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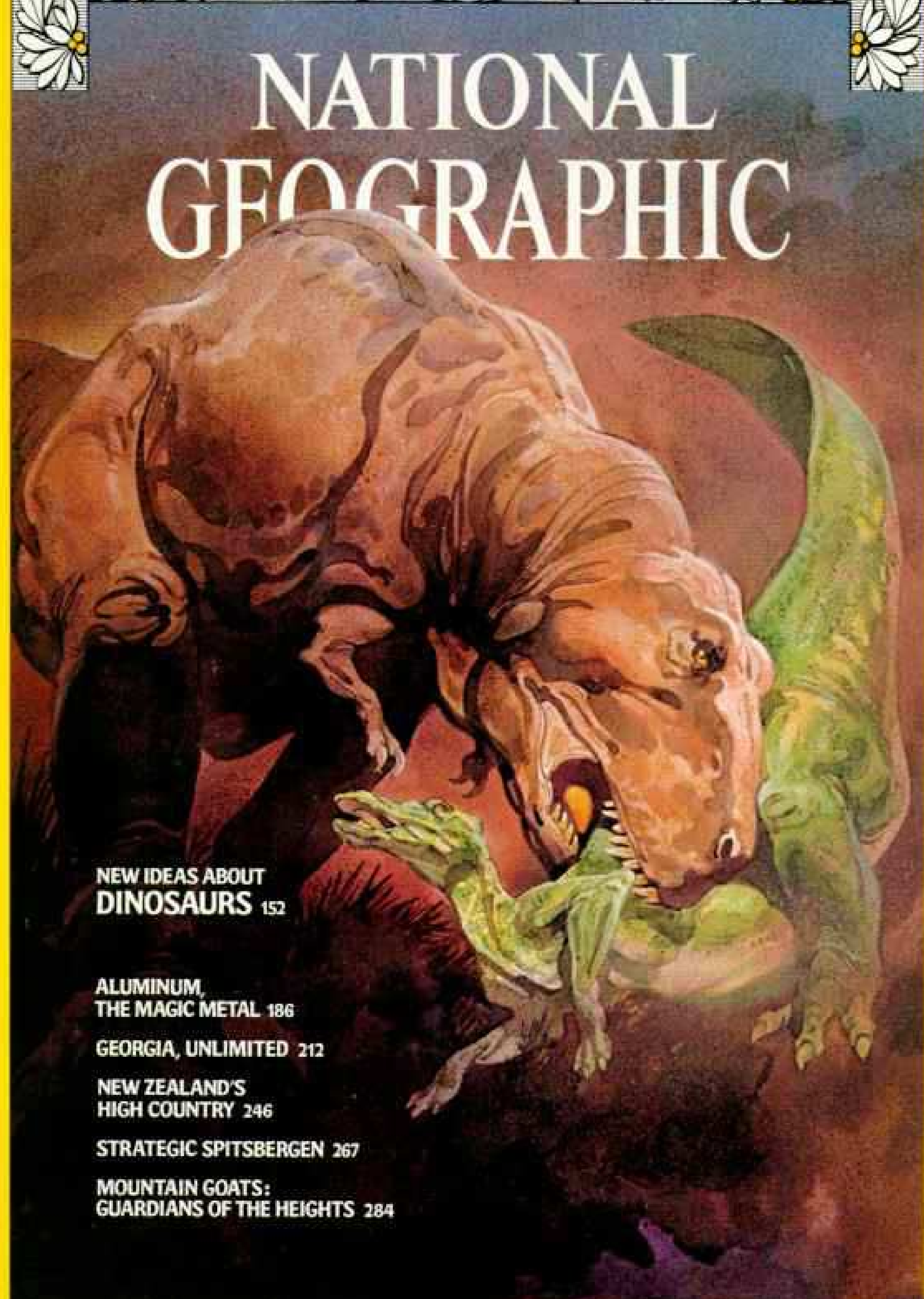
NATIONAL GEOGRAPHIC



OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D.C.

"BUNK." The pointed comment scrawled in the margin of a page proof was that of a university professor whom we had asked to review the article on aluminum that appears in this issue. He obviously disagreed with a statement quoted by author Tom Canby, that aluminum is "friendly to food." The insides of aluminum cans, the professor noted, are coated with lacquer. True enough, for technical reasons. But as cans, cookware, or foil wrapping, the metal is—as we note—"so chemically stable it doesn't react with most foods."

The professor was one of no fewer than 80 experts and organizations our Research Division consulted, in addition to 120 printed sources, to verify what Tom had written after six months and some 16,000 miles covering this major international industry.

I know of no other publication that researches what appears in print more thoroughly than does the GEOGRAPHIC. Our writers are among the best in journalism, and they gather the most complete documentation—but there is always the chance that what they have been told, or heard, or read, is not exact. Or is downright wrong, for one reason or another.

Each manuscript is subjected to a long process of checking facts and verifying information. Like the mills of God, this process grinds exceeding small. When, for example, Tom came across the dramatic fact that a spiderweb-thin aluminum wire stretching around the world would weigh only a pound and a half, researcher Lesley Rogers took the matter up with Alcoa and the U. S. Bureau of Mines, which in turn consulted a spider expert at the Smithsonian Institution.

Alas, spiders are dreadfully untypical in the webs they weave. However, all experts concluded that a wire .002 inch in diameter, which seems a reasonably spidery sort of dimension, would, when belting the planet, weigh 484 pounds—still remarkable!

The process also grinds exceeding large. One reviewer thought we should take note that "If it weren't for the huge government subsidies in the form of hydropower dams, we would not have such 'necessities' as aluminum beer cans today." Canby added the contention.

Each article kicks up its own dust of strong pros and heated cons. We look ahead to what our researchers will meet in checking forthcoming articles on Syria today, "talking" gorillas, and natural gas.

Gilbert M. Grosvenor

NATIONAL GEOGRAPHIC

THE NATIONAL GEOGRAPHIC MAGAZINE VOL. 154, NO. 2

August 1978

COVER: *With a lethal battery of teeth, a six-ton* Tyrannosaurus *dispatches a duck-billed dinosaur,* Anatosaurus. *Painting by Roy Andersen.*

STARTLING FINDS PROMPT...

A NEW LOOK AT DINOSAURS

By JOHN H. OSTROM, Ph.D.
CURATOR OF VERTEBRATE PALEONTOLOGY
PEABODY MUSEUM OF NATURAL HISTORY, YALE UNIVERSITY

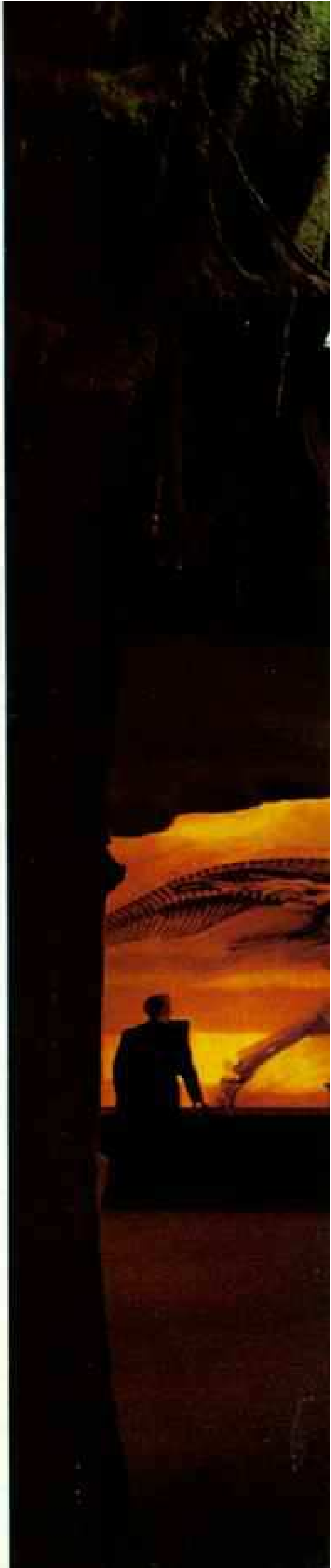
Paintings by ROY ANDERSEN

WHAT KIND OF ANIMALS were the dinosaurs? What ever happened to them? Up until the last decade, many paleontologists would have answered with confidence: Dinosaurs were huge, slow-moving, cold-blooded reptiles of the past. After some 140 million years as lords of the earth, they died out—from no obvious cause—about 65 million years ago, leaving no descendants.

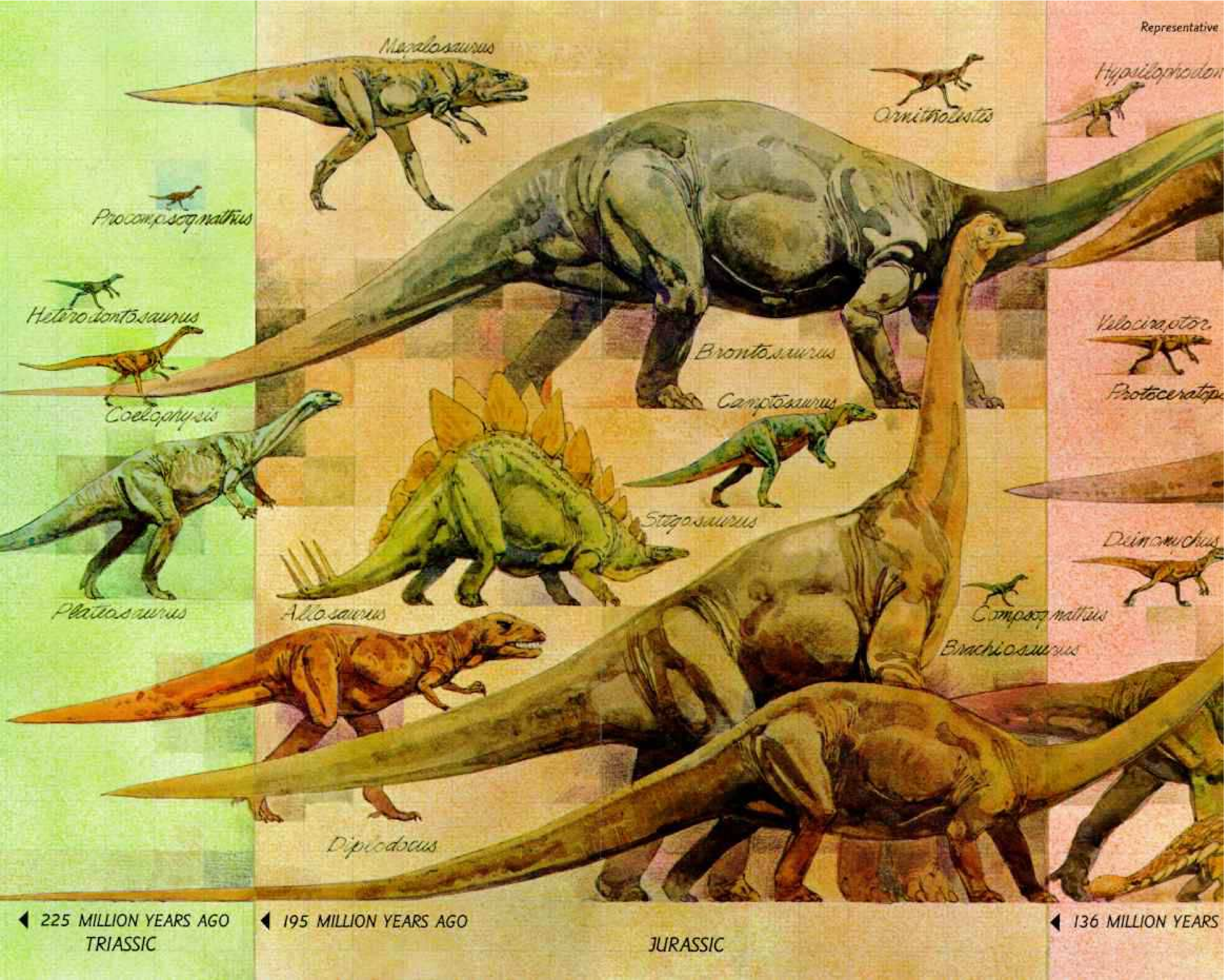
Today, some paleontologists offer radically different views: Dinosaurs were active, perhaps even warm-blooded animals, comparable to modern mammals and birds. Furthermore, they did not completely die out; some left their lineal descendants in today's birds.

