DINO TAKE

New Fossil Finds From China Provide Clues to the Origin of Birds

By JENNIFER ACKERMAN
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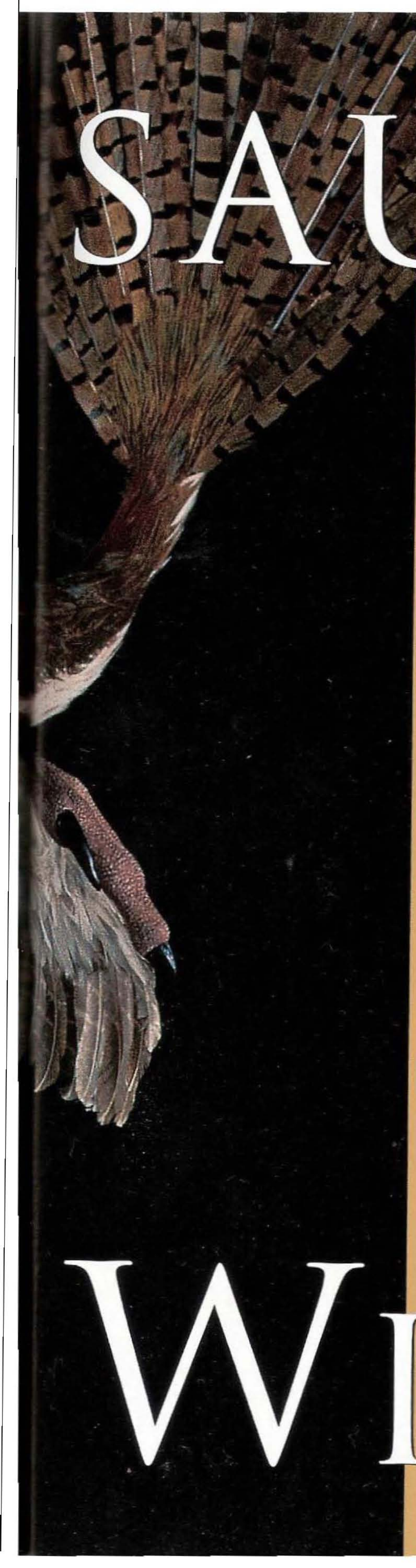

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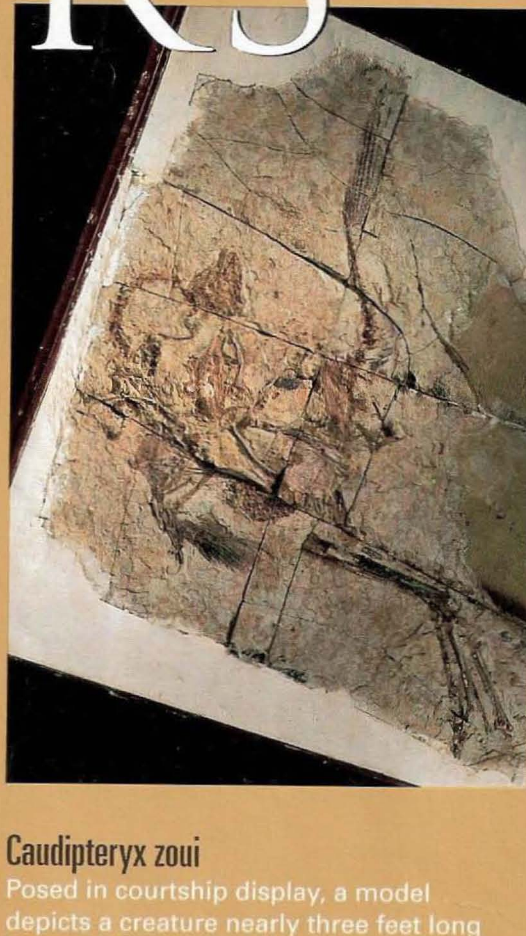
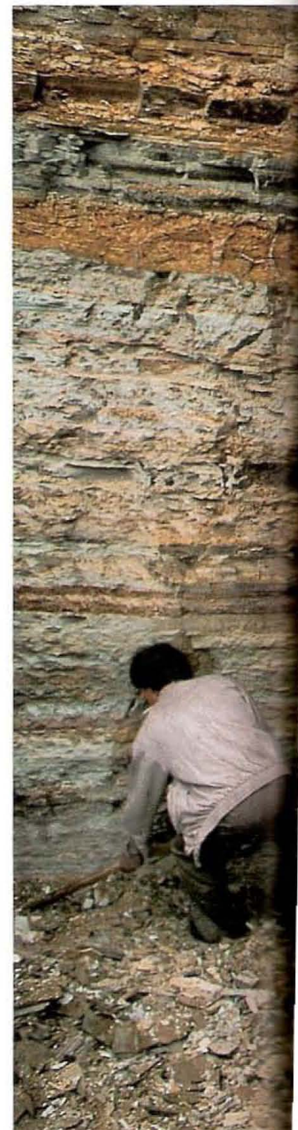


Caudipteryx zoui

Posed in courtship display, a model depicts a creature nearly three feet long that stunned paleontologists when resurrected from its stony grave—a dinosaur with feathers. This plumage appears on the fossil (above) at the end of the tail, at top, and under the arm, at lower left. More than 120 million years old, *Caudipteryx zoui* and three other new fossil species from China support the thinking of most scientists: Birds descended from dinosaurs, a lineage illustrated on pages 90-91.

WING



Storm clouds evoke the volcanic ash that repeatedly coated China's Liaoning Province during the early Cretaceous period, helping create a fossil-laced formation of an archaic lake bed at Sihetun (right). Months before the discovery of *Caudipteryx,* farmer Li Yin Fang, second from right, found another startling creature, given the name *Sinosauropteryx prima.*

One summer day Ji Qiang received a green silk box from a fossil dealer in Liaoning, a far northeastern province of China. Ji, the director of the National Geological Museum in Beijing, suspected that the box contained an ancient fish or reptile—Liaoning is rich in lake bed fossils dating from more than 120 million years ago. But when Ji opened the box, he gasped.

Inside was a creature unlike any he had ever seen. It was about the size of a chicken, frozen as if in mid-stride with its head wrenched back. It had a large skull with needle-sharp teeth, a pair of short, stout forelimbs, and a bony tail nearly double the length of its body. So well preserved was the creature that Ji could see not only the fine details of its skeleton but also its soft tissue and other body parts that usually do not fossilize.

"The fossil looked a lot like a small meat-eating dinosaur," Ji told me, "except for one thing." Along its back, from neck to tail, ran a thin, dark ridge of fibrous lines. To Ji the tiny filaments bristling the animal's neck, the longer fibers furrowing its back and tail, signaled not just one more diminutive dinosaur but a startling new clue to one of evolution's greatest mysteries: the origin of birds.

For generations scientists have been puzzling over where birds came from. Did they arise from dinosaurs? If so, which ones? And where are the missing links between dinosaurs of the deep past and today's finches and warblers? Ji wondered: Could this new fossil, *Sinosauropteryx prima,* or "first Chinese dragon feather," be just such a missing link? Could those strange fibers be the earliest examples of bird feathers?

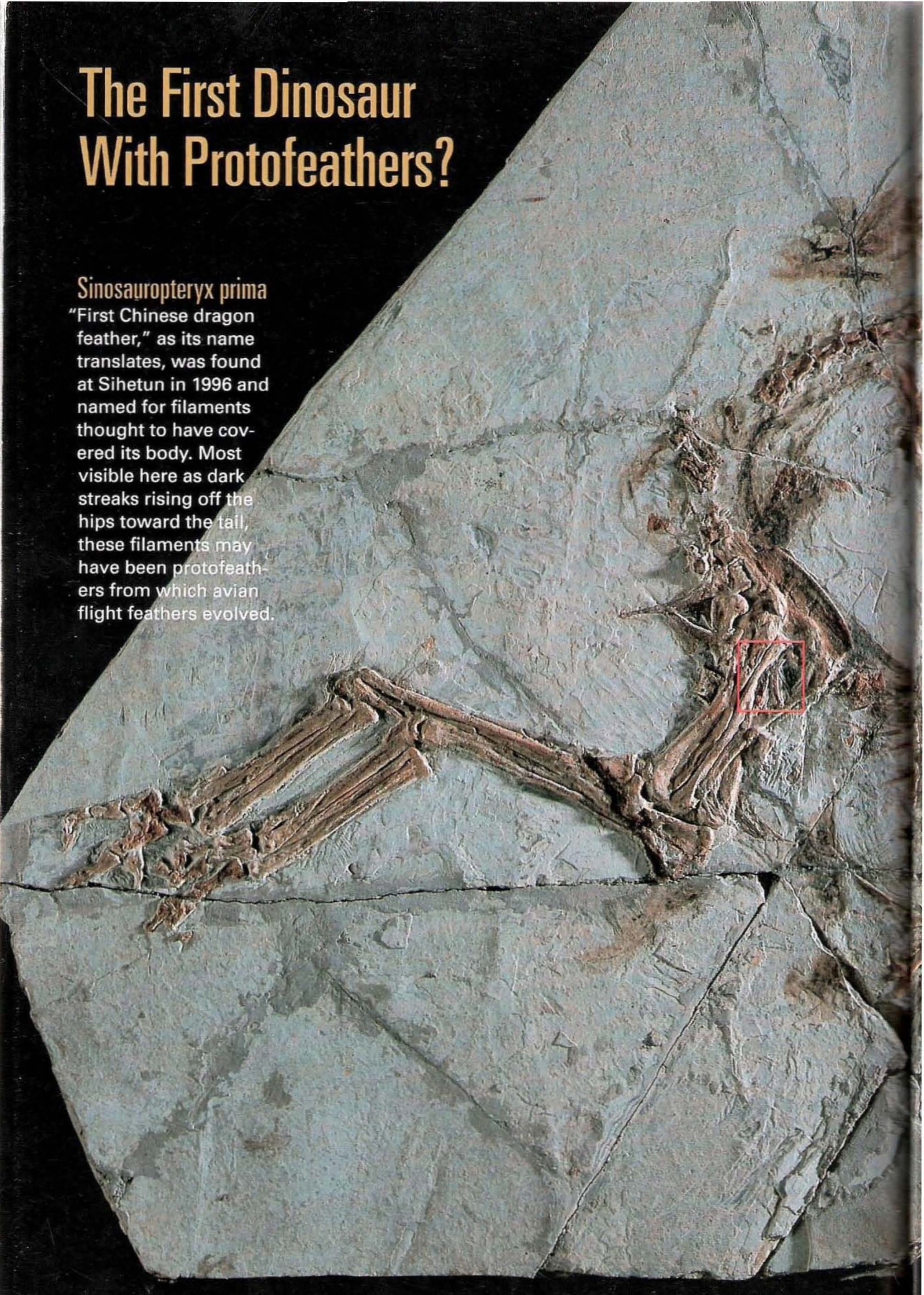
Jennifer Ackerman, the author of *Notes from the Shore,* is working on a book about evolutionary biology. She is a fellow at Radcliffe College's Bunting Institute. Photographer Lou Mazzatenta is a former National Geographic senior assistant editor. Artist Portia Rollings is a staff illustrator at the American Museum of Natural History in New York. Canadian sculptor Brian Cooley has created nearly three dozen life-size dinosaurs ranging from embryos to *T. rex.*

