are four NEOs, discovered in 2003.

Vesta itself was discovered 198 years ago by the German astronomer Heinrich W. M. Olbers. Perhaps its most remarkable feature is a gargantuan impact crater on its surface, stretching some 280 miles across—more than three-quarters of the 330-mile diameter of Vesta itself. Long ago, a massive collision with another large asteroid must have gouged out a huge part of Vesta. The liberated fragments, launched into solar orbit, are called Vestoids.

Planetary astronomers can infer an asteroid's origin by measuring the intensity of its reflected sunlight; all objects that come from a common parent body tend to have the same mineral makeup, and so their reflectivity is the same. Marchi and his associates measured the reflectivity of a number of NEOs across a range of visible and infrared wavelengths, and they identified four NEOs in their sample that matched Vesta's visible-light reflectivity remarkably well—Vestoids.



If they remain in their current orbits, the four Vestoid NEOs will never collide with our planet. As NEOs, however, they are only one unpredictable gravitational slingshot away from a collision course. What would happen if one of them hit Earth? H. Jay Melosh, a planetary scientist at the University of Arizona in Tucson, and Ross A. Beyer of the NASA Ames Research Center at Moffett Field, California, have created a user-friendly Web page (www.lpl.arizona.edu/tekton/

crater.html) that can estimate the results.

The largest of the four NEOs is about 0.7 mile (1.1 kilometer) across and made of solid rock. Type in 1,100 meters on the Web site. In a head-on collision the NEO would hit Earth at around 38,000 miles an hour (17 kilometers a second). Type that in as well. The Web site then calculates that the energy released on impact would equal some 5 million Hiroshima-power atomic bombs, and leave an impact crater one and a half times the size of New York City. For comparison, the earthquake that caused the horrific tsunami of December 26, 2004, released only 0.5 percent the energy of such a devastating strike.

So what made the four Vestoids leave the asteroid belt and swing in close enough to earn the name "near-Earth object"? One possible mechanism is another variety of gravitational slingshot: a random close encounter with another asteroid. Such random events, though, aren't very common; in fact, among asteroids they are so unlikely that even in the billions of years since the beginning of the solar system they could not have given rise to the NEO population we observe today.

To account for the observations, planetary astronomers have proposed a mechanism based on so-called orbital resonances. When large numbers of objects orbit together, they can create complex patterns of motion; the structure within Saturn's rings is a good example. According to Marchi, at least two orbital resonances funnel asteroids from the main asteroid belt into the inner solar system. So, more NEOs will probably be coming down the resonance pike, keeping the threat of a catastrophic collision alive for the foreseeable future.

I suppose we dinophiles might curse near-Earth objects for what one of them did to end the reign of the dinosaurs—not to mention the danger they pose to our own civilization. But geologic and fossil evidence suggests that, some 240 million years ago, an asteroid collision much larger than the Yucatán impact caused an even more devastating extinction, which may have set the stage for the dinosaurs' rise to prominence. Biologically speaking, NEOs present just one more kind of evolutionary crisis, or opportunity, that life on Earth must face—and adapt to or perish. Sooner or later another big interplanetary cannonball will swing into a collision course with our home planet. With adequate knowledge and preparation, we humans might be able to deflect, divert, or destroy it—and dodge the evolutionary hammer blow that dispatched our dinosaurian kin.

Or not.

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

THE SKY IN MAY

By Joe Rao

As May begins, Mercury is continuing the poor apparition it made in April, hanging low in the east at sunrise. Although the planet brightens from magnitude 0.2 to −0.4 in the first two weeks of May, it rises only about forty-five minutes before the Sun. More southerly viewers get a better apparition.

Venus has been lost in the Sun's glare since early February, but this month the planet gradually returns to the evening sky. You might catch sight of it as early as the 1st if you look above the west-northwestern horizon with binoculars a few minutes after sunset. By late May Venus is setting more than an hour after the Sun, but the planet is low in the twilight sky and hard to see.

Mars rises this month about three hours before the Sun, give or take about twenty minutes, and brightens gradually from magnitude 0.6 to 0.3. A crescent Moon visits Mars twice during May. On the 2nd Mars is well to the left of the Moon. A far more striking pairing comes on the morning of the 31st, when Mars is situated about one lunar diameter above the Moon's upper limb.

Jupiter dominates the evening sky from its throne in the south at nightfall. Once Venus sets at dusk, Jupiter becomes the brightest "star" in the sky. All month long the giant planet lies within less than two degrees of the third-magnitude star Porrima, named in honor of the Roman goddess of prophecy, in the constellation Virgo, the virgin.

In 1718 two English astronomers, James Bradley and James Pound, discovered that Porrima is actually two stars, each shining at magnitude 3.9—making Porrima one of the earliest double stars to be discovered with a telescope.

Saturn appears high in the southwestern sky as darkness falls. Take note of how Saturn changes its position relative to the bright stars Castor and Pollux as the planet slowly tracks its way eastward through the constellation Gemini, the twins.