My own involvement with these novel ideas began on a Montana hillside in 1964. Mine were the first human eyes to see those fragments of fossil bone. Their weathered condition told me that they had lain exposed there, unrecognized, for years—perhaps for centuries. But I knew at once that they were unique, and that this was the most important discovery our expedition had made all summer.

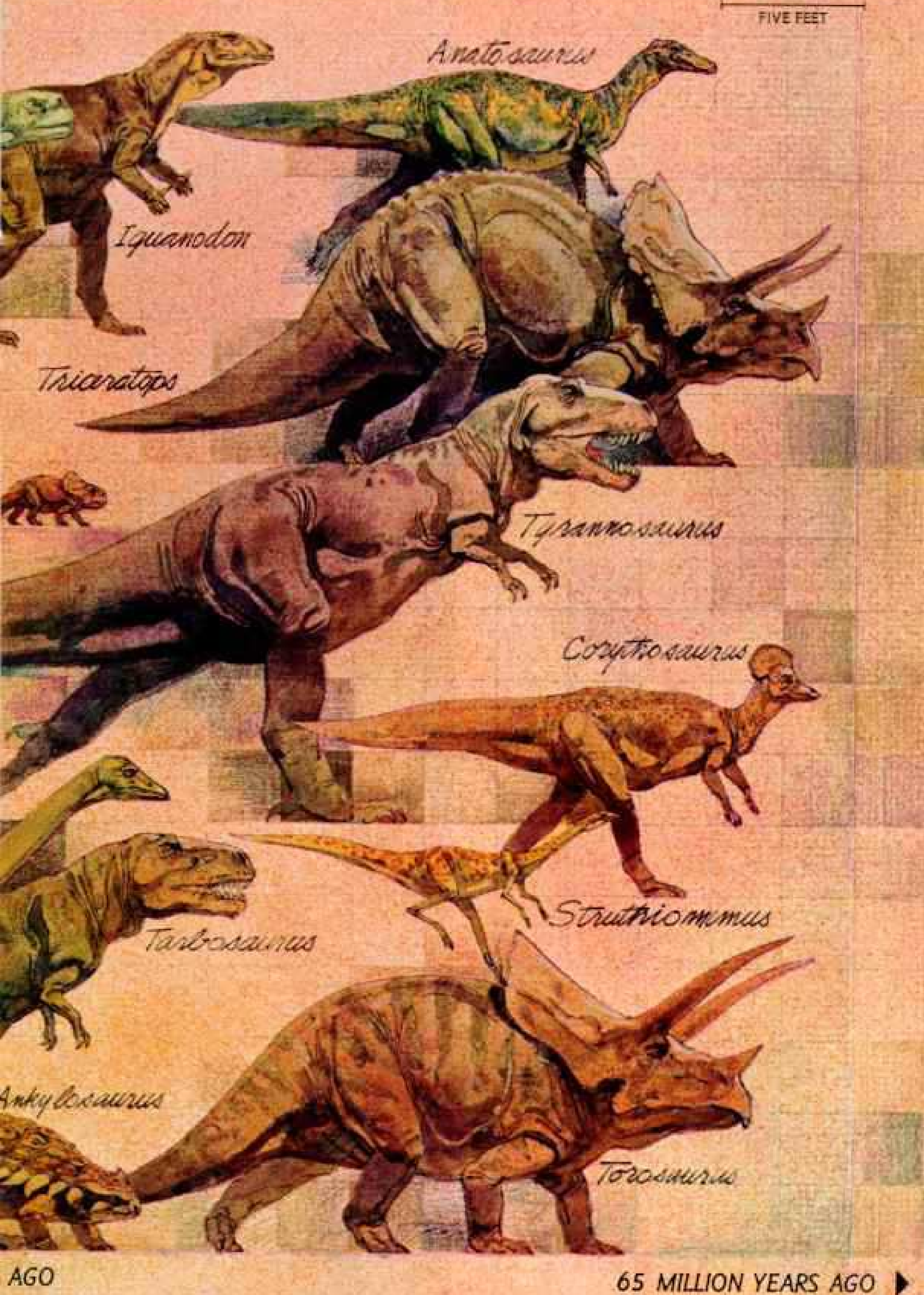
That afternoon my assistant Grant Meyer and I, feeling like the discoverers of lost treasure, gently brushed away the soil and clay from around the fragile fossils. Gradually we uncovered several finger bones, somewhat larger than



Phantoms from a lost world, skeletons at Toronto's Royal Ontario Museum (**right**) evoke the grace and power of earth's rulers for 140 million years. A parade of dinosaurs (**following pages**) suggests their immense diversity in size, anatomy, and adaptation. The author's studies conclude that some dinosaurs were likely warm-blooded, and that one group gave rise to their only living descendants—birds. SAM ABELL


Representative
Megalosaurus
Ornitholestes
Hypsilophodon
Procompsognathus
Heterodontosaurus
Brontosaurus
Velociraptor
Coelophysis
Camptosaurus
Protoceratops
Stegosaurus
Deinonychus
Plateosaurus
Allosaurus
Compsognathus
Brachiosaurus
Diplodocus
225 MILLION YEARS AGO
TRIASSIC
195 MILLION YEARS AGO
JURASSIC
136 MILLION YEARS

sample of dinosaur reconstructions based on fossil evidence and drawn to scale. Placements in time are approximate.



AGO

65 MILLION YEARS AGO ▶

CRETACEOUS

my own, then a couple of large, sharp claws. Finally the other bones of a powerful, three-fingered, grasping hand came to light. Close by, we unearthed the perfectly preserved bones of a foot.

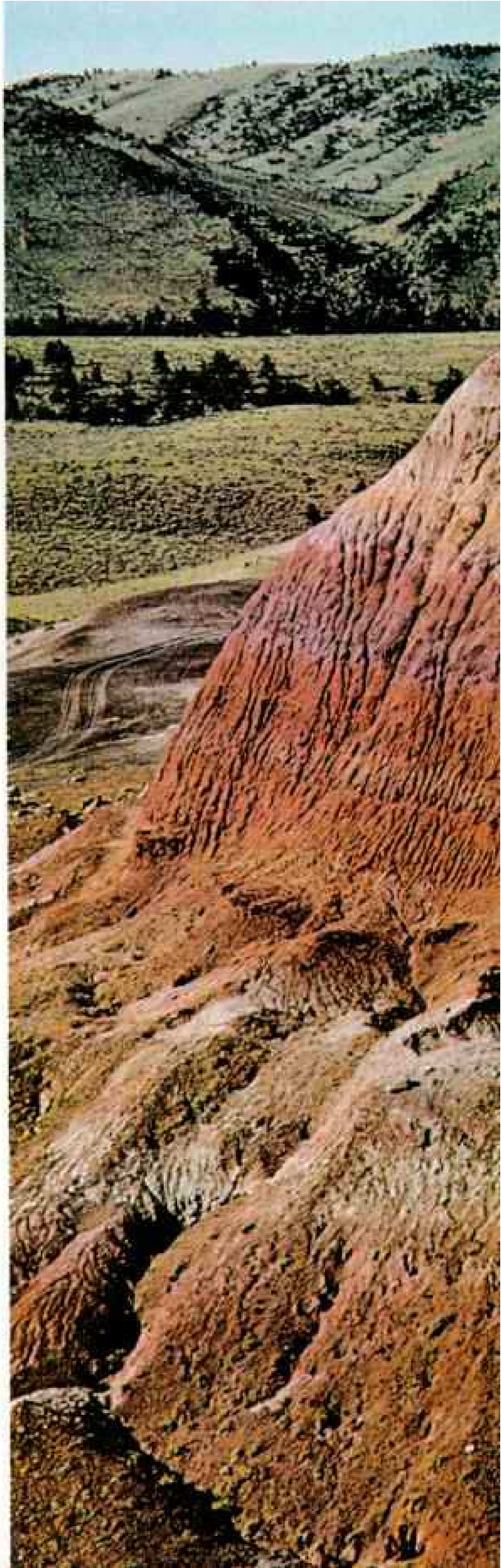
Here, in a remote pocket of badlands not far from the city of Billings, we had uncovered a small, totally new kind of dinosaur more than a hundred million years old. And the creature's fossilized remains offered astounding clues to its life and habits. One such clue prompted the scientific name I later gave this peculiar beast: *Deinonychus*, which means "terrible claw."