The very traits that define birds, especially feathers and thin, hollow bones, make for scarce fossil remains, bedeviling those seeking clues to the origin of birds and avian flight. So rare are the conditions that preserve bird remains—sediments devoid of oxygen and composed of grains so fine they protect the details of delicate feathers and bones—that only a few localities have yielded early bird fossils, tiny windows to the long, dark avian past.

But a burst of new finds from around the globe in the past two decades has quickened the pace of discovery: flightless creatures the size of wild turkeys that wandered the steppes of Central Asia 80 million years ago and tiny skilled fliers from Spain more than a hundred million years old sporting wings nearly as sophisticated as those of modern birds. And now from China *Sinosauropteryx* and two astonishing new creatures with feathers—as well as a flock of ancient birds so beautifully preserved you can see every detail of their skeletons, beaks, claws, and feathers.

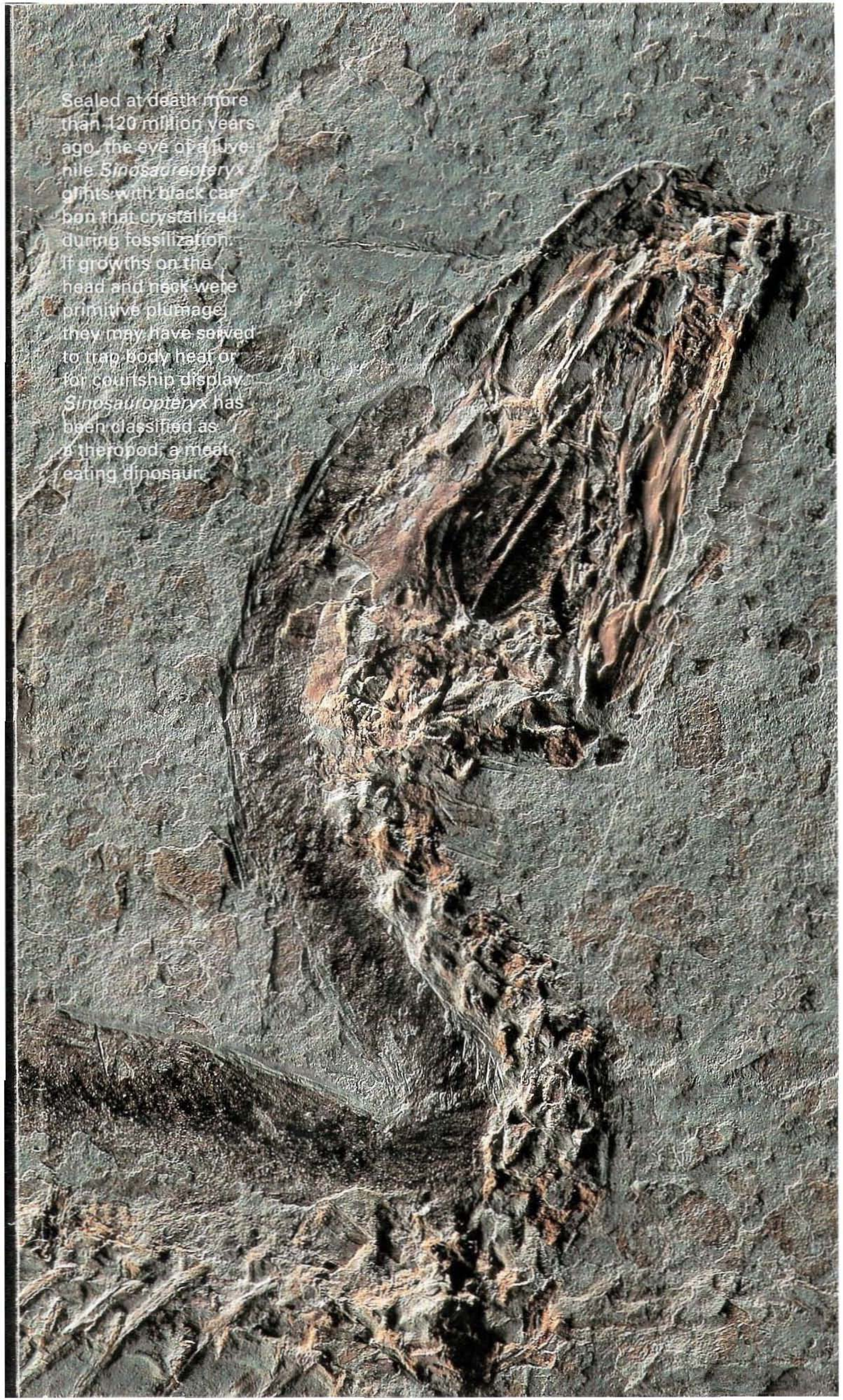
News of the Chinese finds has fired up hot debate over the twigs and branches of the avian family tree. Most scientists place *Sinosauropteryx* squarely on an early branch linking dinosaurs and birds. But a few others still doubt the dinosaur–bird tie, holding that the avian clan evolved from some *(Continued on page 84)*

The First Dinosaur With Protofeathers?



Sinosauropteryx prima
"First Chinese dragon feather," as its name translates, was found at Sihetun in 1996 and named for filaments thought to have covered its body. Most visible here as dark streaks rising off the hips toward the tail, these filaments may have been protofeathers from which avian flight feathers evolved.

The only dinosaur yet found with a mammal in its gut, the specimen exhibits its last meal behind the ribs near the thigh bones (red outline). A close-up (right) pinpoints the toothed jawbone of the unidentified prey.

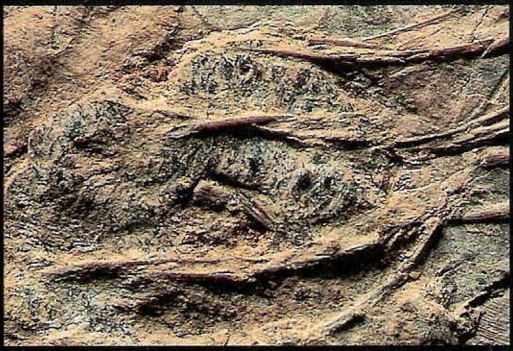


Sealed at death more than 120 million years ago, the eye of a juvenile *Sinosauropteryx* glints with black carbon that crystallized during fossilization. If growths on the head and neck were primitive plumage, they may have served to trap body heat or for courtship display. *Sinosauropteryx* has been classified as a theropod, a meat-eating dinosaur.