The Moon wanes to last quarter on the 1st at 2:24 A.M. and to new on the 8th at 4:45 A.M. It waxes to first quarter on the 16th at 4:57 A.M. and to full on the 23rd at 4:18 P.M. The Moon wanes again to last quarter on the 30th at 7:47 A.M.

On the night of May 23–24 a nearly full Moon occults, or hides, the ruddy star Antares, as seen from North America. Along the West Coast, Antares disappears behind the Moon's bright limb within a few minutes of 11:53 P.M. Pacific daylight time on May 23 and remains hidden for about seventy minutes. Along most of the eastern seaboard, Antares vanishes around 4:22 A.M. on May 24 and reappears about an hour later.

Unless otherwise noted, all times are eastern daylight time.

(Continued from page 28)
birth of a black hole. The telescope had picked up the X-ray "afterglow" of a now-famous burst, GRB 970228. But the X rays were "redshifted." Turns out, this handy feature of light and the expanding universe enables astrophysicists to make a fairly accurate determination of distance. The afterglow of GRB 970228, which reached Earth on February 28, 1997, was clearly coming from halfway across the universe, billions of light-years away. The following year Bohdan Paczyński, a Princeton astrophysicist, coined the term "hypernova" to describe the source of such bursts. Personally, I would have voted for "super-duper supernova."

A hypernova is the one supernova in 100,000 that produces a gamma-ray burst, generating in a matter of moments the same amount of energy as our Sun would emit if it shone at its present output for a trillion years. Barring the influence of some undiscovered law of physics, the only way to achieve the measured energy is to beam the total output of the explosion in a narrow ray—much the way all the light from a flashlight bulb gets channeled by the flashlight's parabolic mirror into one strong, narrow beam. Pump a supernova's power through a narrow beam, and anything in the beam's path will get the full brunt of the explosive energy. Meanwhile, whoever does not fall in the beam's path remains oblivious. The narrower the beam, the more intense the flux of its energy, and the fewer cosmic occupants will see it.

What gives rise to these laserlike beams of gamma rays? Consider the original supermassive star. Not long before its death from fuel starvation, the star jettisons its outer layers. It becomes cloaked in a vast, cloudy shell, possibly augmented by pockets of gas left over from the cloud that originally spawned the star. When the star finally collapses and explodes, it releases stupendous quantities of matter and prodigious quantities of energy. The first assault of matter and energy punches through weak points in the shell of gas, enabling the succeeding matter and energy to funnel through that same point. Computer models of this complicated scenario suggest that the weak points are typically just above the north and south poles of the original star. When seen from beyond the shell, two powerful beams travel in opposite directions, headed toward all gamma-ray detectors (test-ban-treaty detectors or otherwise) that happen to lie in their path.

Adrian Melott, an astronomer at the University of Kansas, and an interdisciplinary crew of colleagues assert that the Ordovician extinction may well have been caused by a face-to-face encounter with a nearby gamma-ray burst. A quarter of Earth's families of organisms perished at that time. And nobody has turned up evidence of a meteor impact contemporary with the event.

When you're a hammer (as the saying goes), all your problems look like nails. If you're a meteorite expert pondering the sudden extinction of boatloads of species, you'll want to say an impact did it. If you're an igneous petrologist, volcanoes did it. If you're into spaceborne bioclouds, an interstellar virus did it. If you're a hypernova expert, gamma rays did it.

No matter who is right, one thing is certain: whole branches in the tree of life can go extinct almost instantly.

Who survives these assaults? It helps to be small. Microorganisms tend to do well in the face of adversity. More important, it helps if you live where the Sun don't shine—on the bottom of the ocean, in the crevices of buried rocks, in the clays and soils of farms and forests. The vast underground biomass survives. It is they who inherit the Earth again, and again, and again.

ASTROPHYSICIST NEIL DEGRASSE TYSON is the director of the Hayden Planetarium at the American Museum of Natural History.

To some, sunglasses are a fashion accessory…

But When Driving, These Sunglasses May Save Your Life!

Driving can expose you to more dangerous glare than any sunny summer day at the beach can…do you know how to protect yourself? An amazing breakthrough in optic technology by NASA called Eagle Eyes® can be your answer. The sun rises and sets at peak travel periods, during the early morning and afternoon rush hours. Many drivers find themselves temporarily blinded as they are driving directly into the glare of the sun. Deadly accidents are regularly caused by such blinding glare. Danger can come from reflected light off of another vehicle, from the pavement, or any other reflective surface. Early morning frost or dew can exacerbate this situation. Salted or snowy road conditions can make matters even worse. Yet, motorists struggle on despite being blinded by the sun's glare and cause countless accidents every year.

Beware of windshield glare!

This glare-induced "blindness" is especially prevalent in the early morning or late in the afternoon, and due to the extremely reflective qualities of other cars. Even your windshield can make matters worse because of small scratches that can increase reflected glare. This powerful glare of the sun can be damaging to the various layers of the eye. Certain road conditions can raise the amount of UV that you are exposed to by up to 85%.