Patient Study Reveals New Genus

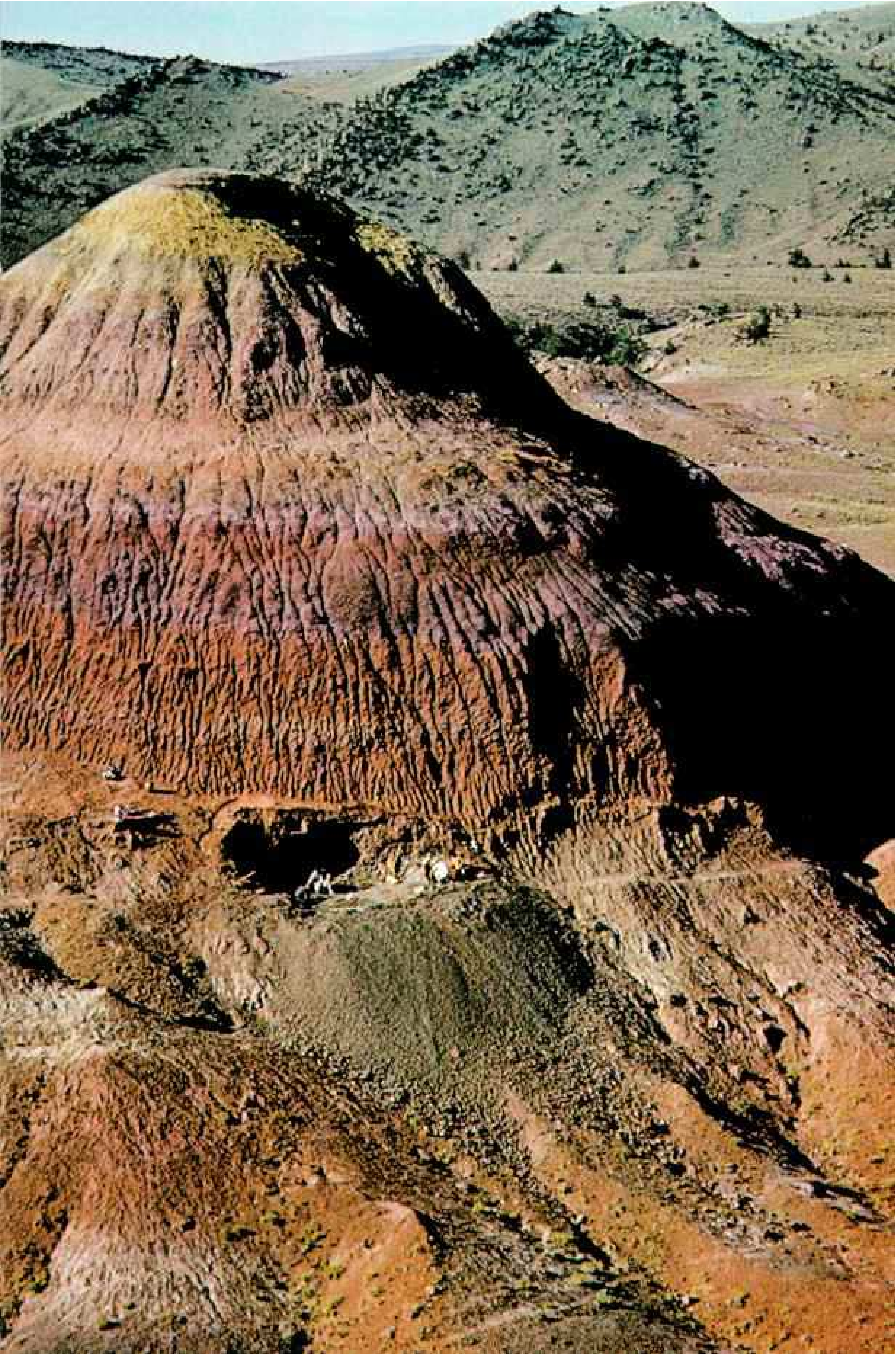
Indirectly this claw was important in my later speculations on warm-bloodedness in dinosaurs. But that came after years of work on the more than a thousand bones of at least three *Deinonychus* skeletons recovered from our Montana excavations during the next two summers.

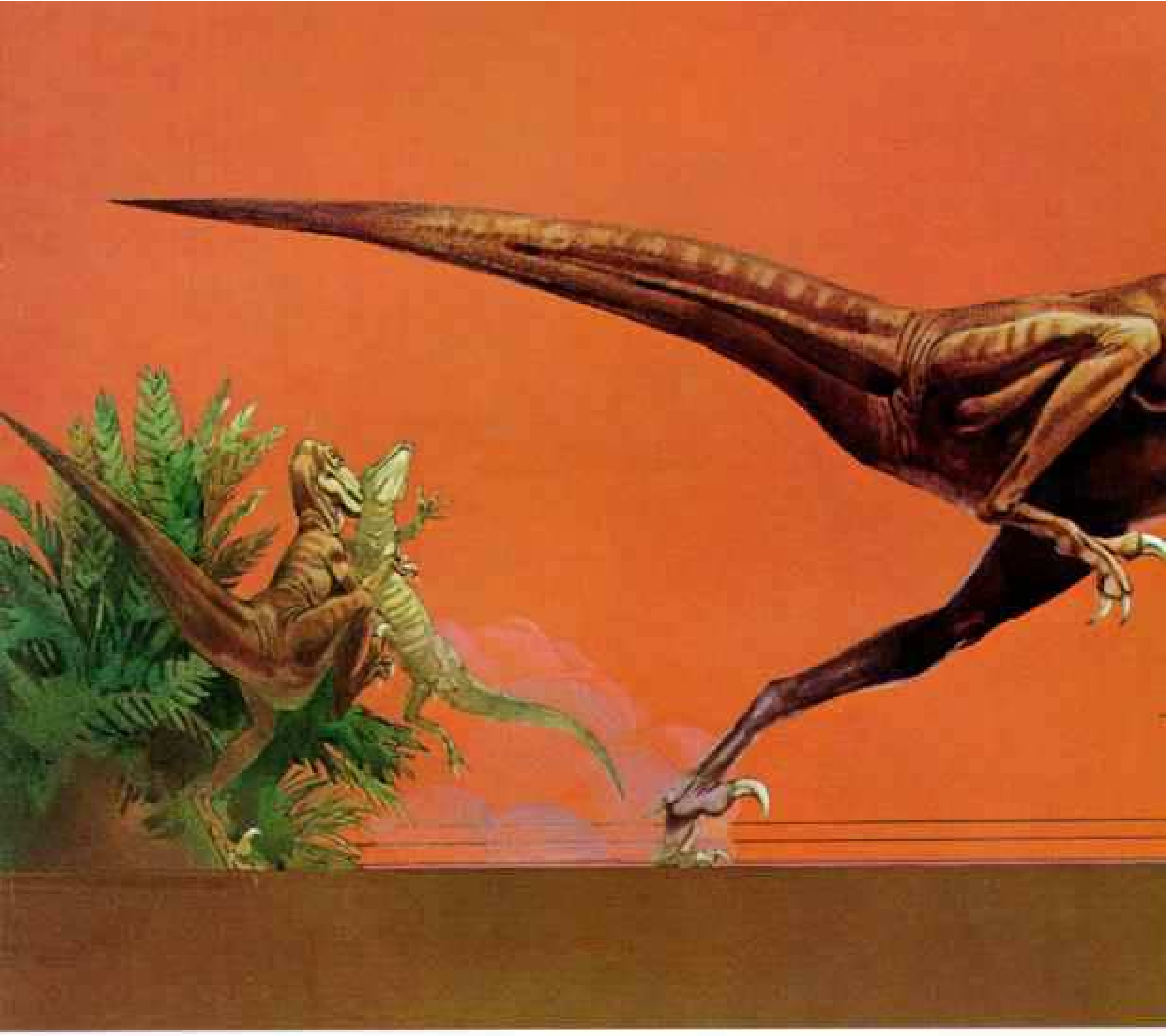
For three years after that, in my laboratories at Yale University's Peabody Museum of Natural History, these fossilized bones were painstakingly removed from the enclosing rock matrix. Only then was I able to compare them with other dinosaurian kinds, and, literally, put the skeletons back together. A most remarkable animal grew out of these reconstructions.

Deinonychus's sharp, serrated teeth revealed that it had been a carnivore, and its skeletal structure indicated it belonged to the suborder of dinosaurs known as the Theropoda (meaning "beast foot"). Included among the theropods is perhaps the best known of all dinosaurs—the giant, fearsome *Tyrannosaurus* ("tyrant lizard"), which also stalked its prey across Montana, but some



OMINOUS MOUND in Montana proved to be a killer's 200-foot-high crypt when the author found the first remains of a swift, carnivorous biped. One lethal claw on each hind foot suggested the name *Deinonychus*—"terrible claw." Here was evidence of a dinosaur (**following pages**) very unlike the stereotyped picture of the slow-moving, cold-blooded reptiles. If anything, it was more like an oversize roadrunner. JOHN H. OSTROM

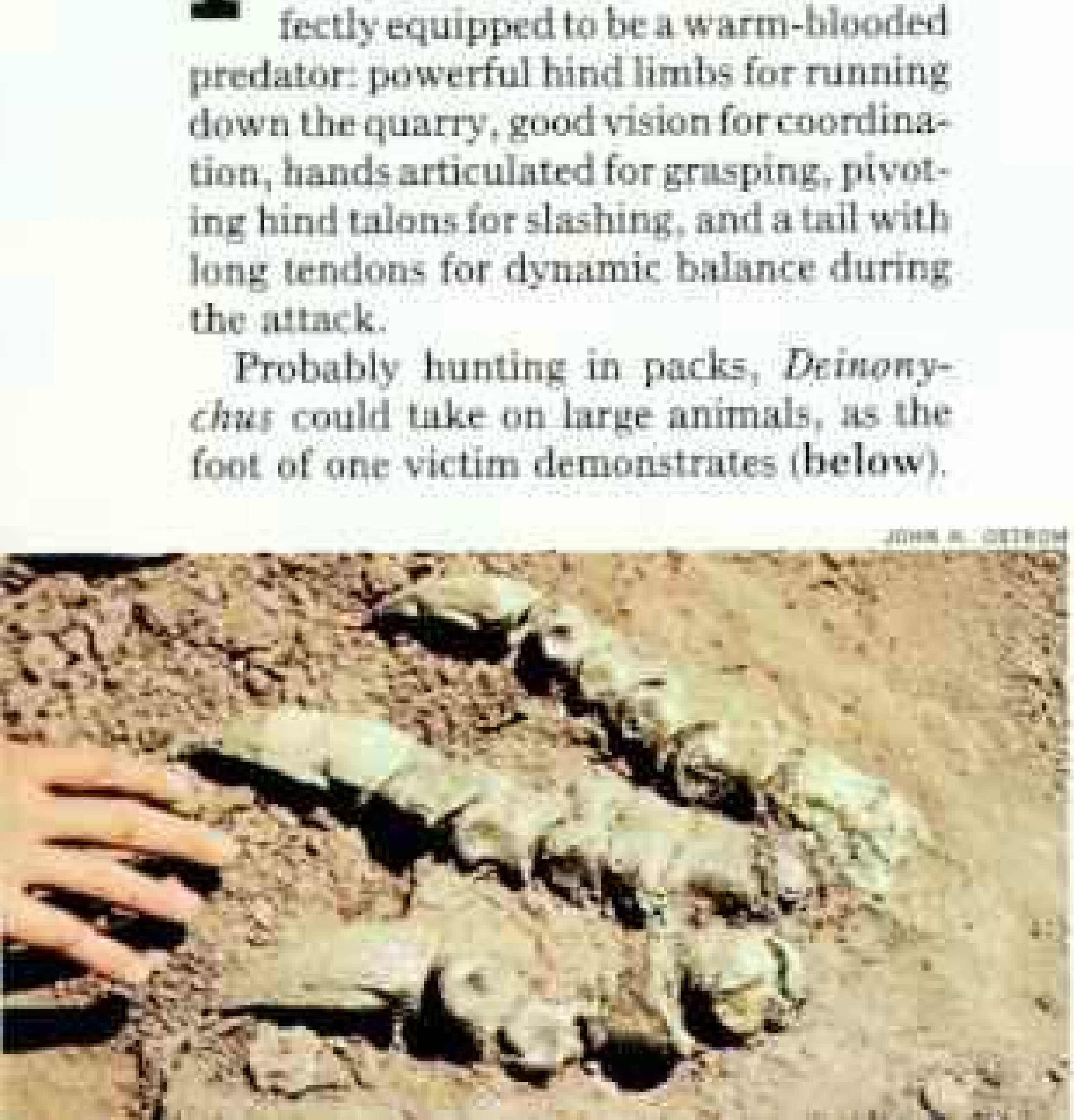




FLESHED OUT at four feet tall and 150 pounds, *Deinonychus* was perfectly equipped to be a warm-blooded predator: powerful hind limbs for running down the quarry, good vision for coordination, hands articulated for grasping, pivoting hind talons for slashing, and a tail with long tendons for dynamic balance during the attack.