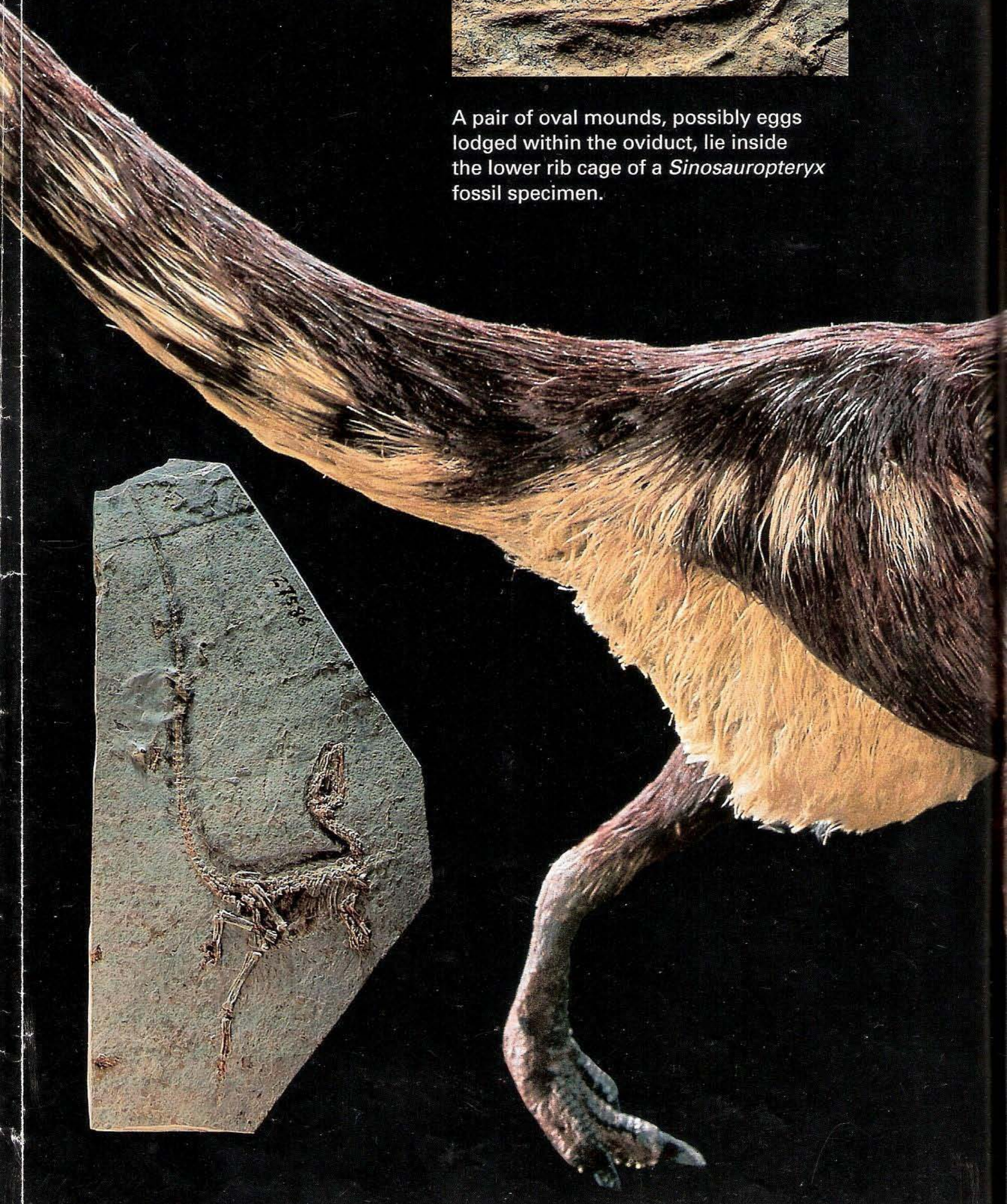
Fossil Bonanza

Hopes for another big discovery draw scientists to the dig at Sihetun, where layers of rock entomb birds, dinosaurs, plant life, and multitudes of fish, including *Lycoptera* (right). Dating from more than 120 million years ago, the lake bed formation is a hundred feet thick and covers 20 square miles. Legitimate excavators compete with unsanctioned diggers, who, despite the efforts of local authorities, still remove fossils to sell on the black market.

As if felled in mid-stride, a *Sinosauropteryx* (fossil at right) hoists a flexible tail with 64 vertebrae—the longest tail of any known theropod—probably used for balance. Such features shrank as some dinosaur species became ever more birdlike.



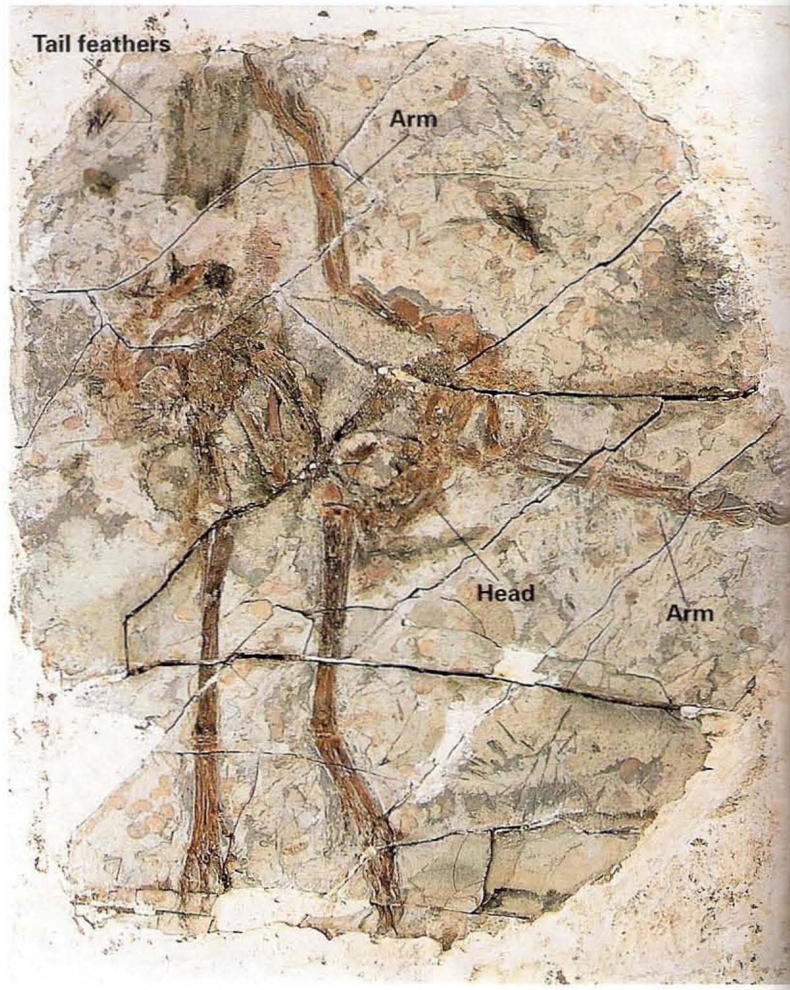
A pair of oval mounds, possibly eggs lodged within the oviduct, lie inside the lower rib cage of a *Sinosauropteryx* fossil specimen.



The downy filaments of *Sinosauropteryx* measure as long as 1.5 inches but lack aerodynamic quality. Such material is so fragile that it is rare to find it well preserved.

Shown near life-size, a *Sinosauropteryx* model peers down with arms extended, ready to pounce on a lizard or small mammal. If its body covering first evolved to preserve heat rather than for display, it would suggest that *Sinosauropteryx* was warm-blooded. Scientists have long debated the question of dinosaur metabolism.

(Continued from page 77)
earlier reptile, long before *Sinosauropteryx* feasted on its last meat.



That a small dinosaur with a hint of kinship to modern birds would ruffle feathers is hardly surprising. The ancestry of birds has aroused as much passionate debate as any puzzle in evolution, except perhaps the origin of life itself and the beginnings of our own tribe.

"We are obsessed with birds," says John Ostrom, a paleontologist at Yale University's Peabody Museum of Natural History, "in part because we envy their apparent freedom and ability to fly. Just look at our myths and symbols: Daedalus, the dove, the eagle, the raven."

I know this bewitchment. Birds leaped into my heart at an early age. There was the thrill of seeing a flight of snow geese pink-bellied in the western sun or a hummingbird so close I could almost feel the thrum of its tiny wingbeat. Human limbs are the heavy limbs of earthbound creatures. Birds are masters of the sky, superbly designed to defy gravity through the gift of wings, light bones, and airy, flexible feathers.

AN 18TH-CENTURY SAGE once proposed that birds arose from fish cast upon the land: "Fins turned to quills, the dried scales became feathers, the skin assumed a coating of down, the belly-fins changed into feet." Not until the mid-19th century did scientists note that birds were built a lot like reptiles but with a beak instead of teeth and three reptilian fingers hidden inside wings. No one had a snatch of evidence, however, to connect the two.

Then in 1861, while the bed of an ancient lagoon in Bavaria was being quarried for limestone, workmen uncovered a flat flag of stone with the remains of a birdlike creature. It was about the size of a crow, with the clawed fingers and long bony tail of a reptile but with the wishbone and feathered wings of a bird. The feathers resembled those of modern birds not just in number and arrangement but also in their asymmetrical shape, with narrow outer vanes that could neatly cut the air. The creature was named *Archaeopteryx* (from the Greek for "ancient wing") and eventually dated at 150 million years old.