Slip on a pair of Eagle Eyes and everything instantly appears more vivid and sharp. You'll immediately notice that your eyes are more comfortable and relaxed and you'll feel no need to squint. The scientifically designed sunglasses are not just fashion accessories—they are necessary to protect your eyes from those harmful rays produced by the sun in many peak driving times.

> *"As a board certified opthamologist, I recommend Eagle Eyes to all my patients to protect and enhance their vision!"*
>
> —Dr. Lyda D. Tymiak

NASA's researchers looked to nature for a solution.

Conventional sunglasses can actually blur your vision by allowing harmful UV, blue light rays, and reflective glare in. They can also darken useful, vision-enhancing light rays. At NASA's Jet Propulsion Laboratory scientists looked to nature for a solution by studying the eyes of eagles, known for their extreme visual acuity. The result of this breakthrough technology is Eagle Eyes®. NASA's researchers studied how eagles can simultaneously distinguish their prey from their surroundings with utmost precision, while protecting their eyes from the daily exposure of harmful high-energy sunlight. These studies led to revolutionary protection for human eyesight.

Patented triple filtering lens system.

With a patented triple filtering system, Eagle Eyes® will reduce the blinding glare you may encounter while driving or enjoying outside activities. The lenses will also block the UV light while enhancing the colors of your surrounding environment. Eagle Eyes® provides 100% eye protection from harmful blue, violet and ultraviolet light rays. You can experience enhanced visual acuity, even at great distances in most weather conditions.

Not just one pair.

We are so anxious for you to try the Eagle Eyes® breakthrough technology that when you try the Eagle Eyes® Extremes™ we will give you the Explorers™ FREE! That's two ways to protect your eyes and prevent blinding glare for less than the price of one pair of traditional sunglasses. You'll also receive one hard leatherette case and one soft cloth pouch so you can carry and protect your Eagle Eyes® in style. Plus, if you are not thrilled with the Eagle Eyes® technology, just send them back for a full refund of the purchase price. You should always have a pair of sunglasses available when you drive, so put Eagle Eyes® in all of your cars and start seeing the world without the dangerous squinting and with more clarity than you've ever imagined.

Extremes™

Explorers™

OFFICIAL NASA SPINOFF TECHNOLOGY COMPANY

*Eagle Eyes are patented, officially recognized NASA Spinoff technology and are on display at NASA's Houston Space Visitors Center.

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Universal Clip-ons available for $29.95 +S&H

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28. LITTLE ST. SIMONS ISLAND
Excl. 10,000-acre Georgia island paradise, priv. 7-mi. pristine beach, natural history tours, birding and recreational activities galore, gourmet regional cuisine and gracious accommodations await just 30 guests.

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

30. MONTANA/WYOMING/ SOUTH DAKOTA
Explore Grand Teton, Yellowstone and Glacier National Parks and Mount Rushmore National Memorial this year. Free Guide.

31. MONTANA'S MISSOURI RIVER COUNTRY
Explore Dinosaur digs and museums, the Lewis & Clark trail, Native American cultures, pioneer history and more. Free Travel Planner available.

32. MONTGOMERY COUNTY, MD
Experience transportation history along the C & O Canal and the National Capital Trolley Museum. So many things to do with easy access to the nation's capital.

33. NEW BRUNSWICK, CANADA
Walk on the ocean floor along the Bay of Fundy, home of the World's Highest Tides!

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

35. NEW YORK STATE
Come out and play this summer in New York State. We have everything from Family Fun Vacations to Romantic Getaways! Free Travel Guide!

36. NORTH CAROLINA OUTER BANKS
Pristine Beaches. Fishing. History. For FREE Travel Guide & Getaway Card good for seasonal values.

37. NORWAY
Norway is nature at its most spectacular. A land of cosmopolitan cities, charming towns, ancient Viking ships, and breathtaking coastal voyages.

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

39. NOVA SCOTIA
Yes, please send me my FREE 400 page Nova Scotia Doer's & Dreamer's Travel Guide - packed with everything I need to plan and book my vacation.

40. ORIENT LINES
Explore Scandinavia and Russia. Cruise to the Mediterranean's most glamorous playgrounds. Enjoy luxury at sea, aboard the elegant mid-sized ships sophisticated travelers prefer.

41. PENNSYLVANIA
Pack your bags and plan your long weekend with our online itineraries. Then hit the road in the State of Independence.

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

43. PRINCE GEORGE'S COUNTY, MD
Wonderful museums and historic sites, the National Wildlife Sanctuary, affordable accommodations and much more. All just minutes from Washington, DC.

44. QUEBEC CITY
Discover the magic of North America's most European City! Only 40 minutes from the Old City, go birdwatching, hiking and enjoy yourself.

45. QUEBEC MARITIME
Nature destination par excellence, Le Quebec Maritime is a vast land whose shores are washed by the Gulf St. Lawrence and the St. Lawrence River.