Probably hunting in packs, *Deinonychus* could take on large animals, as the foot of one victim demonstrates (**below**).

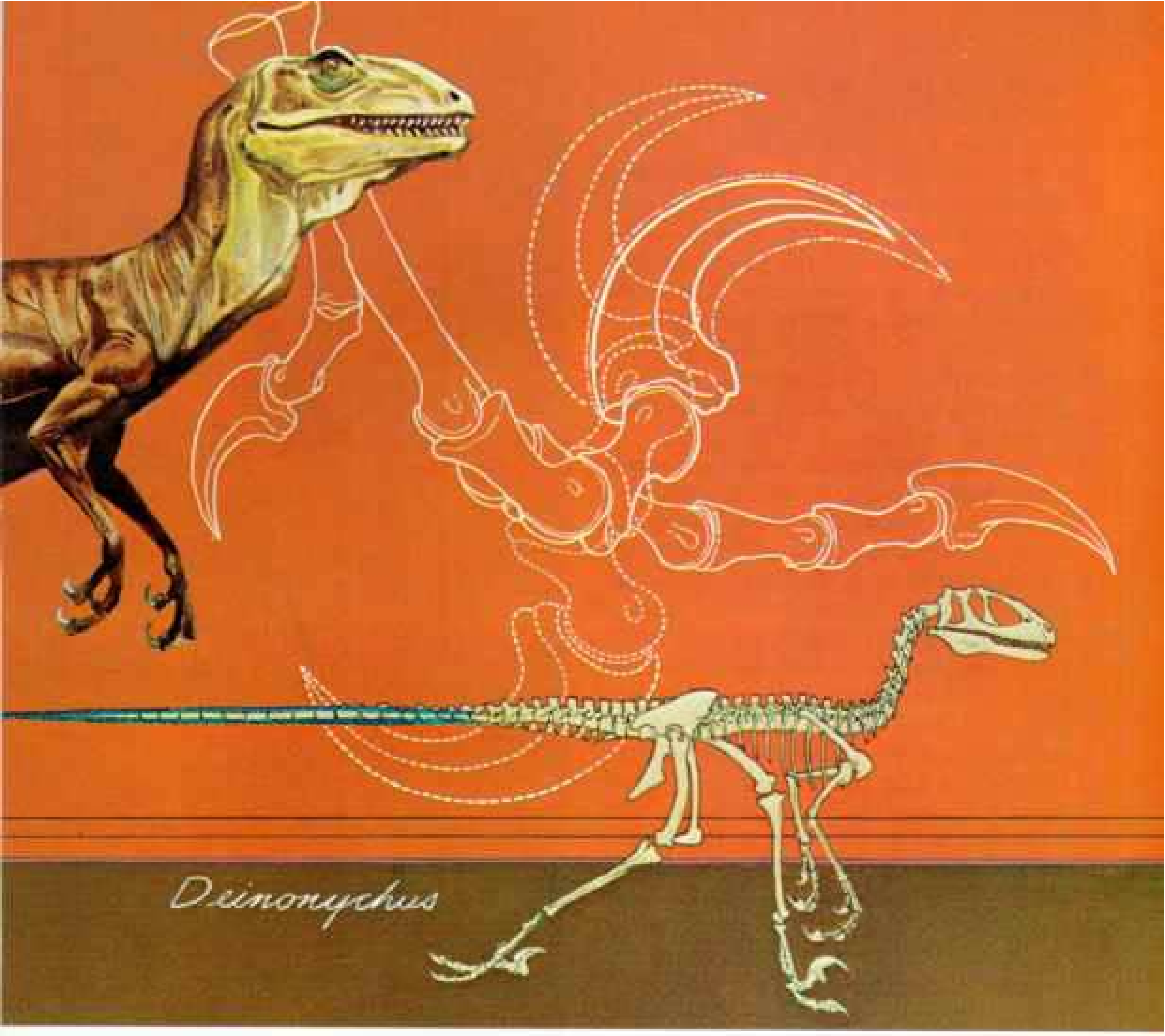
JOHN H. OSTROM



fifty million years after *Deinonychus*.

Compared to *Tyrannosaurus*, *Deinonychus* was a lightweight: 150 to 175 pounds, eight or nine feet from snout to tail tip, and standing only four to five feet high. Like all other theropods, *Deinonychus* stood, walked, and ran on its hind legs like a large bird. The forelimbs and hands were so constructed that they could not possibly have been used for walking. To assist in this two-legged stance, *Deinonychus* had a relatively long tail, with a feature that had never been seen before: The entire length of the tail was reinforced by peculiar rodlike tendons, which we found in an ossified state. These must have made the tail an extremely effective balancing appendage—with control much like that of a cat's or a squirrel's.

But the striking feature of *Deinonychus*



—and the reason for its name—was on its feet. All previously known theropods had birdlike feet, but *Deinonychus* also had a huge, sicklelike bone more than three inches long on one toe of each foot. In life, sharp, curved, nail-like sheaths covered these claw bones and must have been four or five inches long. Obviously they served as weapons—most probably to kill prey. When not in use these claws were carried in a retracted position, so as not to be damaged.

Ideally Suited to Catch and Slash

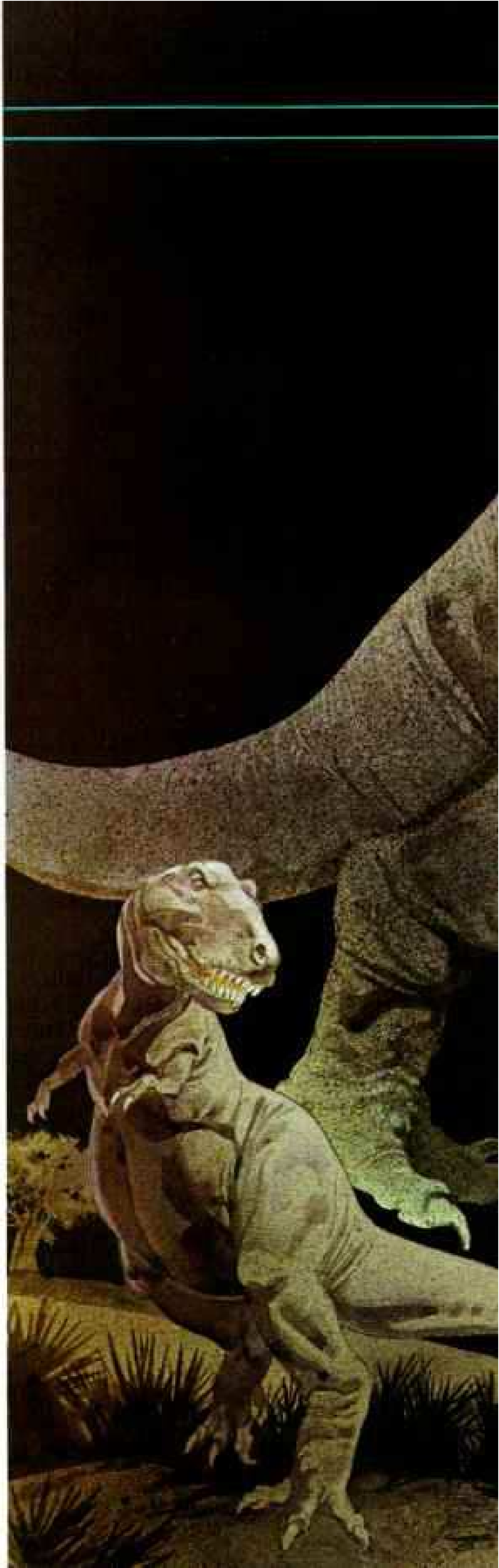
Since *Deinonychus* was bipedal and could not walk, or even stand, on all four legs, it must have been extremely agile to employ its foot talons against an enemy or victim—perhaps jumping from one foot to the other, while kicking out at its prey or attacker with its free foot. That slashing attack required highly accurate foot-eye coordination and a keen sense of balance. Such agility and speed are not what we usually visualize in cold-blooded reptiles. The image is more that of the large flightless birds like the ostrich, or of predatory runners like the secretary bird of Africa or the roadrunner of the American West.

The arms and hands of *Deinonychus* were another surprise. The long hands bore three powerful fingers with large sharp claws designed for grasping. The wrist joints enabled the hands to turn toward each other, permitting precise grasping of prey by both hands working together—something only man and certain other mammals can do. *Deinonychus* almost certainly was a swift-footed predator that ran down its prey, seized it in its powerful hands, and then slashed at the belly and flanks of its victim with those razor-sharp talons.