The *Archaeopteryx* fossil arrived on the scene just two years after Charles Darwin's publication of *The Origin of Species*. Naturalist Thomas Henry Huxley, Darwin's whiskered, griffinlike champion, seized on the creature as a perfect example of a transitional form between reptiles and birds. Go down into the dark of time and watch the alchemy of evolution: the heavy bone of the reptile transforming into light, hollow bird bone, the forelimbs

Archaeopteryx and Protarchaeopteryx

Earliest known bird, 150-million-year-old *Archaeopteryx* (right) was the first fossil evidence linking birds and dinosaurs. The first of these crow-size creatures came to light in 1861 in the same Bavarian limestone that yielded a lone asymmetrical flight feather (above). A new Chinese fossil more than 120 million years old, *Protarchaeopteryx* (left) has more primitive, symmetrical feathers and may be how *Archaeopteryx*'s ancestors looked.

stretching into wings, the shallow breastbone deepening to anchor massive wing muscles, the reptilian scales blooming into feathers. *Archaeopteryx,* Huxley believed, was a midcourse snapshot, evolution caught in the act.

When a small dinosaur named *Compsognathus* turned up in the same deposit as the ancient bird, Huxley noted the uncanny resemblance between the two and made a surprising suggestion: Birds did not just coexist with dinosaurs, they were close relatives.

But Huxley's critics raised the question, Isn't it possible that birds and dinosaurs look alike not because they were closely related but because they lived in similar niches and did things in a similar way? Separate development of like features, or convergence, is common in the history of life. Just look at the wings of a bat and those of a butterfly: Both allow for flapping flight but arise from different body parts and reflect no common ancestry.

Still, few cared to seriously challenge Huxley's dinosaur–bird link until the publication in 1926 of the English-language edition of Gerhard Heilmann's *The Origin of Birds,* which claimed that dinosaurs lacked wishbones, a defining avian trait. Birds and dinosaurs are likely related, said Heilmann, but only by way of a common ancestor from deeper in time. This ancestor, he suggested, was a small, slender, bipedal reptile that climbed trees and then learned to glide among them 230 million years ago in Triassic times.

So went the conventional wisdom for nearly half a century. Paleontologists occasionally stumbled on the fossilized bones of birds from late Cretaceous times, more than 65 million years ago. But nothing turned up to fill the abyss between these later birds and *Archaeopteryx*—or to illuminate what came before.

ON A ROCKY SLOPE near the tiny village of Sihetun in northeastern China fossils lie everywhere, imprinted on thin, brittle sheets of siltstone. Chen Pei-ji, a scientist from the Nanjing Institute of Geology and Paleontology, stoops often as he moves up the slope, gleefully retrieving splendid specimens of conchostracans, tiny freshwater crustaceans. Even my amateur eye easily spots stone fragments with the perfect impressions of mayfly larvae.

It is early June 1997, a year after the discovery of *Sinosauropteryx*. A team of three Chinese paleontologists has set out by foot from Sihetun, a huddle of low stone huts in the poor, arid country of western Liaoning Province. With us is Li Yin Fang, one of the farmers who unearthed *Sinosauropteryx* and sold it to the dealer who sent it to Ji.

As we ascend a gully in the slope, the air is cool and quiet but for the occasional shrill cry of a magpie. To our left, in a cliff excavated by Sihetun's farmers, is a layer-cake formation of siltstone, clay, and volcanic tuff, not yet conclusively dated but probably more than 120 million years old—the early Cretaceous period, a time of burgeoning creation.

From these fossil beds have come millions of insects, hundreds of plant fossils, whole schools of fish that look as if they might at any moment flick into a new position. This was once a lake surrounded by lush vegetation and populated by a riot of insects, frogs, lizards, crocodiles, fish, mammals. Apocalypse came from the west, from what is now Inner Mongolia, where volcanoes erupted, spewing poisonous gas and ash that drifted east hundreds of miles. At Sihetun plants and animals died instantly, dropped to the lake bottom, and were buried by fine ash. Over time the layers of ash and silt settled and solidified, imprisoning and recording an ark of ancient organisms.

The first primitive bird fossil was found here in 1994 by a farmer who sold it to a trumpet player who gave it to Hou Lianhai, a specialist in avian fossils at the Chinese Academy of Sciences. Hou was instantly struck by the fossil's similarity to *Archaeopteryx*. About the size of a magpie, it had wings with long fingers and large, curved claws like those of *Archaeopteryx*. But where *Archaeopteryx* had a mouth full of teeth, this creature had a horny,

LATEST DISCOVERY

Caudipteryx Revealed

By PHILIP J. CURRIE

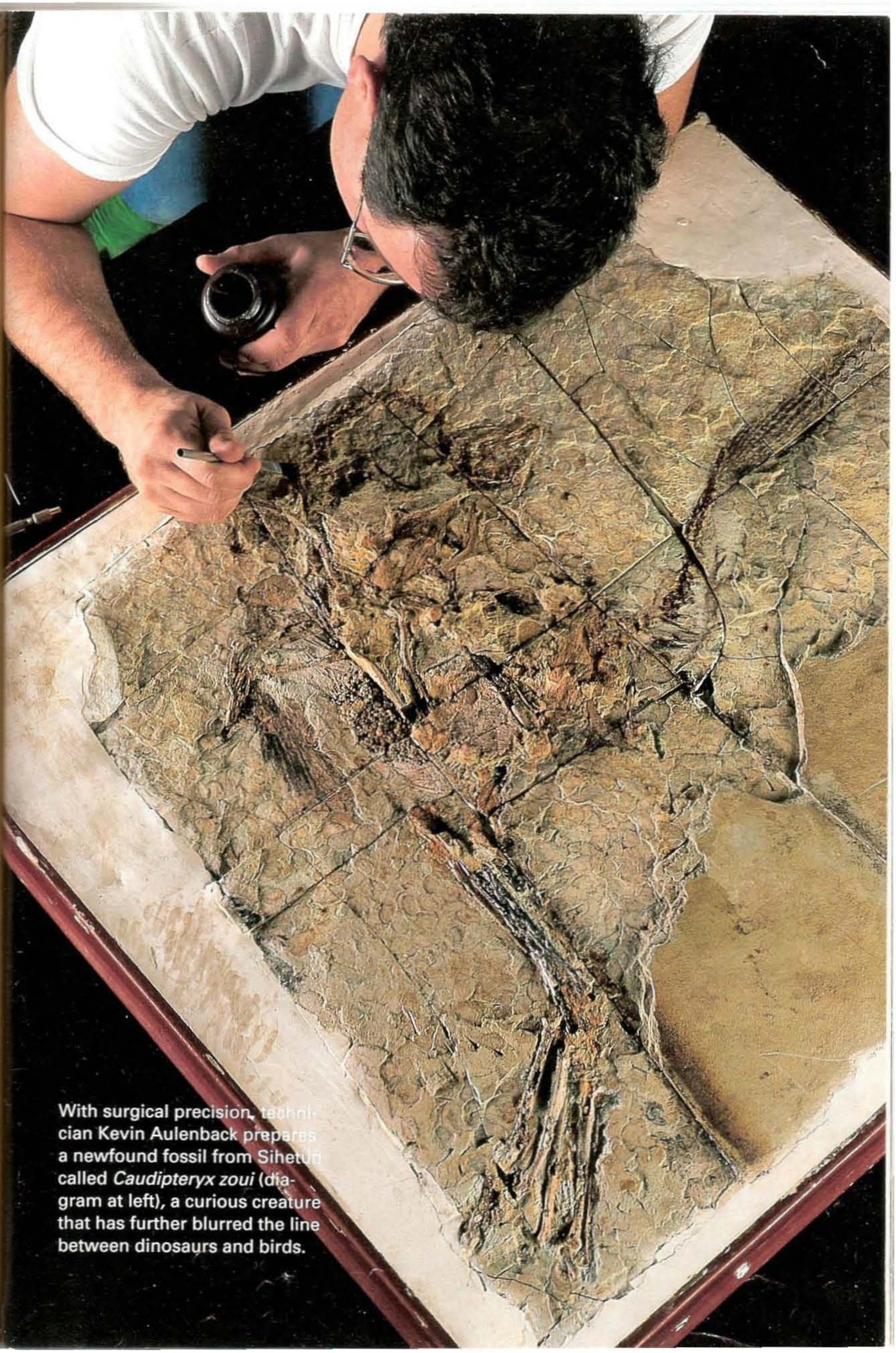
RESEARCH PROJECT

Supported in part by your Society

It was late when a visitor appeared in my dimly lit hotel room in Beipiao, China. Geologist Ji Qiang carried a cloth sack containing a broken slab of rock. He had just acquired it from a collector who works the rich fossil beds of Liaoning Province. These formations have produced more specimens relevant to the origin of birds than all the world's other sites combined.

The director of China's National Geological Museum, Ji believed he now possessed the best specimen yet of *Protarchaeopteryx*. This feathered creature is even more primitive than *Archaeopteryx*, a fossil considered the earliest bird since its discovery in Bavaria in 1861. Yet as we would soon discover, Ji had found something entirely new.

Three months later Ji and I were in Beijing, huddled in the red-carpeted conference room of Ji's museum. As we studied three specimens identified as *Protarchaeopteryx*, some inconsistencies began to appear. The three fossils were the same size and all had body feathers, but two had much shorter arms. Were we looking at males and females? Was



With surgical precision, technician Kevin Aulenback prepares a newfound fossil from Sihetun called *Caudipteryx zoui* (diagram at left), a curious creature that has further blurred the line between dinosaurs and birds.

Protarchaeopteryx a creature with much variation?