46. SCOTLAND
Scotland's rich cultured heritage is celebrated in museums, galleries, theaters, concert halls, vibrant festivals, pubs and street corners.

47. ST. MARY'S COUNTY, MD
A Maryland original! Visit Maryland's first colony...historical sites and outdoor adventure await. 400 miles of Chesapeake shoreline and 3 1/2 centuries of history.

48. SWAN HELLENIC CRUISES
Ocean and sea cruises, expedition and river cruises all with the accent on discovery. Exotic destinations and distinguished guest speakers.

49. TALBOT COUNTY, MD
Talbot County's five beautiful rivers, 602 miles of shoreline, unique charming hamlets, St. Michaels, Oxford, Tilghman Island and Historic Easton offer a timeless treasury of natural beauty and history.

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

51. TOYOTA
In the U.S., Toyota is more than the cars we sell here. Together with our dealers and suppliers, Toyota is responsible for creating over 200,000 good jobs across the U.S. Learn more about our eight manufacturing plants, design, and R&D facilities, and how we invest in local communities.

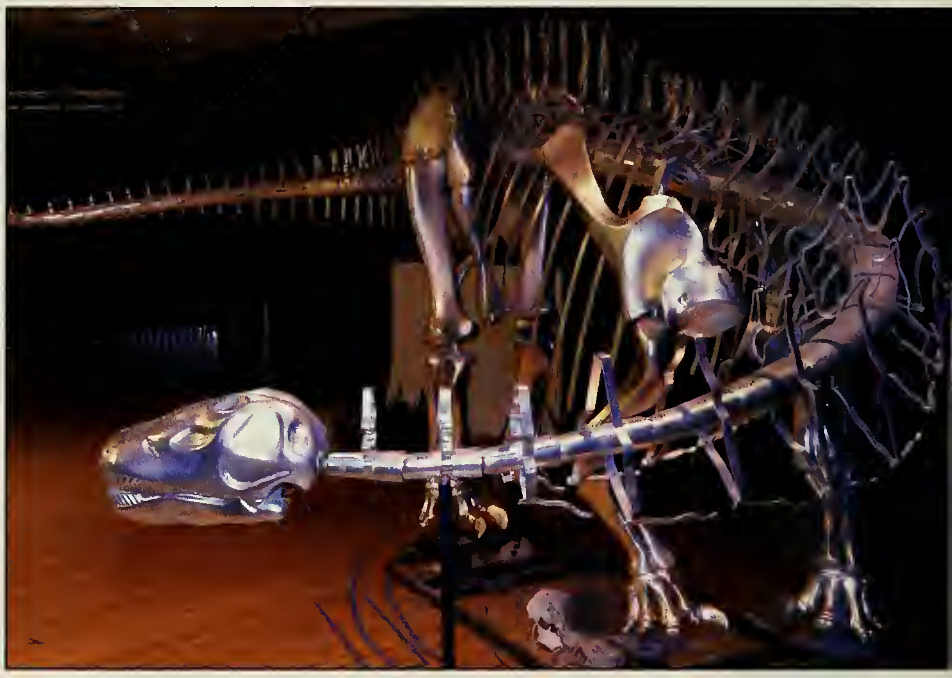
52. VICTOR EMANUEL NATURE TOURS
Over 140 tours annually worldwide, including special cruises, and introductory tours for new birders.

53. WORCESTER COUNTY, MD
Maryland's only seaside county. Visit Assateague Island National Seashore. Kayak, canoe, bird watch or golf. Stay in one of our many Bed & Breakfast Inns.

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

Dinosaur Exhibition Sheds New Light on Old Bones

Fantastic images of dinosaurs have captivated the public's imagination for more than 150 years, from the bulky *Iguanodon* models created by Waterhouse Hawkins in 1853 to the computer animated *Tyrannosaurus rex* charging through *Jurassic Park*. On May 14, 2005, the American Museum of Natural History presents the next step in our understanding of these great beasts with the opening of the groundbreaking exhibition *Dinosaurs: Ancient Fossils, New Discoveries*. On view through January 8, 2006, the exhibition reveals how current thinking about dinosaur biology has changed dramatically over the past two decades and highlights ongoing cutting-edge research by Museum scientists and other leading paleontologists around the world. *Dinosaurs* presents the most up-to-date look at how scientists are reinterpreting the mysteries of dinosaurs—from their appearance and behavior to the hotly debated theories of their extinction.



This gleaming model of an *Apatosaurus* skeleton is a 3D realization of computerized biomechanical studies.

"*Dinosaurs* presents us with an ideal opportunity to expand upon many of the dinosaur lifestyle topics that we introduced in our renovated fossil halls on the Museum's fourth floor," says Ellen V. Futter, President of the American Museum of Natural History. "Once again, the Museum is on the leading edge of presenting science to the public as we update them on the latest dinosaur research. After visitors see this exhibition, they will never think of dinosaurs in the same way again."