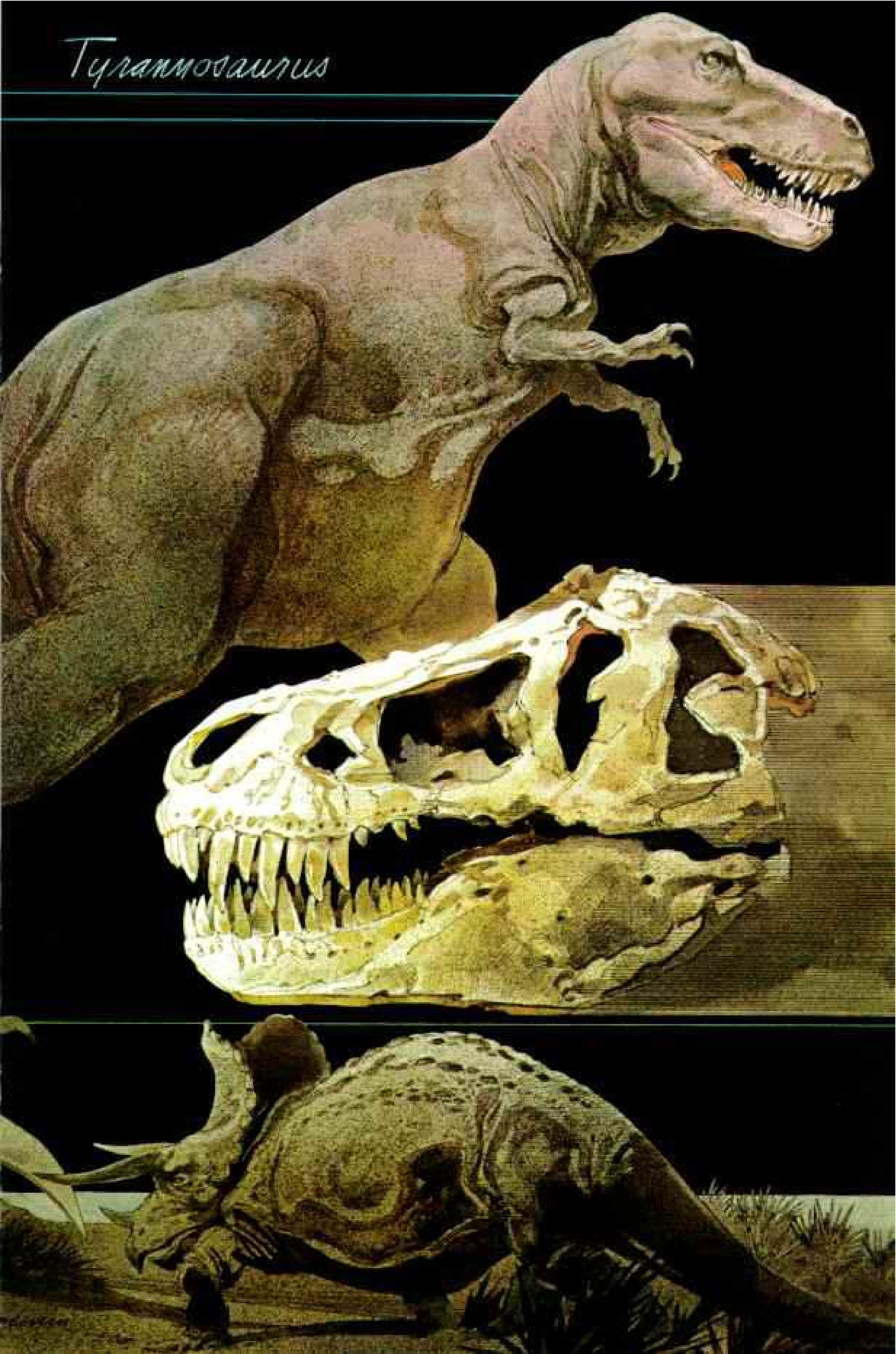
Together with the several specimens of *Deinonychus*, we found a few parts of a single herbivorous dinosaur, *Tenontosaurus*. Since *Tenontosaurus*, the presumed prey animal, was six times larger than its attackers, weighing 800 to 1,000 pounds, I concluded that *Deinonychus* probably hunted in packs. The much larger size of the prey animal also explains the dead predators at the site—victims of the struggle.

We normally associate pack hunting with warm-blooded animals, but, in addition to *Deinonychus*, some other dinosaurs appear to have moved in packs. At Connecticut's Dinosaur State Park, thousands of dinosaur footprints have been uncovered. Some of them are parallel, suggesting herd movement. Another site, in Holyoke, Massachusetts, preserves the trackways of 28 bipedal dinosaurs, 19 of which led in a near-parallel westerly direction—clear evidence of group behavior. A third site, in Texas, records the passage of a herd of brontosaurlike animals, huge herbivores. First recognized by Roland Bird of the American Museum of Natural History as evidence of herding behavior, those trackways have been interpreted by Dr. Robert Bakker of Johns Hopkins University as resulting from a "structured" herd, with the young in the center surrounded and protected by the adults.

So there is persuasive evidence for the idea of *Deinonychus* as a pack hunter. But I was especially gratified to find my hypothesized killing techniques—those slashing kicks of the foot talons at the belly of its victims—confirmed by colleagues halfway



THE "KING" of carnivorous dinosaurs (and villain of many a monster movie) was fifty feet and six tons of bad news for the ponderous herbivores of its time. No speedster like *Deinonychus* 50 million years earlier, *Tyrannosaurus* may have patiently stalked its prey as fossilized trackways suggest. It might only warily try to employ its sixty teeth, set in a four-foot skull, against the powerful, three-horned *Triceratops*, whose defenses were formidable. Like all predators, *Tyrannosaurus* preferred easy prey.


Tyrannosaurus

round the world. A team of paleontologists led by Dr. Zofia Kielan-Jaworowska of the Institute of Paleobiology in Warsaw, Poland, made an incredible discovery in Mongolia's Gobi Desert in 1971. Her expedition, jointly sponsored by the Polish and Mongolian Academies of Sciences, uncovered the skeletons of two dinosaurs tangled together. One was the fairly well-known *Protoceratops*, a calf-size plant eater with a turtlelike beak. The other was a rare, two-legged, near-man-size carnivore—*Velociraptor* ("swift robber").

These two animals had apparently killed each other, and their skeletons had been buried and preserved exactly as they died. *Velociraptor*, like *Deinonychus*, had a large sicklelike talon on each hind foot, and it died with one of those foot claws embedded in the belly of *Protoceratops*—an amazing life-and-death drama from 80 million years ago!

Birds May Be Direct Descendants

This image of *Deinonychus* and *Velociraptor* as agile, pursuing, leaping predators, running down their prey and slashing it to death, is quite different from the sit-and-wait hunting strategy that we associate with most cold-blooded modern reptiles. It seems more like that of the stalk-chase-and-attack technique used by predatory birds adapted to running and by many mammalian carnivores. It suggests that, like these modern hunters, at least some of the predatory dinosaurs might have been warm-blooded and have had high metabolic rates.

Other small theropods earlier than *Deinonychus* and *Velociraptor* feature in another fascinating aspect of the dinosaur story. I am convinced that modern birds are their direct living descendants. So, in a sense, not *all* dinosaurs became extinct, as we were taught in school.

Among the most important of all fossil specimens are those of *Archaeopteryx*, the oldest known bird, which lived 140 million years ago. Only five specimens are known, but they constitute excellent examples of a transitional form between two kinds of animals. Concrete evidence of evolutionary change, they are a missing link (no longer missing) between reptiles and birds.

Impressions of feathers, "wings," and a long, feathered tail are seen in the limestone surrounding the skeletons. But the skeletons are reptilian, not avian, and the jaws are full of teeth, tiny but sharp. The skeleton is extraordinarily similar to that of some small carnivorous dinosaurs, like *Deinonychus*, *Velociraptor*, and *Ornitholestes*. Its feathers establish that it was a bird, but its skeleton shows me it had not evolved very far from its dinosaurian ancestors.

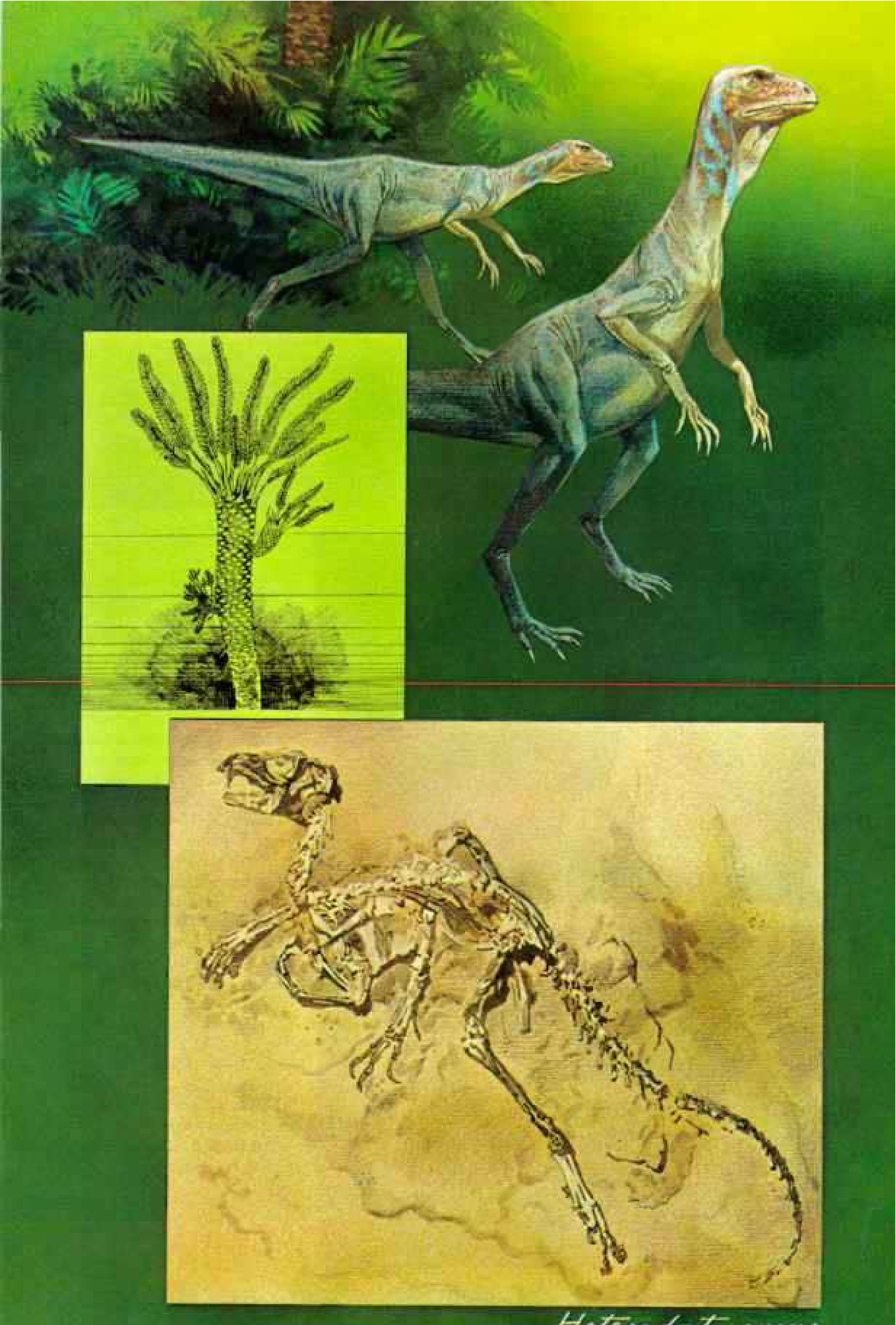
Modern birds, of course, are warm-blooded and very active creatures. I wonder whether *Archaeopteryx* might not have been also. And doesn't this evolutionary linkage between birds and theropods suggest that at least the theropod dinosaurs might have been warm-blooded too?

The idea that birds might be related to dinosaurs is not entirely new. The celebrated English biologist Thomas Henry Huxley suggested it more than a century ago. He noted the similarities between the tiny dinosaur *Compsognathus* ("elegant jaw") and the first specimen of *Archaeopteryx*, both of which were reported from Bavarian limestone deposits in 1861. Huxley's theory fell into disfavor, but I believe the evidence for a theropod dinosaurian origin of birds, by way of *Archaeopteryx*, is overwhelming.