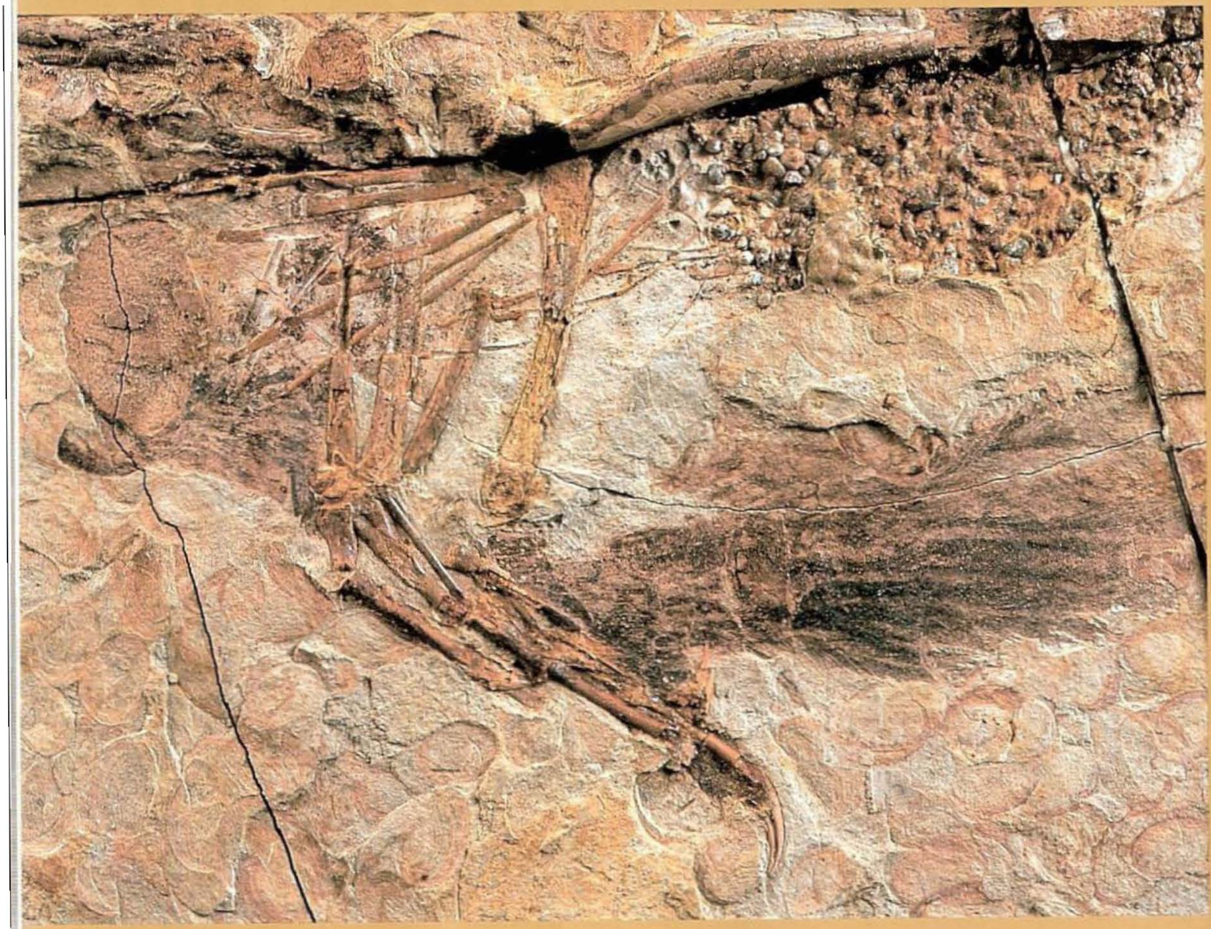
Fortunately Kevin Aulenback, one of the most skillful technicians at the Royal Tyrrell Museum of Palaeontology in Drumheller, Alberta, where I am curator of dinosaurs, was with us. As he cleaned the skulls under a microscope with a dental probe, we were startled by differences in the teeth. In both upper and lower jaws *Protarchaeopteryx* has *Archaeopteryx*-like conical teeth, except that they are serrated. But the two short-armed specimens had long, sharp teeth with deep, bulbous roots. And the teeth were confined to the front of the upper jaw, pointing more forward than down. They may have been incorporated into a birdlike beak with only the tips protruding.

Caudipteryx Revealed

We were now convinced that we had found a species never before seen. We named it *Caudipteryx*, or "tail feather," for the tail plumes that the creature likely fanned out for display. The feathers of *Protarchaeopteryx* and *Caudipteryx* seal their relationship to the earliest known birds, though neither animal had the ability to fly. In their body form they look less like that 19th-century evolutionary icon *Archaeopteryx* and more like those slender, meat-eating dinosaurs called theropods.

Caudipteryx becomes the fourth type of "feathered" animal from the remarkable Sihetun locality. It joins *Protarchaeopteryx* and *Confuciusornis*—a creature with relatively short, clawed wings that was probably one of the first birds to fly well—and *Sinosauropteryx*, one of the most important dinosaur finds of the 20th century.

My introduction to *Sinosauropteryx* had taken place during another memorable meeting with Ji. A year earlier at his museum he opened a



silk-wrapped gift box for me. Inside was a stunningly complete chicken-size fossil with a halo of feather-like structures on its back and tail, yet with the body of a theropod—a sensational find that made news as a possible missing link between dinosaurs and birds. Paleontologists and ornithologists are now grappling with redefining what constitutes a bird.

Caudipteryx and *Protarchaeopteryx* make the dividing line between dinosaurs and birds even less distinct and strengthen the theory that birds evolved from small carnivorous ground-dwelling dinosaurs.

These four discoveries were made within just a few years at Sihetun. I can't help but wonder what other treasures are to be found there.

Fossils of *Protarchaeopteryx*, *Caudipteryx*, and *Sinosauropteryx* and models of the latter two species will be displayed at Society headquarters through July 19.

Peering into a cloudy past, Aulenback and paleontologist Philip Currie (above, at right) examine *Caudipteryx* with Ji Qiang of China's National Geological Museum, a co-author of the specimen's scientific description. Below its feathered arms the fossil shows stones called gastroliths (left, at upper right). These were ingested to grind food, as in the gizzards of modern birds.

toothless beak. Until this discovery, Hou had been among the scientists who supposed that birds did not evolve beaks for another 70 million years. Here was a bird nearly as old as *Archaeopteryx* with a practically modern jaw. Hou named the bird *Confuciusornis sanctus*, which means "sacred Confucius bird."

Since that first fossil was found, hundreds of specimens of *Confuciusornis* have been plucked from these rocks. "So many birds packed into such a small area suggests a communal lifestyle," Hou tells me. I think of skimmers nesting gregariously on beaches, a gaggle of geese descending on marshes.

Later in his office in Beijing, Hou would show me his specimens. It takes up to two months to liberate the fine outline of a *Confuciusornis* fossil from its matrix of rock. What emerges is an exquisite glimpse of ancient birdlife frozen in stone: a female adult nestled skull to skull with a baby bird, or a male with long, lovely tail feathers like a fork-tailed flycatcher side by side with a female. Hou runs his fingers lightly over the fossils. Skull, beak, wishbone, tibia, wings. It's no big leap to imagine this bird snatching up an insect in mid-flight.

"*Confuciusornis* is the earliest bird we know of that could fly for any distance," he says. "It had wings nearly as primitive as those of *Archaeopteryx*, but it had other, more modern features—lighter bones and a shorter tail," which may have improved its flying skills.

From their reptilian beginnings the ancestors of birds evolved traits that would later aid the cause of flight. They gave up jaws with heavy teeth in favor of beaks, for example, and thinned and hollowed their bones (the skeleton of a three-pound frigatebird weighs but four ounces). Tiny air sacs and tubes evolved to honeycomb nearly every body space. Metabolism and temperature were souped up to sustain the chemical reactions that produce sufficient energy to stay aloft, so that a thrush now lives at what for us would be a fever heat, 105°F. The genome of birds is smaller than that of reptiles or mammals. Some scientists speculate that birds evolved a smaller genome to make their cells more metabolically efficient.