Dinosaurs features a wide range of fossil specimens and casts, including a full-size cast of a *T. rex* and numerous recently discovered fossils of well-known prehistoric animals including *Gorgosaurus*, *Triceratops*, and *Protoceratops*. An enormous immersive diorama—the most detailed re-creation of a prehistoric environment ever attempted—depicting the rich diversity of the Mesozoic forest in China will also be featured. The Museum is developing several interactive computer simulations and animations, as well as a number of videos offering behind-the-scenes glimpses of fieldwork and discussions among leading scientists currently investigating the mysteries of dinosaur biology.

Dinosaurs: Ancient Fossils, New Discoveries is organized by the American Museum of Natural History in collaboration with the following institutions to which the exhibition will travel after it closes in New York: the Houston Museum of Natural Science (March 3–July 30, 2006); the California Academy of Sciences, San Francisco (September 15, 2006–February 4, 2007); The Field Museum, Chicago (March 30–September 3, 2007); and the North Carolina State Museum of Natural Sciences, Raleigh (October 26, 2007–July 5, 2008).

"This exhibition illustrates how scientists are using new ideas, new discoveries, and new technologies to revolutionize our understanding of dinosaurs," says Mark A. Norell, curator of *Dinosaurs* and Curator and Chairman of the Division of Paleontology. "Our work reaches across many disciplines involving paleontologists, biomechanical engineers, paleobotanists, and others to showcase how we go about reconstructing the mysterious life of dinosaurs."

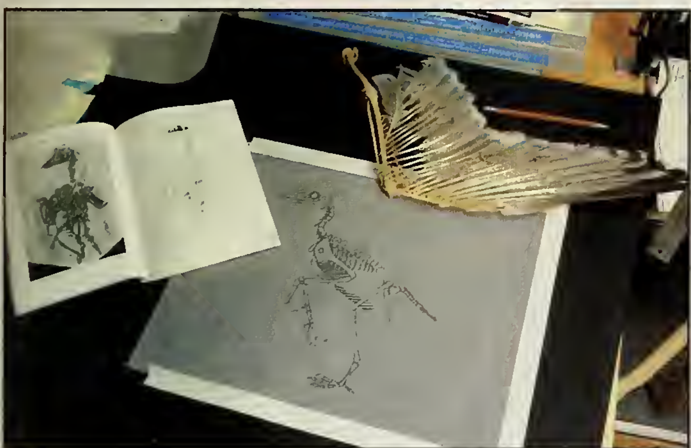
The exhibition is divided into several major sections:

Introduction: By viewing graphics and CT scans, visitors will see how the fossil of *Bambiraptor feinbergi*, the best-preserved and most complete dromaeosaur yet found in North America, provides new evidence for the evolutionary links between birds and dinosaurs.

How Dinosaurs Moved: In this section, the latest biomechanical studies on dinosaur movement spring to life. Highlights include:

- A stunning 60-foot-long model of an *Apatosaurus* skeleton based on computer drawings and made of chrome in geometric arcs, stretching across the center of the exhibition.
- A full-size cast skeleton of a *T. rex* standing in a dynamic pose and bearing down on visitors below, paired with a six-foot-long mechanical *T. rex* skeleton that illustrates the typical speed of a rampaging tyrannosaur.

The Liaoning Forest: Visitors can stroll back in time through a 700-square-foot diorama depicting a 130-million-year-old forest that existed in what is now Liaoning, China, a province that has yielded a rich diversity of well-preserved specimens.



C CHESEK/AMNH

An early study of dinosaur skeletal structure

This re-created forest is populated with relatives of some modern trees and more than 35 different species of scientifically accurate, fleshed-out models of dinosaurs, reptiles, early birds, insects, and mammals.

How Dinosaurs Behaved: This section demonstrates how scientists use new approaches and technologies to unlock the secrets of dinosaur behavior. Highlights include:

- A 15-by-10-foot re-creation of the famous Davenport Ranch Trackway, a collection of sauropod dinosaur prints unearthed in Texas by Museum scientists in the 1930s, that shows visitors how recent analysis has uncovered new information on dinosaur herding behavior. Special lighting displays retrace the steps of individual dinosaurs across the face of the trackway.
- A large "trophy wall" of mounted dinosaur skulls that illustrates the latest theories on the purposes of the unusual horns, frills, crests, and domes found on many dinosaur skulls. This section highlights the full range of these mysterious structures, investigating whether they were used for defense, mate recognition, or sexual selection.

R. MICKENS/AMNH

Beipiaosaurus model in progress

Extinction: In this section, visitors can explore the hard evidence behind theories on the factors that ended the Age of Dinosaurs, including asteroid impact, global climate change, and massive volcanic eruptions. A newly discovered slab of sedimentary rock that shows a thin layer of iridium—a metallic element that marks the boundary between the Cretaceous and Tertiary periods—is believed to represent the remnants of an asteroid or comet that caused the extinction of 85 percent of all species on Earth about 65 million years ago.