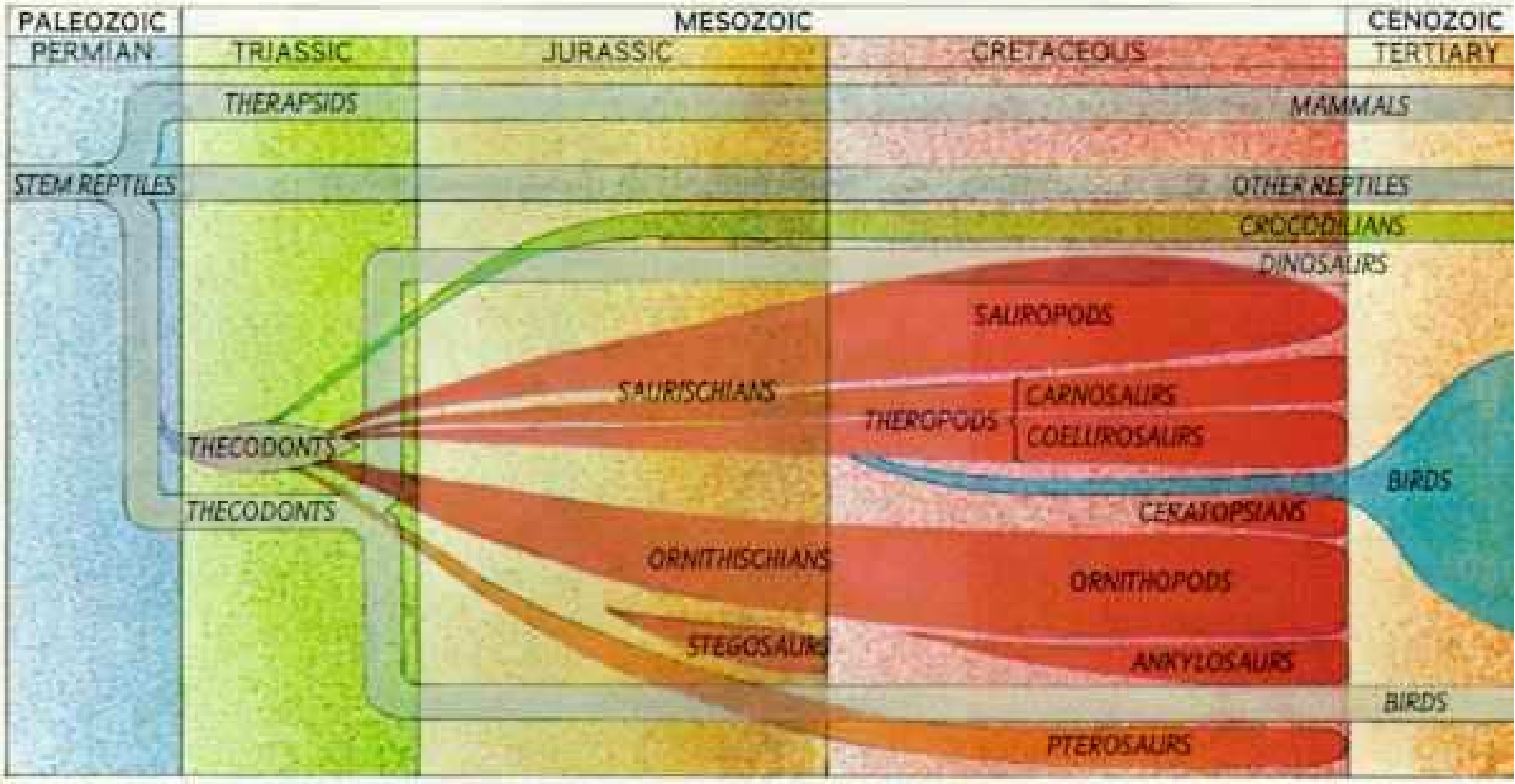
I am, however, intrigued by some new evidence that might modify the role of *Archaeopteryx* as a single missing link. My friend Dr. James Jensen of Brigham Young University in Utah, in part with a grant from the National Geographic Society, has been making important discoveries high up on

A CHAMPION TURKEY would match in size the curious *Heterodontosaurus*, an early dinosaur of about 200 million years ago. Unlike most herbivores that had only one sort of teeth, it had three kinds. Front teeth were adapted to biting or nipping, followed by a pair of canines, used in mammals for tearing, and rear teeth for chewing—a mammal-like system for efficient processing of large amounts of food.

This, plus small size and light build for rapid bipedal locomotion, seems to point toward endothermy—warm-bloodedness based on high metabolism and internal heat regulation—although the evidence is not as compelling as for the larger and later *Deinonychus*.



Heterodontosaurus



BOTH BY DAVID CUPP

TRADITIONAL WAY of classifying the descent of dinosaurs and birds is shown by gray bars in the diagram (**above**). Each evolved independently from a group called thecodonts, themselves an offshoot of predecessor reptiles. The author believes new evidence (colored shapes) has fixed birds as descendants of theropods, two-legged carnivorous dinosaurs, one of a number of dinosaurian heirs of thecodonts. Unchanged is the descent of mammals from reptiles through the intermediate forms called therapsids.

Such rethinking is based on the slow accumulation of fossil remains. The author (**middle, left**) studies a bone found by colleague Dr. James Jensen and compares it (**left, below**) to a modern bird bone. Firm identification awaits further finds and analysis.

the Uncompahgre Plateau in western Colorado's Dry Mesa quarry. This may be one of the most important fossil sites of the late Jurassic Period to be found in North America in the past half century.

Discovered in 1971, the site not only revealed the gigantic bones of what may be the largest dinosaur known, but also very tiny, matchstick-size bones, which Jim thought might relate to my theory of bird origin. He showed me one of these tiny fragments, and I was surprised to recognize it as part of the wing of a flying reptile, a pterosaur, rare in this part of the world.

Last summer the Dry Mesa quarry produced more than a dozen bones of pterosaurs, plus a fragment from a primitive mammal, and one that might be from a bird. I visited Jim at the quarry to have a look at his find and was impressed with its birdlike form: a hollow bone about two inches long that appeared to be part of a thighbone. Although almost as ancient as *Archaeopteryx*, this fragment seemed in some ways to be more birdlike than the same part in *Archaeopteryx*.

Jim and I debated the creature's identity: bird? pterosaur? mammal? dinosaur? If it could be shown to be a bird, it would be extremely important, because *Archaeopteryx* is the only known Jurassic bird. If this proved to be a bird as old, or nearly as old, as *Archaeopteryx* and more evolved, it could be a challenge to *Archaeopteryx*'s unique role in bird origin.

But all we had was a fragment. Birdlike as it appeared, it could not be certified. Jim and his crew are determined to excavate "grain by grain" to uncover conclusive evidence of a Jurassic bird in North America. So far we have been disappointed, but treasure hunters don't stop hoping for a lucky find. Recently another small birdlike bone has come to light, but its identity has not yet been established.

Answers Still Elude Scientists

Many intriguing questions about dinosaurs remain. Why were the dinosaurs so unlike any other animals living now or in the past? How did they live? Why were so many of them so large—some unbelievably huge? Did they simply never stop growing? How long did it take for them to grow so large? How could such creatures move about? How could they have eaten enough to keep them going? We don't know.

And finally, the greatest mystery of all: The vast array of dinosaurian kinds all became extinct apparently quite suddenly, about 65 million years ago. After dominating the earth for 140 million years, they disappeared. Why? What could have killed off so many different kinds of well-adapted and highly successful creatures?

"Terrible Lizards" Found in England

The earliest recorded dinosaur find, some large fossilized teeth and a few bones, was made in 1822 by an English doctor, Gideon Mantell, and his wife in Sussex, England. They named the creature *Iguanodon* ("iguana tooth"). In 1824, another Englishman, the Reverend William Buckland, published a description of a fossil jawbone with bladelike teeth found near Oxford. He named the beast *Megalosaurus* ("great lizard").

These fossils were recognized as the remains of large reptiles—far larger than any living reptile—but not until 1842 were such creatures called dinosaurs. The anatomist Sir Richard Owen coined the term Dinosauria ("terrible lizards") for these and other large fossil reptiles that were unearthed in southern England.

Occasional dinosaur remains were found elsewhere in Europe and in North America too, but the big push to discover dinosaurs did not begin until the late 1870's. Then a series of finds of gigantic fossil bones occurred at several places in Wyoming Territory and Colorado, precipitating a great rush among rival paleontologists.

The sedimentary rocks in which most dinosaurs have been found are chiefly lowland deposits. Few upland deposits are known, and thus little evidence exists that would shed light on what kinds of dinosaurs may have roamed across the high plateaus and mountain foothills. (My own finds in Montana, as well as those in Colorado, were in shales and other deposits that once formed lowland areas but subsequently were elevated by geologic forces.)

The lowland dinosaur environs appear to have been similar to America's low coastal plain that borders the Gulf of Mexico—heavily forested and inundated by wide