It's hard to imagine all this hot life and free flight arising from a sluggish reptile. But in 1964 John Ostrom, the Yale paleontologist, upended this image of reptiles as universally creeping crawlers. While digging for fossils in

EVOLUTION OF A WING

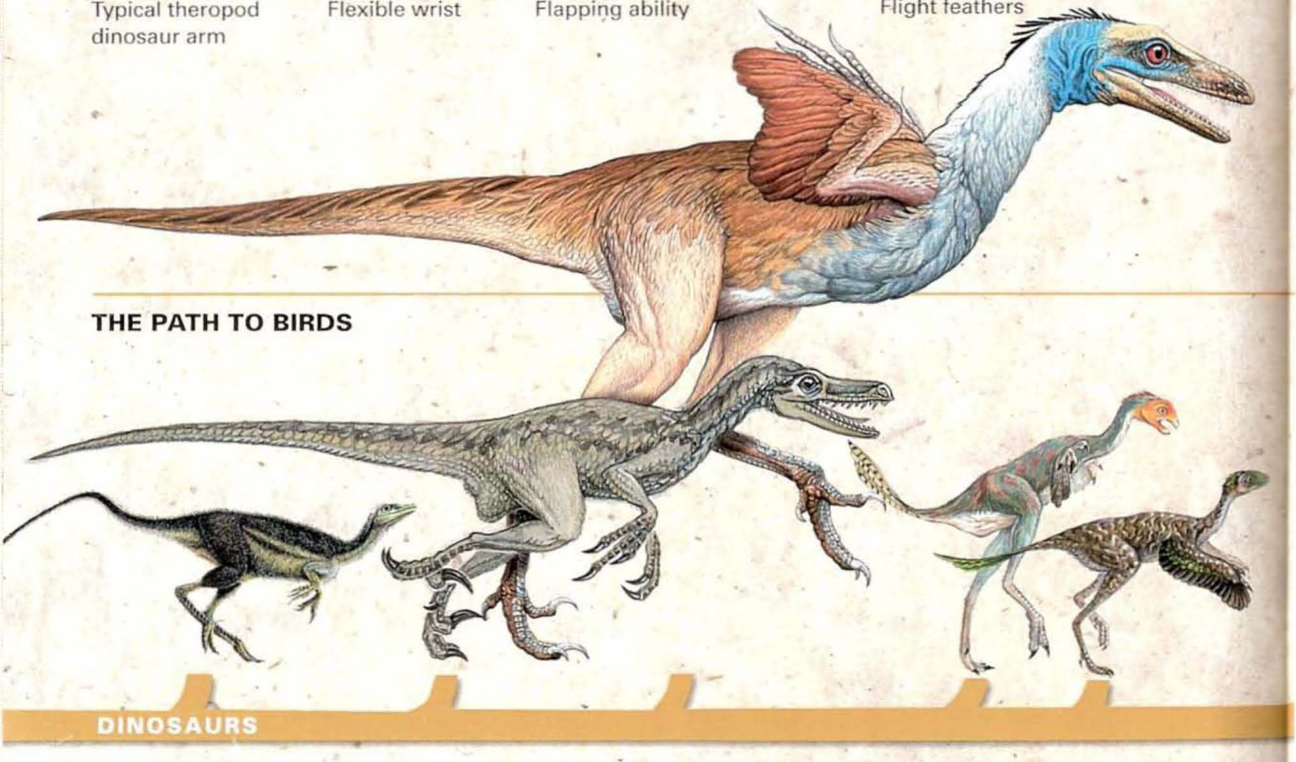
Sinosauropteryx
Typical theropod dinosaur arm

Velociraptor
Flexible wrist

Unenlagia
Flapping ability

Archaeopteryx
Flight feathers

THE PATH TO BIRDS



Sinosauropteryx
Covered with filaments that may have evolved for insulation or display, *Sinosauropteryx* was a ground-dwelling runner with short arms and three-fingered hands.

Velociraptor
This predatory theropod, whose fossils were found in Mongolia, was endowed with a wrist bone that permitted the animal's grasping hands to swivel, helping it capture prey. A flexible wrist is required for powered flight.

Unenlagia
Found in Patagonia, this flightless, eight-foot-long creature could move its arms up and down much as a person on a surfboard moves his arms for balance. A precursor to flapping, this action is critical to the flight stroke.

Caudipteryx
Straddling the realms of dinosaurs and birds, *Caudipteryx* is the latest in a series of sensational fossil finds in China. A speedy runner, it was covered with primitive feathers that lacked the aerodynamic quality necessary for flight.

Protarchaeopteryx
Another discovery in China, *Protarchaeopteryx* resembles *Archaeopteryx* in many ways but is more primitive. The symmetrical feathers on its arms and tail appear longer than those of *Caudipteryx*, but it probably could not have achieved true powered flight.

Eoalulavis
First alula

***Corvus* (Crow)**
Modern wing

Archaeopteryx
The feathers of this bird's celebrated fossils are asymmetrical, with the leading edge narrower and more streamlined than the trailing edge. This enabled the wings to slice the air, permitting at least rudimentary flight.

Eoalulavis
Found in Spain, this bird exhibits the earliest known alula, a tuft of feathers attached to the thumb. By altering airflow, the alula permits good maneuverability and control at low flying speeds, crucial for takeoffs and landings.

Corvus
At the zenith of forelimb evolution, the crow and other modern avian species, with their shortened tailbones and expansive wing surfaces, represent the full flowering of the ability to fly.

To Fly

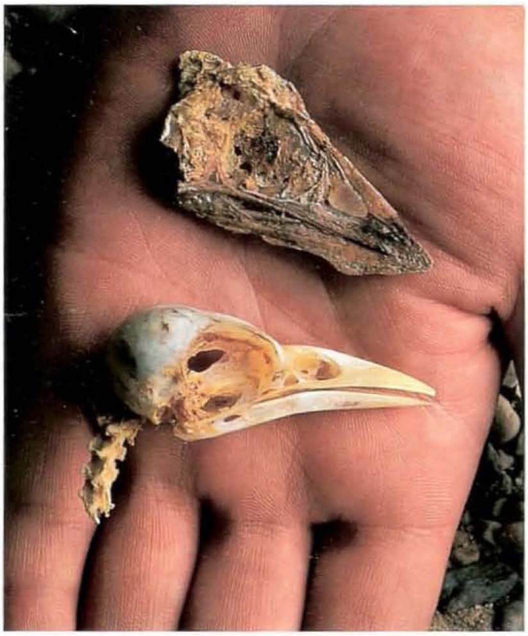
Just as humans are mammals, birds belong within the great clan of dinosaurs in the view of most paleontologists. The idea that the defining traits of birds first arose in dinosaurs dates from the early expoundings of evolutionary theory. British biologist Thomas Henry Huxley, a champion of Charles Darwin, broached the notion in the mid-19th century. The idea was examined anew in the 1970s by Yale University paleontologist John Ostrom, who cited a host of similarities between *Archaeopteryx* and theropods.

This family tree (left) is not a chronological progression but rather an illustration of how the traits of the modern wing evolved in different creatures in different locations at different times. "The wing is a perfect example of how nature incorporates attributes that came about for unrelated reasons into a new structure," explains paleornithologist Luis Chiappe of the American Museum of Natural History.

Feathers that evolved to keep a ground dweller warm, for example, might give it the ability to glide and better catch prey, leading to more feather development.

A great boost to flight came with the alula, specialized feathers on the thumb that are essential for maintaining controlled airflow over the wings during slow flight. It made its earliest known appearance 115 million years ago in Spain in a bird called *Eoalulavis* (fossil above, with alula outlined).

SINOSAUROPTERYX BY MICHAEL SKREPNICK; *UNENLAGIA* BY ALDO CHIAPPE BASED ON FOSSIL INTERPRETATION BY FERNANDO NOVAS



Skulls of a modern Old World oriole, at bottom, and *Confuciusornis,* from the formation at Sihetun, have large eye sockets and prominent nasal openings. *Confuciusornis* is the earliest known bird with a toothless beak.

Wyoming and Montana, Ostrom uncovered a dinosaur about ten feet long and lightly built, with a huge, sickle-like claw on its foot. *Deinonychus,* or "terrible claw," was no lumbering creature but a fierce, leaping predator. Known as a coelurosaur, it represented a new variety of small, bipedal theropod, the meat-eating dinosaur group that includes *Tyrannosaurus rex. Deinonychus* was fleet of foot and agile as any hawk snatching up its rodent prey.

Ostrom is a smallish man in his 70s with a heron-like crest of white hair and a habit of cocking his head so that his better ear will catch the conversation. When he talks about birds, his eyes shine with childlike excitement.