The exhibition ends with an intriguing conclusion—dinosaurs still walk among us, and more often fly above us, as birds.

Dinosaurs: Ancient Fossils, New Discoveries and its accompanying education and public programs are made possible by **Bank of America.**

Major funding has also been provided by the Lila Wallace-Reader's Digest Endowment Fund.

PROGRAMS

SYMPOSIUM:

Dinosaurs: Ancient Fossils, New Discoveries
Saturday, 5/14
Learn about the cutting-edge research behind the exhibition at this scientific symposium—open to the public—with world-renowned paleontologists. Visit www.amnh.org for details.

Walking with Dinosaurs
Sunday, 5/15, 12:00 noon–1:00 p.m. (For the whole family)
John R. Hutchinson, University of London, turns his scientific attention to the *Tyrannosaurus rex.*

Tracking Dinosaurs around the World
Sunday, 5/15, 1:30–2:30 p.m. (For the whole family)
Martin Lockley, University of Colorado at Denver, takes us on a global tour of dinosaur trackways.

Casting Dino Tracks
Sunday, 5/22, 11:00 a.m.–12:00 noon (Ages 5–7, each child with one adult) or 1:00–2:00 p.m. (Adults)
Learn what dinosaur footprints tell us and create your own cast of one.

Museum Events

AMERICAN MUSEUM ♁ NATURAL HISTORY

www.amnh.org

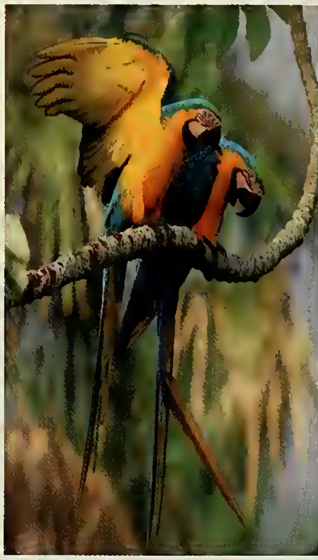
EXHIBITIONS

Totems to Turquoise: Native North American Jewelry Arts of the Northwest and Southwest
Through July 10, 2005
This groundbreaking exhibition celebrates the beauty, power, and symbolism of the magnificent tradition of Native American arts, examining techniques, materials, and styles that have evolved over the past century as Native American jewelers have transformed their traditional craft into vital forms of cultural and artistic expression.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 30, 2005
A return engagement of this popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed habitat that approximates their natural environment.

Exploring Bolivia's Biodiversity
Through August 8, 2005
These lush photographs of Bolivia take viewers on a journey through the mountain landscapes of the Andes to the dense lowland tropical forests of the Amazon and the dry forests of the Chaco. Captions in English and Spanish.

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



HERMES JUSTINIANO

The vibrantly colored blue-and-yellow macaw *(Ara ararauna)* lives throughout most of the Amazon basin.

Sunscapes
Through September 5, 2005
Special optical systems and detectors capture the fiery images of the Sun's atmosphere. This exhibition displays the most dramatic of these images.

Vital Variety: A Visual Celebration of Invertebrate Biodiversity
Ongoing
Invertebrates, which play a critical role in the survival of humankind, are the subject of these extraordinarily beautiful close-up photographs.

PEOPLE AT THE AMNH

Kate Holmes, Biodiversity Specialist,
Center for Biodiversity and Conservation

Three years ago, having been offered a position at the American Museum of Natural History, Kate Holmes sat on a beach on a remote island of Vanuatu, listening to a rooster crow and thinking she would never hear such a sound in New York City. Starting work at the Museum six months later, she discovered her Morningside Heights apartment building was next door to a rooster breeder.

DANIEL MORRIS

Kate Holmes

Kate spent three years in Vanuatu, a South Pacific archipelago, making a documentary on women's roles in marine resource management. "As western approaches to conservation move in, people start to forget about their traditional techniques. We tried to help people realize the value of these practices."

Her master's degree in biology, combined with this anthropological project, made her ideal for the CBC's Bahamas Biocomplexity Project, which examines marine protected area networks. This project brings biological, socioeconomic, oceanographic, and other components to bear on local biodiversity recommendations, and was funded by the Jaffe family and the National Science Foundation.

One of Kate's favorite experiences at the Museum was contributing to the renovation of the Milstein Hall of Ocean Life. "It was a tiny part of my job, but getting to see the results . . . you back up and see this marvelous hall. It really is fantastic, and to be a piece of that is really satisfying."

GLOBAL WEEKENDS

Asians in America: Metaphors of Change
Saturday and Sunday, 5/7 and 5/8, 1:00–5:30 p.m.
The Asian community is one of the fastest growing in the United States. This two-day program of art, film, panel discussions, and dance and musical performances explores the experience of Cambodian refugees and the larger immigrant perspective.

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

LECTURES

An Evening with Susan Orlean
Thursday, 5/5, 7:00 p.m.
Susan Orlean conducts a tour of the world via its subcultures.