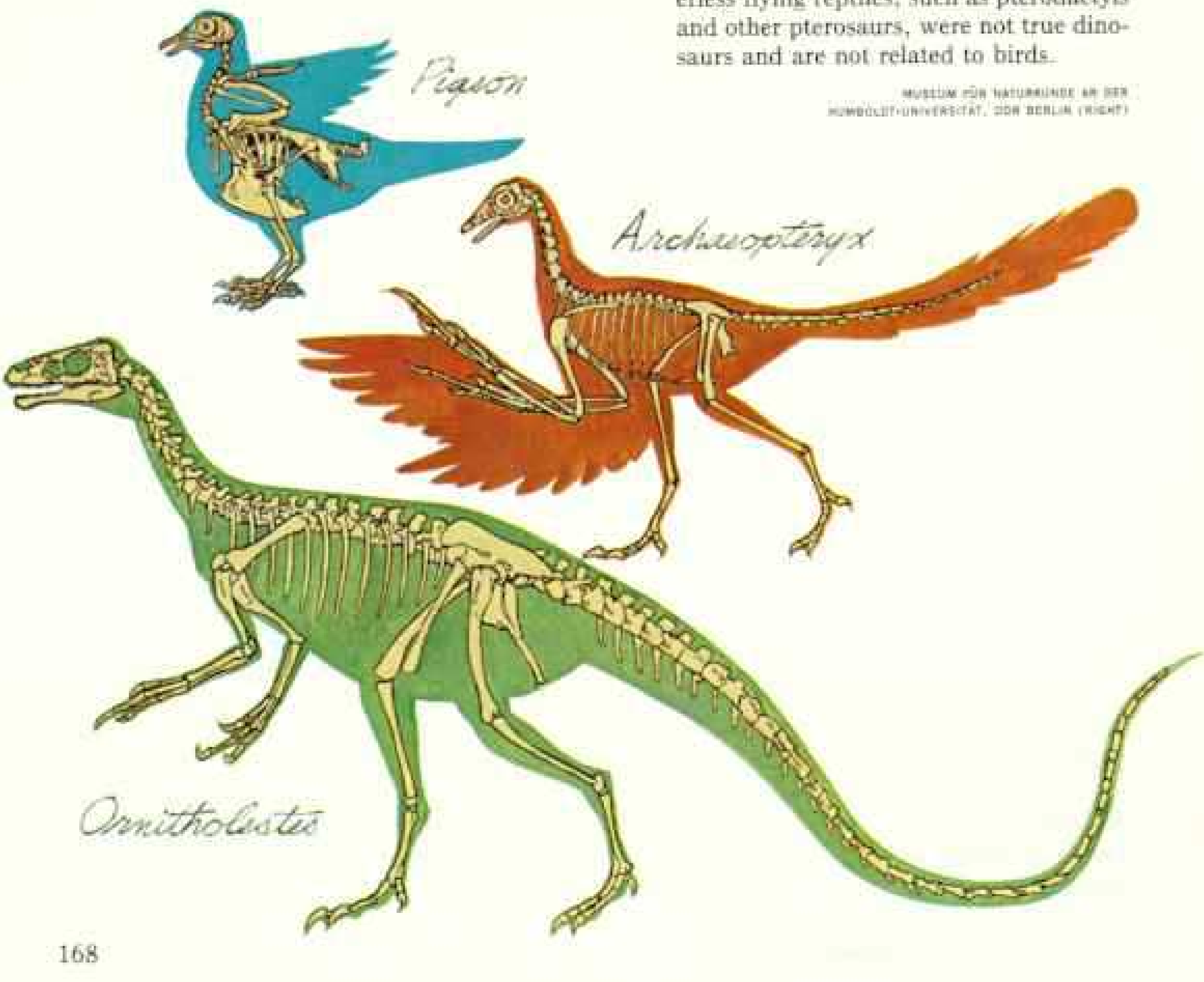
From dinosaur to bird: the missing link

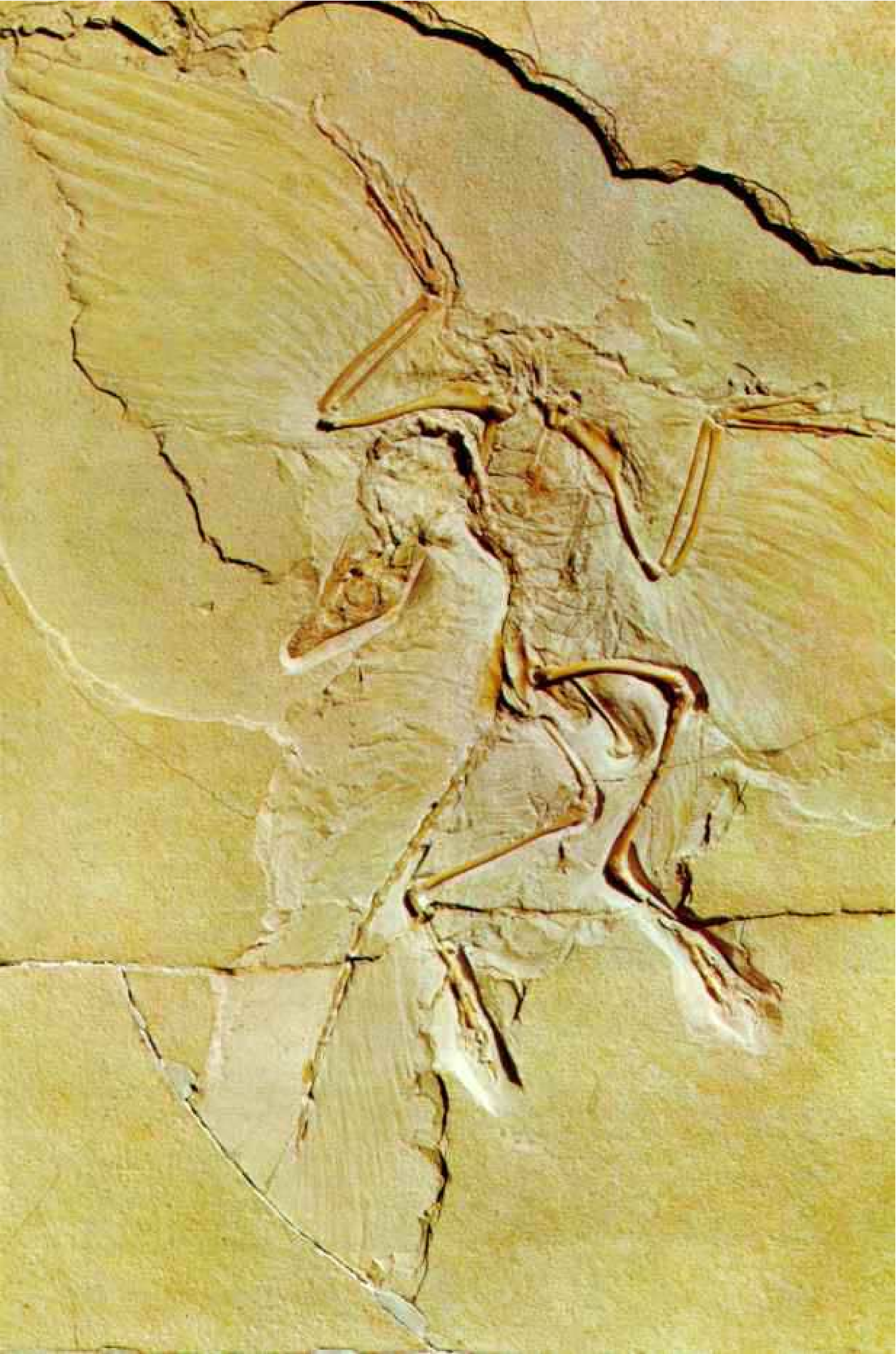
EVER SINCE ITS DISCOVERY in the 19th century, the fossil that looked like a small dinosaur with wings (**facing page**) has provoked debate. Was *Archaeopteryx* the first bird or a feathered dinosaur? Did it evolve parallel to dinosaurs from some earlier stock, or from dinosaurs themselves? The author's extensive anatomical studies demonstrate its skeleton to be dinosaurian—almost.

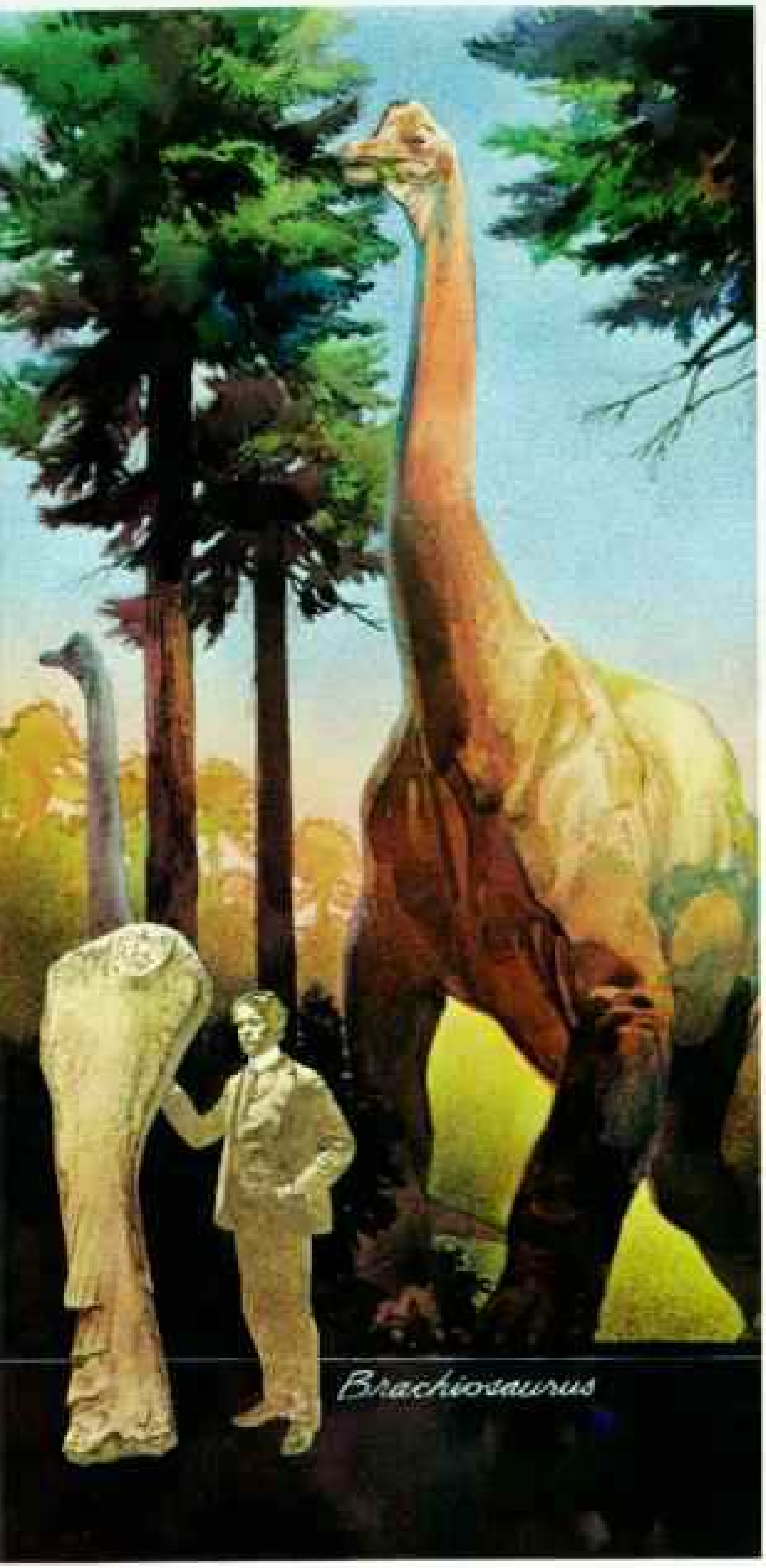
When compared to the skeleton of *Ornitholestes* (**bottom**), a small theropod dinosaur, that of *Archaeopteryx* (**below, middle**) was essentially similar. But besides having longer forelimbs, it had two features critical to classification as a bird: a wishbone and, of course, feathers. The skeletal differences were subtle, and in one case, an *Archaeopteryx* was mistakenly identified as a dinosaur for twenty years before the error was realized.

Because the differences are so small, parallel evolution seems unlikely. The feathered form, just barely a bird, must have evolved from a dinosaurian ancestor, the author feels. Feathers were not for powered flight, since the skeleton lacks the large breastbone and other flight-muscle anchors of the modern pigeon (**below, left**). They were in part for insulation. Only warm-blooded animals have insulation. Thus *Archaeopteryx* supports two theories: warm-bloodedness in dinosaurs and dinosaurian ancestry of birds. Featherless flying reptiles, such as pterodactyls and other pterosaurs, were not true dinosaurs and are not related to birds.

MUSEUM FÜR NATURKUNDE AN DER HUMBOLDT-UNIVERSITÄT, DDR BERLIN (RIGHT)







EIGHTY TONS OF APPETITE browsing at forty feet, *Brachiosaurus* munched through forests. Nostrils atop its head suggest a snorkel, but its lungs could not have functioned under the pressure of 20 feet of water. Painted beside the upper bone of a forelimb, H. W. Menke of Chicago's Field Museum of Natural History helped uncover the first specimen in 1900, an era when paleontologists were scouring the American West in a great competitive bone rush.

marshes, bayous, and rivers. The forests were made up largely of conifers, cycads, and ferns during the dinosaur reign in Jurassic and early Cretaceous times (200 to 100 million years ago). Gradually the flora changed to include subtropical hardwoods, such as magnolia, dogwood, and oak, toward the end of the Cretaceous Period. All things considered, the climate of regions where dinosaur remains have been discovered appears to have been tropical to subtropical, and only mildly seasonal.