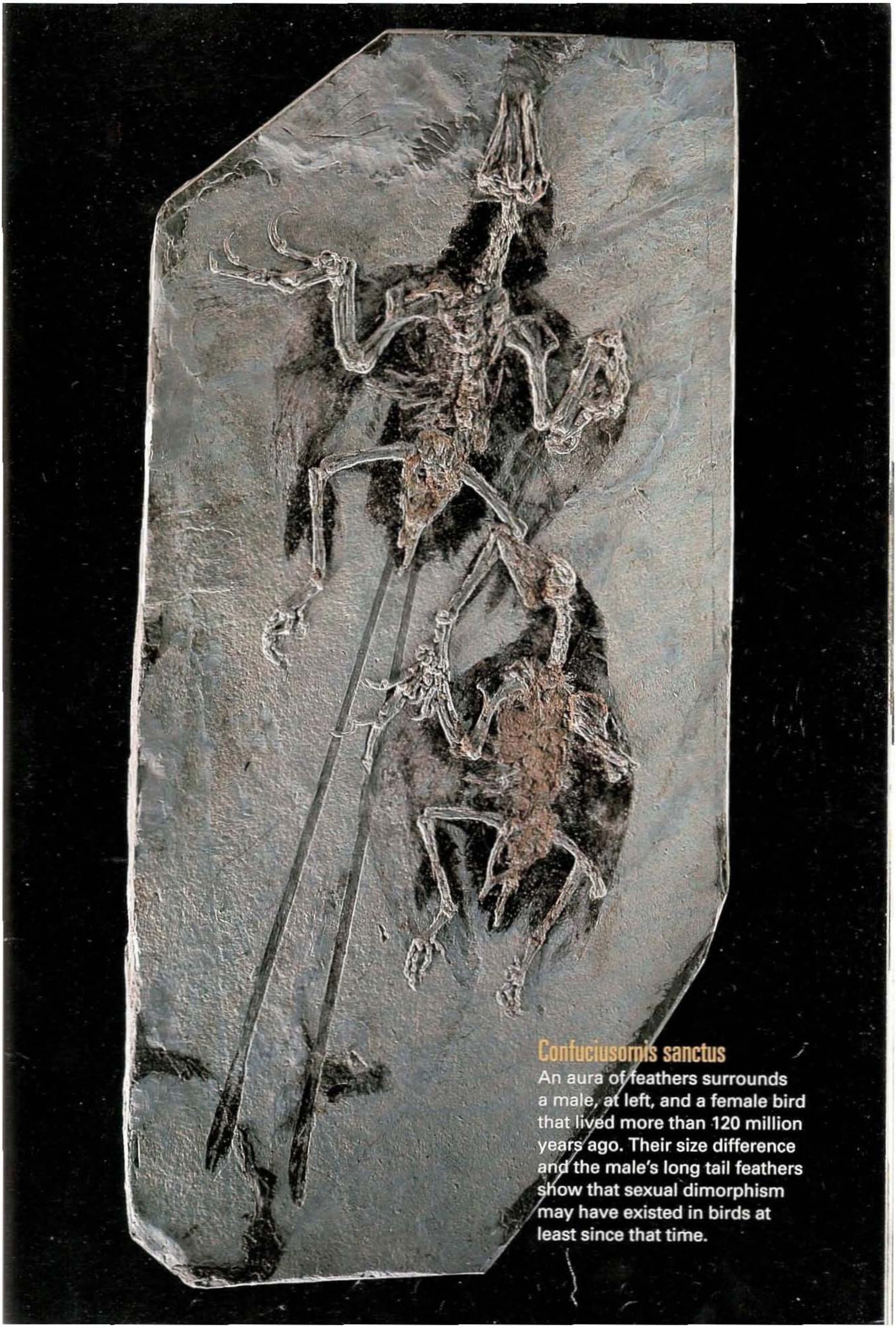
A decade after unearthing *Deinonychus,* Ostrom launched a meticulous study comparing the anatomical details of *Archaeopteryx* with those of dinosaurs. He concluded that *Archaeopteryx* resembled nothing so much as a scaled-down version of *Deinonychus.* There were far too many similarities, he said, to be the result of convergence. He pointed in particular to a small, distinctive half-moon-shaped wrist bone shared by the creatures, which allowed them both to pivot their hands in similar fashion, a critical movement for catching prey—and for flapping flight. "Dinosaurs did not become extinct," he proclaimed. They live today in feathered form, as swallow, hawk, hummingbird, magpie.

TERRESTRIAL DINOSAUR to *Archaeopteryx* to swallow. This is not to suggest a direct lineage, grandfather to father to son. More like the loose line of lemur to ape to human. "We don't have the evidence to support any kind of direct lineal descent," says Ostrom. "There are too many gaps in the fossil record. We're in the business of connecting dots scattered in time and space."

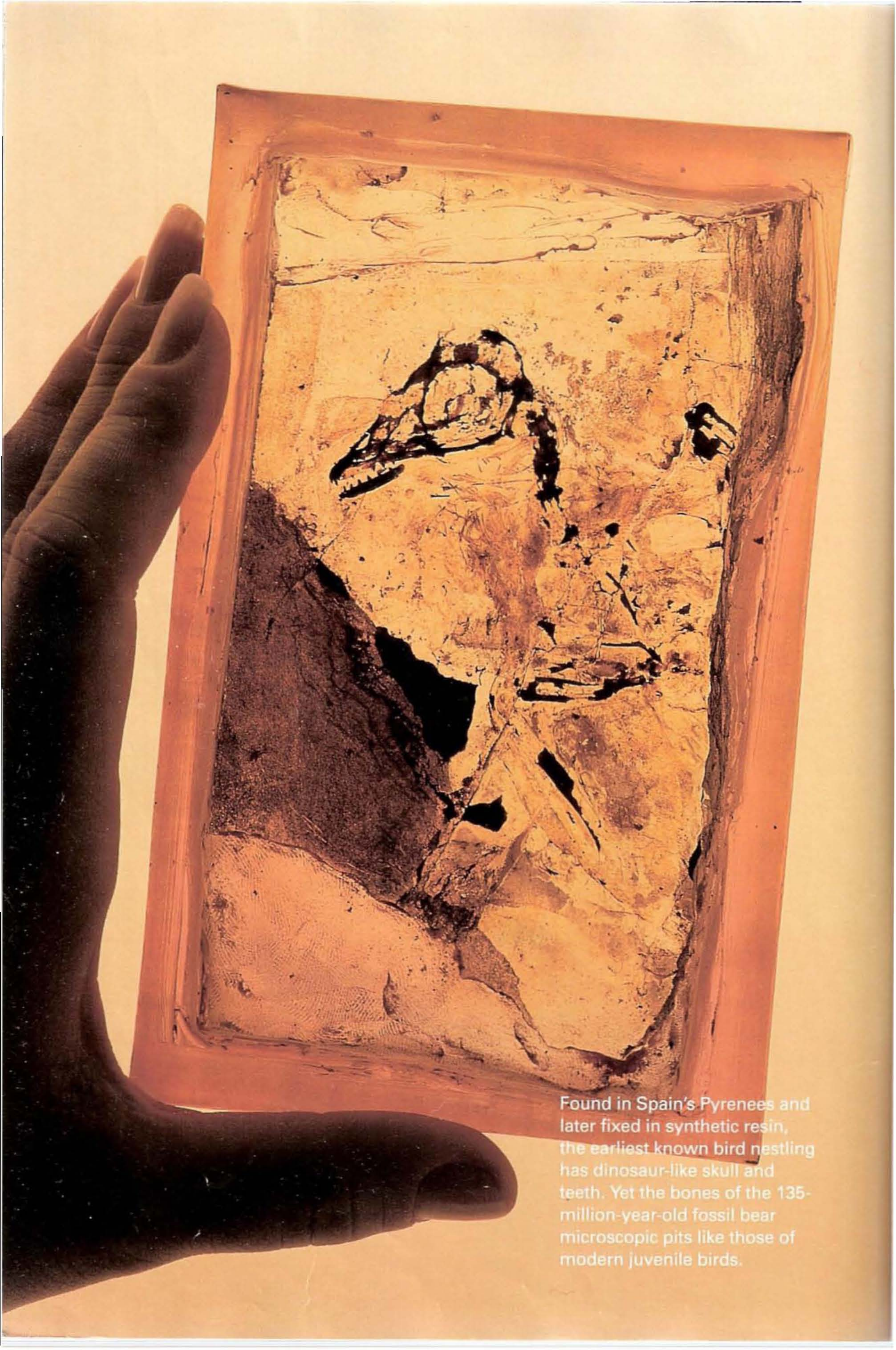
In the past few decades a generous sprinkling of new dots has popped up around the world, a bizarre collection of birdish dinosaurs and dinosaur-like birds that tighten the lines. From 80-million-year-old strata in the Gobi desert has come *Velociraptor* ("swift robber"), a small, agile, predatory theropod with slim legs, clasping hands, and two key bird traits—a wishbone and a sternum, or breastbone. Also the skeleton and nest of *Oviraptor,* a theropod with a wishbone, clawed feet, and the birdlike habit of brooding its eggs.

In January 1996 the badlands of Patagonia gave up the partial remains of a 90-million-year-old two-legged dinosaur with surprisingly birdlike limbs. Called *Unenlagia,* "half bird" in the language of the Mapuche Indians, the creature folded its forelimbs much in the way birds tuck their wings and could move its shoulder joint to raise its front limbs as a bird would to start a downward flight stroke. Close on the heels of this discovery came news of one from Spain, a 135-million-year-old nestling with a primitive, dinosaur-like head but nearly modern wings.

These days most paleontologists are convinced that birds are a subcategory of dinosaurs. "The anatomical similarities are overwhelming," says Mark Norell, chairman of the department of vertebrate paleontology at the American Museum of Natural History in New York. He rattles off a few of more than one hundred shared features: wishbone, skull, three forward-pointing toes. The links between dinosaurs and birds are upheld by cladistics, a technique for drawing up family trees by analyzing the shared inheritance of specific



Confuciusornis sanctus
An aura of feathers surrounds a male, at left, and a female bird that lived more than 120 million years ago. Their size difference and the male's long tail feathers show that sexual dimorphism may have existed in birds at least since that time.



Found in Spain's Pyrenees and later fixed in synthetic resin, the earliest known bird nestling has dinosaur-like skull and teeth. Yet the bones of the 135-million-year-old fossil bear microscopic pits like those of modern juvenile birds.

features, such as specialized bones. At present cladistics firmly nests birds within the category of theropod dinosaurs.

Still, there are scientists who favor the notion that birds arose from a pre-dinosaur form, a small, tree-climbing reptile. These skeptics of the dinosaur–bird theory ask: If birds came from dinosaurs, why can't paleontologists find missing links of an appropriate age? "The majority of dinosaurs considered most birdlike are younger than *Archaeopteryx*," Hou Lianhai told me.