STARRY NIGHTS
Live Jazz

ROSE CENTER
FOR EARTH AND SPACE
Friday, May 6
6:00 and 7:30 p.m.

Houston Person Quartet

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

Out of Eden: An Odyssey of Ecological Invasion
Thursday, 5/19, 7:00 p.m.
Alan Burdick considers what is "natural."

FIELD TRIPS

New! Evening Bat Walks in Central Park
Friday, 5/13, or Friday, 5/20, 7:30 p.m.
A walk through Central Park with the New York Bat Group.

The Backwaters of New York
Tuesday, 5/24, 6:00–9:00 p.m.
A tour of geology and history along New York's waterways.

FAMILY AND CHILDREN'S PROGRAMS

Dr. Nebula's Laboratory: Science Theater
Saturday, 5/14, 2:00–3:00 p.m. (For families with children ages 4 and up)
Join Scooter to track Dr. Nebula's planetary vacation in our solar system.

Space Explorers: Eclipses of the Sun and Moon
Tuesday, 5/10, 4:30–5:45 p.m. (Ages 8 and up)
On the second Tuesday of each month, kids (and their parents) can learn under the stars of the Hayden Planetarium.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

Virtual Universe
The Closest Stars
Tuesday, 5/3, 6:30–7:30 p.m.

This Just In . . .
May's Hot Topics
Tuesday, 5/17, 6:30–7:30 p.m.

Celestial Highlights
Planetary Triple Play
Tuesday, 5/31, 6:30–7:30 p.m.

LECTURES

How Great Earthquakes Change a Planet
Monday, 5/2, 7:30 p.m.
With John E. Ebel, Boston College.

Empire of the Stars
Monday, 5/9, 7:30 p.m.
With Arthur Miller, University College, London.

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!

PLANETARIUM SHOWS

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

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

Passport to the Universe
Narrated by Tom Hanks

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

Made possible through the generous support of Swiss Re.

LARGE-FORMAT FILMS

LeFrak Theater

Vikings
Discover the historical and technological achievements

SKY HIGH ENTERTAINMENT

of this legendary society of seafaring explorers.

Jane Goodall's Wild Chimpanzees
This breathtaking film takes visitors into the realm of our closest animal relatives.

Become a Member of the American Museum of Natural History

As a Museum Member you will be among the first to embark on new journeys to explore the natural world and the cultures of humanity. You'll enjoy:

- Unlimited free general admission to the Museum and special exhibitions, and discounts on Space Shows and IMAX® films
- Discounts in the Museum Shop and restaurants and on program tickets
- Free subscription to *Natural History* magazine and to *Rotunda*, our newsletter
- Invitations to Members-only special events, parties, and exhibition previews

For further information, call 212-769-5606 or visit www.amnh.org/join.

ENDPAPER

The Past Recaptured, Again

By Carl Mehling

I've come to expect stunned looks from visitors when I lead behind-the-scenes tours of fossil collections at the American Museum of Natural History. Stored in the museum's division of paleontology are piles of specimens—wrapped in their original protective shielding—that have never seen the light of day. Fossil hunters are constrained by time, money, and luck. In the field those constraints often prompt paleontologists to "jacket" their most promising stuff, for closer inspection when time and tools are available indoors. So they swaddle the fossil-bearing blocks of rock in plaster and burlap for safe transport home, a procedure that hasn't changed much since the late 1800s.

I see a lot of these plaster-shrouded packages—ranging from grapefruit size to a two-ton tombstone—in the vertebrate paleontology collections at the museum. Much of the material that has come into the museum in the past century has been cleaned of stone, studied, and even displayed. Still, our storage areas remain stuffed with jacketed fossils. Funding for expeditions to exotic places is easier to secure than for the preparation of specimens. How many pulses quicken at the prospect of paying for someone to sit alone for weeks or months at a microscope, picking grains of sediment away from bone? Thus, our surplus.

Yet discoveries made from digging in old plaster or crumbling crates are no less likely or less exciting than the ones made poking around in some remote badlands. This past year a graduate student named Sterling Nesbitt, from Columbia University in New York City, validated that principle, when he came to our collection with an interest in our jackets from Ghost Ranch. Ghost Ranch was, and still is, an unusually rich bone bed that was discovered in New Mexico in 1947. The American Museum excavated part of this stony cemetery of prehistoric beasts, and many of the fossils are still sequestered in our collections.

Ghost Ranch jacket, stored at the American Museum of Natural History, was recently opened, and a new species of ancient reptile was discovered inside.

Nesbitt became passionate about these Late Triassic time travelers, and he was keen to start liberating them. In my two-year tenure managing the museum's library of reptilian relics he has been the only one to open a Ghost Ranch jacket, and I was thrilled to see someone finally chipping away at the raspberry-yogurt-colored stone. Within weeks, Nesbitt was rewriting the Ghost Ranch story. He discovered complete skeletons of two new species of reptiles. Before Nesbitt's discoveries the Ghost Ranch bone bed was thought to have recorded a mass die-off of only one kind of dinosaur, the primitive meat-eater *Coelophysis*. Now, fifty-eight years after the initial New Mexico dig, we realize that Ghost Ranch sediments hold the carcasses of a diverse number of *Coelophysis*'s contemporaries as well.