"But fossilization is a rare event," counters Mark Norell. "You could take all the fossils ever collected relevant to this debate and fit them nicely in my office." Norell and most other paleontologists think that dinosaurs such as *Velociraptor* represent vestiges of older ancestral lineages that did give rise to birds, probably in middle Jurassic times; the older species just haven't been found yet. Fossil beds in Utah dating from the late Jurassic have yielded teeth from what was probably a birdlike theropod, though as yet no complete skeletons.

BECAUSE OF THE LAY OF THE LAND in Liaoning, we move deeper into time as we climb, the rocks above us being older than those below. Li Yin Fang, the farmer, jumps down from the path into a deep pit to point out a thick layer of gray volcanic tuff. A wiry, energetic man with a quick grin, Li has been mining these fossil beds for years and has named the layers: thin yellow wax, great white band, thin red strip. "See that color?" he says, pointing to the gray volcanic layer. "If I was looking for fossils, this is where I'd dig."

Dozens of deep pits pockmark the fossil beds of Sihetun. Though Chinese scientists and government officials applaud the farmers for discovering the bird fossils, they want to halt the destruction of the site and the smuggling of its treasures. "If a fossil isn't collected right, it loses its context," explains Hou Lianhai, "the kind of rock it was buried in, the animals that surround it, how it was buried"—in effect, its story. But stopping the smuggling may be difficult. For a farmer who earns less than \$400 a year, selling a single bird fossil on the black market for as much as \$1,400 can mean a quick lift out of poverty. And market demand is high. At a fossil show in Arizona last year about 50 specimens of *Confuciusornis* were up for sale, most fetching close to \$5,000. To thwart the illegal trade, local authorities have filled many pits at Sihetun, posted warning signs, and offered to buy fossils already extracted from the site. But the illicit digging continues.

When we reach a high ridge, Li shows us the pit where farmers digging for Ji Qiang recently uncovered a new specimen of *Sinosauropteryx*. Nearby they found an extraordinary turkey-size animal with wings and tail feathers. It resembles *Archaeopteryx* but is more primitive and larger, with stronger legs, hence the name Ji has given it, *Protarchaeopteryx robusta*. Its

A new find is scrutinized by paleontologist José Sanz, director of work at Las Hoyas in central Spain. The site has yielded *Eoalulavis* and two other genera: significant links between *Archaeopteryx* and later birds.

feathers are symmetrical (unlike those of *Archaeopteryx*), suggesting that it could not fly. In the same area another flightless creature turned up—*Caudipteryx zoui*—this one with peculiar teeth, tail feathers, and long, symmetrical feathers sprouting from its second finger (see pages 74-5 and sidebar, pages 86-9).

These stunning new finds promise to illuminate the puzzles of early bird evolution, from the origin of feathers to the birth of winged flight. Are those fibers on *Sinosauropteryx* examples of protofeathers that might have helped conserve body heat or served in colorful mating display? What was the role of feathers on *Caudipteryx* and *Protarchaeopteryx*? Just where do those odd new creatures fit into the story of avian flight?

Velociraptor

There's a Dinosaur in Your Backyard

The evidence that birds descended from dinosaurs—indeed are dinosaurs—has become conclusive for most paleontologists and evolutionary biologists. The theory had fallen out of favor in the early 20th century because, although theropods and birds share a great many features, no dinosaurs appeared to have a furcula, or wishbone. But furculae are now known in many species of theropods, including *Velociraptor,* unearthed in Mongolia in 1991. Its two clavicle bones are joined to make a V-shaped furcula (below).

A few scientists reject the dinosaur–bird connection. They see the similarities as convergent evolution—the development of like traits in separate species. To them

dinosaurs and birds share a common ancestor (which has yet to be discovered) but evolved along separate paths.

"But they have no physical evidence," says paleontologist Hans-Dieter Sues of Toronto's Royal Ontario Museum. "Only dinosaurs are anatomically suited to be the precursors of birds."

COMPARING DINOSAURS AND BIRDS

1 ***Wishbone and breastbone***
Many theropod dinosaurs have two clavicle bones fused into a furcula, or wishbone, as well as a sternum, or breastbone—both seen in modern birds.

2 ***Shoulder blade***
Birds and theropods have long, thin scapulae, or shoulder blades.

3 ***Bone mass***
Birds and birdlike dinosaurs have hollow and thin-walled bones, thus less body weight.

4 ***Swiveling wrists***
Half-moon-shaped bones enable the hands to fold against the lower arm and body.

5 ***Hand design***
Both birds and advanced birdlike theropods have lost two fingers. Of the three that remain, the middle is the longest.

6 ***Pubis***
The pubic bone extends forward in most dinosaurs but backward in birds and some theropods.

7 ***Legs***
Birds and theropods are "obligatory bipeds," meaning that their muscle and bone structure dictates moving on the two hind limbs.

8 ***Feet***
Both birds and theropods have three forward-pointing toes and a hallux. In dinosaurs the hallux is not fully rotated to the rear, as it is in most perching birds.

"The answers will require years of study," says John Ostrom. "Perhaps even centuries." More than a hundred years after the discovery of *Archaeopteryx,* scientists still aren't sure how well it could fly. Nor is it clear how its ancestors first took wing.

A small group of scientists believes that a tree-climbing reptile with the habit of jumping from tree to tree evolved wings that allowed it first to glide and then to fly. But most paleontologists contend that a small, two-legged dinosaur much like *Velociraptor* ran along the ground flapping its forelimbs and eventually developed the characteristics that allowed it to take off.

Ted Goslow believes that clues to the origin of bird flight can be found in living birds. An evolutionary biologist at Brown University, Goslow studies the bones and muscles used by birds in takeoff, flight, and landing to try to understand how these features might have evolved. He flies birds in wind tunnels and records their motion with high-speed film and with electrodes that measure their muscle activity to capture the subtle and complex movements in a single wingbeat.

"The flapping flight of a bird—the streamlined upstroke and powerful downstroke—is incredibly efficient," Goslow says. "The muscle that lifts the wing for the upstroke, for instance, can generate force ten times the body weight of the bird."

Recently Goslow and his colleague Sam Poore analyzed the wingbeat of starlings to decipher the role of this specialized muscle. They found that the muscle was critical not just for raising the wing but for repositioning it for the downward stroke—a finding that might shed light on *Archaeopteryx* flight. Anatomical evidence suggests that the bird had some ability to fly. But it lacked features essential to sophisticated flapping flight—the large, deep breastbone, for instance, that anchors wing muscles in modern birds.

"The modern bird wing also has this clever, weird pulley mechanism that allows the muscle to raise and twist the wing," Goslow explains. "There's no evidence of this mechanism in *Archaeopteryx,* suggesting that it might have been hampered in the trickier movements of slow flight, such as takeoff and landing, and was perhaps only at the threshold of true powered flight."

Avian studies take flight in a wind tunnel at Brown University. As graduate student Sam Poore, at left, controls air speed, evolutionary biologist Ted Goslow observes the wing motion of a starling. To prepare for the all-important downstroke, the bird must quickly position the wing high above its back. Goslow and Poore's study of *Archaeopteryx* shows that it lacked the shoulder structure necessary for rapid wing upstroke. If the archaic bird did flap its wings to remain airborne, it did so by some as yet unknown mechanism. Evidence of a modern shoulder didn't appear in birds until several million years after *Archaeopteryx,* another gap in the still puzzling history of the development of true flight.

BIRDS HAVE COME A LONG WAY since the first avian creature took wing. The most numerous vertebrates on Earth, after fish, they are exquisitely adapted to exploit nearly every airy niche. A peregrine falcon can dive out of the sky for prey at well over a hundred miles an hour. A hummingbird hovering above a flower beats its green and burnished wings nearly 60 times a second. A wandering albatross rides the currents over oceans for thousands of miles slung beneath ten feet of narrow wing.

Late in the afternoon at Sihetun I'm watching the antics of a magpie, cousin to the crow, flashing its iridescent black feathers. High above, swallows with swept-back, state-of-the-art wings are circling, diving in sudden turns. I have been trying to think of bird evolution as a smooth linear progression, but it is no

go. Cladograms and family trees may give the impression of tidy order, but there is nothing neat about bird evolution. Birds slipped through many shapes, with different traits evolving at different rates, odd mosaics of primitive and modern like those strange chimeras out of my childhood bestiary. The nearly 10,000 species of birds that live today are but the tip of an evolutionary iceberg of species that may run to hundreds of thousands.

On a hill just above me the Chinese paleontologists are hunched over a set of geologic maps that mark the spots of fossil finds at Sihetun with bright red painted birds. They are consulting on plans to study the fossils with x-rays, CT scans, and other high-tech equipment in a joint venture with a team of international scientists to examine the details of bones, eggs, beaks, and feathers. They are also planning to build a geologic corridor, "like a little Grand Canyon," Ji says, to study the formation layer by layer.

"We can't even begin to imagine what's in there," says John Ostrom. "A whole chunk of time is represented in those rocks that we've not found preserved anywhere else—a chunk that may very well hold the key to early bird evolution."

There are some who might say that the discovery of fossilized winged things scarcely affects our daily rounds. It's true, the slabs of bone and stone hold no promise for improving our health or material well-being. But they do offer a rare dose of perspective. Birds have been fluttering across the sky for more than a hundred million years. Our tribe has been walking the Earth for little more than four million. In our minds, sky has never been separate from bird. And for me, at least, the two are joined in an indescribable sweetness of union. □