What other ghosts are haunting the burial grounds of museums, subject to academic priority and funding? We hope to find out—in effect, discovering them twice. Every year new jackets arrive in my department, most of them nowadays from Mongolia's Gobi Desert, and join the queue. Sometimes I get a little sad when a plaster wall, just millimeters thick, barricades us from ancient faces, but it usually just humbles me and teaches me patience. After all, when some of our specimens haven't seen the sun for 220 million years, what's a few more decades?

Carl Mehling manages part of the vertebrate paleontology collections at the American Museum of Natural History.

EXPLORER GUIDE

American Museum
2006 Discovery To

January

- Baja Whale Watch Aboard *Sea Lion*—
  January 14–21, 2006
- Antarctica & South Georgia Aboard *Polar Star*
- Wolves & Wildlife of Yellowstone—
  January 23–January 29, 2006
- The Galápagos Islands & Machu Picchu—
  January 23–February 4, 2006
- Tahiti & Marquesas Aboard *Spirit of Oceanus* — January 27–February 6, 2006

February

- New Zealand Aboard *Spirit of Oceanus*—
  February 15–27, 2006
- Southeast Asia Unveiled

March

- Total Solar Eclipse over Egypt Aboard *Sunboat II* — March 14–30, 2006
- Africa Air Safari by Private Plane
- Peoples of the Pacific Rim by Private Jet—
  March 29–April 20, 2006

April

- Southern Africa aboard *Rovos Rail*—
  April 5–20, 2006
- Japan Aboard *Spirit of Oceanus* —
  April 9–23, 2006
- Mysteries of the Azores Aboard *Polar Star*

April *(continued)*

- Red Sea Voyage Aboard *Le Ponant*—
  April 21 – May 6, 2006
- Madagascar & Seychelles Aboard *Hanseatic*

May

- Journey Through the Trans-Caucasus: Georgia, Armenia & Azerbaijan— May 27–June 14, 2006
- The Crimean Express: Russia, Belarus, Moldova, and Ukraine By Private Rail—
  May 31–June 18, 2006
- Southwest China's Minority Peoples: Xishuanbana to Shangri-la
- Alsace: Cruising the Rhine River by Luxury Private Barge
- Cruising the Dalmatian Coast Aboard *MY Monet*

June

- The Golden Ring of Russia Aboard Kazan—
  June 7–20, 2006
- Ethnology & Cultural Traditions of Siberia, Mongolia & Tuva— June 8–27, 2006
- Family Galápagos Aboard *Santa Cruz*—
  June 18–27, 2006
- Family China— June 27 – July 8, 2006
- Family Greece Aboard *Panorama*—
  June 27 – July 8, 2006
- Alaska Aboard *Seabird*

To Make a

Contact Discovery Tours at 800-462-8687

Natural History

s Preview Schedule

June (continued)

- Bridging East and West: A World Leader Symposium in the Baltic— June 29–July 10, 2006
- Safari Sketching for Families in Tanzania

July

- Spitsbergen & the Russian White Sea Aboard *Hanseatic* — July 25 – August 18, 2006

August

- *Trans-Siberian Express:* Russia by Private Train From Moscow to Vladivostok— August 7–24 2006
- Native American Cultures of the Pacific Northwest
- Lost Cities of Central Asia: Archaeology in Uzbekistan & Turkmenistan— August 31–September 15, 2006

September

- Earth Orbit 2006: Red Carpet Seminar on Planetary Science & Space Travel *dates pending Russian launch*
- China & the Yangtze River Aboard *President*
- The Black Sea Aboard *Le Levant*— September 14–25, 2006
- Cruising the Mighty Mekong Through Vietnam & Cambodia — September 24–October 10, 2006

September (continued)

- The Way of Chinese Philosophers, Monks, and Poets
- Cultural & Archaeological Treasures of Bulgaria

October

- The Silk Road by Private Train: From Beijing to Moscow— October 3–24, 2006
- Antiquities of the Eastern Mediterranean Aboard *Le Levant*— October 6–20, 2006
- Melanesia: Featuring Papua New Guinea, the Solomon Islands, and Vanuatu Aboard *Clipper Odyssey*—October 18–November 2, 2006
- Festivals of India Aboard *Palace on Wheels* Featuring the Pushkar Camel Fair— October 19–November 4, 2006
- Egypt & Jordan by Private Plane— October 20– November 6, 2006
- Great Trade Routes by Private Jet— October 30–November 16, 2006
- Polar Bear Watch on Canada's Hudson Bay— October 31 – November 5, 2006

November

- Archeology of Libya
- Day of the Dead Celebration in Oaxaca

December

- Family Antarctica Aboard *Polar Star*
- Family Costa Rica

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