Viewed in terms of today's geography, the dinosaurs seem to have ranged almost from Pole to Pole. They have been found in abundance in regions of all continents except Antarctica. Dinosaur remains have been found as far south as southern Argentina (latitude 48°S.), and their footprints occur on the island of Spitsbergen, well inside the Arctic Circle at close to latitude 80°N.

Do not presume, however, that dinosaurs ranged into high Arctic regions. The continents occupy very different positions now. Because of a phenomenon known as seafloor spreading, earth's landmasses have moved about over the surface of the globe throughout geologic time. In the age of dinosaurs, what is now Spitsbergen was farther from the North Pole than it is today.

Different Sizes, Different Shapes

When I found *Deinonychus* in 1964, many people expressed their surprise to me: "Haven't all prehistoric animals been found?" Far from it. Since then, dozens of other new kinds of dinosaurs have been discovered in widely separated parts of the world—Mongolia, Brazil, China, Argentina, South Africa, India, Rhodesia, Australia, France, Canada, and several western states of the United States.

The variety of dinosaurs discovered in little more than a century is staggering. Big and little, carnivores and herbivores, lumbering quadrupeds and fleet-footed bipeds, they obviously were diverse in their habits and habitats, some perhaps warm-blooded, others not.

There is no end to spectacular finds. Another Polish-Mongolian expedition to the Gobi Desert, in 1965, uncovered the shoulders, arms, hands, and rib fragments of a gigantic carnivorous dinosaur. The arms and hands measured almost eight feet long! The hands alone were more than two feet long, which is why the creature was named *Deinocheirus* ("terrible hand"). The huge hands appear to have been designed for grasping and tearing apart what must have been very large victims.

The bones of *Deinocheirus* are very similar to those of a North American dinosaur, *Struthiomimus* ("ostrich mimic"), except that they are more than three times larger. The arms and hands of *Struthiomimus* are only two and a half feet long (pages 174-5). If *Deinocheirus* was of the same general design as *Struthiomimus*, the missing parts of its skeleton must have been gigantic. It must have stood 25 feet tall and was perhaps 45 feet long. That is about the size of *Tyrannosaurus*, which, until *Deinocheirus* came along, was the biggest land carnivore of all time: 18 feet tall, 50 feet long, six tons. But we cannot know *Deinocheirus*'s size for certain until other parts of its skeleton are discovered. In the meantime, we do have an entire skeleton for *Tyrannosaurus*, and a six-ton biped seems astonishing enough.

When Supersaurus Ruled the Earth

An even more astonishing find than *Tyrannosaurus* or *Deinocheirus* has come out of Jim Jensen's excavations at Dry Mesa quarry. Jim has uncovered bones of what may be the largest dinosaur ever found. As with *Deinocheirus*, only a few bones of this creature have been dug out so far—but these include a pair of shoulder blades eight feet long as well as neck vertebrae nearly five feet long. These measurements are 20 percent larger than in any previous find. The bones are from a huge, herbivorous animal that may have towered to 50 feet and weighed perhaps a hundred tons—*if* its anatomical design resembled that of *Brachiosaurus* or other more completely known relatives (pages 176-7).

The team in Jim's Dry Mesa quarry was quick to call this animal by the unofficial name of "Supersaurus." It may have been as much as one-fifth larger than anything else known among the dinosaurs.

Imagine, if you can, an animal larger than the famed *Brachiosaurus* from East Africa. Its skeleton, at Humboldt University in East Berlin, stands about 40 feet high. A live *Brachiosaurus* may have weighed 70 or 80 tons. How could Supersaurus, weighing perhaps a hundred tons, have sustained itself? One hundred tons is approximately fifteen times the weight of an adult African bull elephant—an animal that consumes 300 to 600 pounds of fodder every 24 hours and spends up to 18 hours a day feeding. Are we to believe that Supersaurus consumed as much as 15 elephants? It seems totally out of the question.

Warm-bloodedness Theory Hits Snag

This Supersaurus-elephant comparison draws us to the very center of the controversy over whether dinosaurs were warm-blooded like today's mammals and birds. The traditional view is that they were cold-blooded, like all living reptiles. If Supersaurus was warm-blooded like the elephant, and comparably active, it would have required a preposterous daily food consumption. This is a critical stumbling block to the warm-blooded-dinosaur theory, at least for the largest kinds.

Warm-blooded birds and mammals can maintain a high and uniform body temperature even when environmental temperatures are lower (or higher). They do this by generating heat internally or shedding excess heat through such means as perspiration or panting. Such internal temperature regulation is termed endothermy. Endothermic animals, like the elephant, have high metabolic rates and are usually capable of long periods of sustained activity as compared with modern reptiles. But these qualities require much fuel: An elephant consumes approximately its own weight in food each month.

Reptiles, such as crocodiles, lizards, and snakes, are cold-blooded—that is, their body temperatures are not internally generated but approximate the environmental temperatures. They are called ectotherms because they are dependent on external heat—the sun. They control their temperature by moving in and out of the shade.

Compared with mammals and birds, most living reptiles have low metabolic rates and are capable of only short bursts of high activity. But they can go for long periods without food. A large snake may eat only two or three times its own weight over an

EVERYBODY'S EXCAVATION on the Utah-Colorado border is the heart of Dinosaur National Monument. From an elevated gallery, visitors can watch as technicians chip away at rock to reveal a veritable zoo of fossilized bones dating from the Jurassic Period. One of the rare finds: the skeleton of an infant *Stegosaurus* without back fins.

What is now stone was once a bend in an ancient river where the flotsam of dinosaur bones piled up to be covered by sand. Those layers preserved the shapes of the bones while minerals exactly replaced the dissolving matter.

The monument lies along extensive exposures known as the Morrison formation, a mother lode for paleontological studies for more than a century.

entire year. The moral: More work (either in generating higher body temperatures or in greater exercise) requires more fuel.

Supersaurus appears a more plausible creature viewed as a typical ectothermic reptile rather than as an endotherm like the elephant. As an ectotherm, Supersaurus would have consumed perhaps 500 to 1,000 pounds a day, rather than the 5,000 pounds it would have required as an endotherm. But this is still much more than an African elephant consumes. It just does not seem possible that these huge brontosaurlike animals, with their small mouths and tiny teeth, could have eaten enough to operate as endotherms.

Nevertheless, the idea that at least some dinosaurs, though classified as reptiles, may have been warm-blooded and capable of

DAVID HISER

a high and sustained activity level will not go away. More than a century ago Huxley and Owen—the eminent British scientists—hinted at this when they compared the first dinosaur finds with mammals and birds, rather than just with reptiles. Today the warm-blooded-dinosaur theory is the centerpiece of one school of thought, which sees it as *the* explanation of the 140-million-year success story of the dinosaurs.

Erect Posture Points to Endothermy

Several lines of evidence suggest that some dinosaurs might have been more like mammals or birds than like today's reptiles. Most dinosaurs walked with the legs held in near-vertical positions. This same erect posture is found today in mammals and birds—all of which are endothermic and capable of prolonged activity. I have a strong suspicion that this erect posture may be related to high metabolic rates and therefore to endothermy.

By contrast, most living ectothermic land vertebrates are sprawlers; they stand and move about with the legs held out to the side in a push-up posture. Their walk is a side-to-side waddling. Although crocodiles and alligators can assume a somewhat higher, semierect pose and gait, modern reptiles and amphibians, with only a few exceptions, are not capable of fully erect posture. It hardly seems a chance correlation that ectotherms are sprawlers, while erect animals are endotherms.

Critics of this reasoning claim that the erect posture of dinosaurs is a requisite of their large size, the most effective means of supporting great weight. But small dinosaurs like *Deinonychus*, *Compsognathus*, and many others had erect posture, while certain other large non-dinosaurian reptiles, such as the dicynodonts, exhibited the primitive sprawling stance.

Some dinosaurs, again like *Deinonychus* and also the ostrichlike struthiomimids, were clearly designed for speed. The bipedal posture of all theropods and some other dinosaurs, by analogy with birds, suggests high activity and perhaps endothermy.

Bob Bakker of Johns Hopkins finds support for his theory that all dinosaurs were warm-blooded in the relative abundance of dinosaurian prey to dinosaurian predators. A given population of prey animals can support far fewer warm-blooded predators than cold-blooded ones. He determined that lions and cheetahs consume their weight in food every seven to ten days, while a large lizard like the Komodo dragon consumes its weight in food only every 60 days.

Bakker tallied the flesh-eating dinosaurs against the herbivorous dinosaurs in late Cretaceous rock strata and found the ratio of predators to prey very low, comparable to modern mammalian predator-prey ratios. He concluded this was strong evidence of dinosaurian endothermy.

Of course, his conclusion rests on the critical assumption that the specimens collected from these strata accurately reflect the abundance of the many different kinds of dinosaurs that coexisted then. That is a very large and completely untestable assumption. But an even more serious flaw in this

WHAT RAN like an ostrich, looked like an ostrich, and maybe even lived like an ostrich? *Struthiomimus*, the "ostrich mimic" of about 80 million years ago. Although probably carnivorous, this dinosaur had no teeth, leading to speculation that it may have eaten, among other things, the eggs of fellow dinosaurs.

As with some obvious features, its pelvis is not birdlike. Paradoxically, dinosaurs without birdlike hips gave rise to birds, while those with such hips did not. However, when *Struthiomimus* roamed, birds had already become established as a divergent group.


Struthiomimus

line of evidence for dinosaurian endothermy is that it applies only to the predators; the herbivorous dinosaurs could all have been cold-blooded.

Dr. Armand de Ricqlès of the University of Paris has explored the warm-blooded theory from another tack. He has found that the bone tissue of various dinosaurs is similar to that of many living mammals but quite unlike the bone tissue of most modern reptiles. The correlation is not absolute, though, and may not be related to warm-bloodedness or endothermy.

Body Heat Linked to Climate?

Some critics of the endothermy theory will go halfway. They concede that some dinosaurs might have been warm-blooded, but were unable to regulate body heat internally and thus were not endothermic. They reason that because of their large size dinosaurs, once warmed up by basking, would achieve an almost stable body temperature, a state called homoiothermy.

Thirty-four years ago, in their experiments with live alligators, dinosaur authority Edwin Colbert, herpetologist Charles Bogert, and physiologist Raymond Cowles demonstrated that *if* the large dinosaurs were cold-blooded like alligators, they were probably homoiothermic. The scientists determined that the larger the basking gator, the slower the rate of heat absorption and heat loss. Thus, the much larger dinosaurs of the Mesozoic Era, in a warm and equable climate, very likely had warm and nearly uniform body temperatures, without necessarily being endothermic.

Other quite different evidence may be viewed as supporting their work. An investigation of the curious bony plates along the back of *Stegosaurus* by students James Farlow and Carl Thompson and Professor Daniel Rosner of Yale's engineering department came up with a surprise. The bony back fins of *Stegosaurus* have long been regarded as protective armor against predators. Farlow discovered that these plates were penetrated by a complex network of canals that must have contained large blood vessels. What function could they have served?

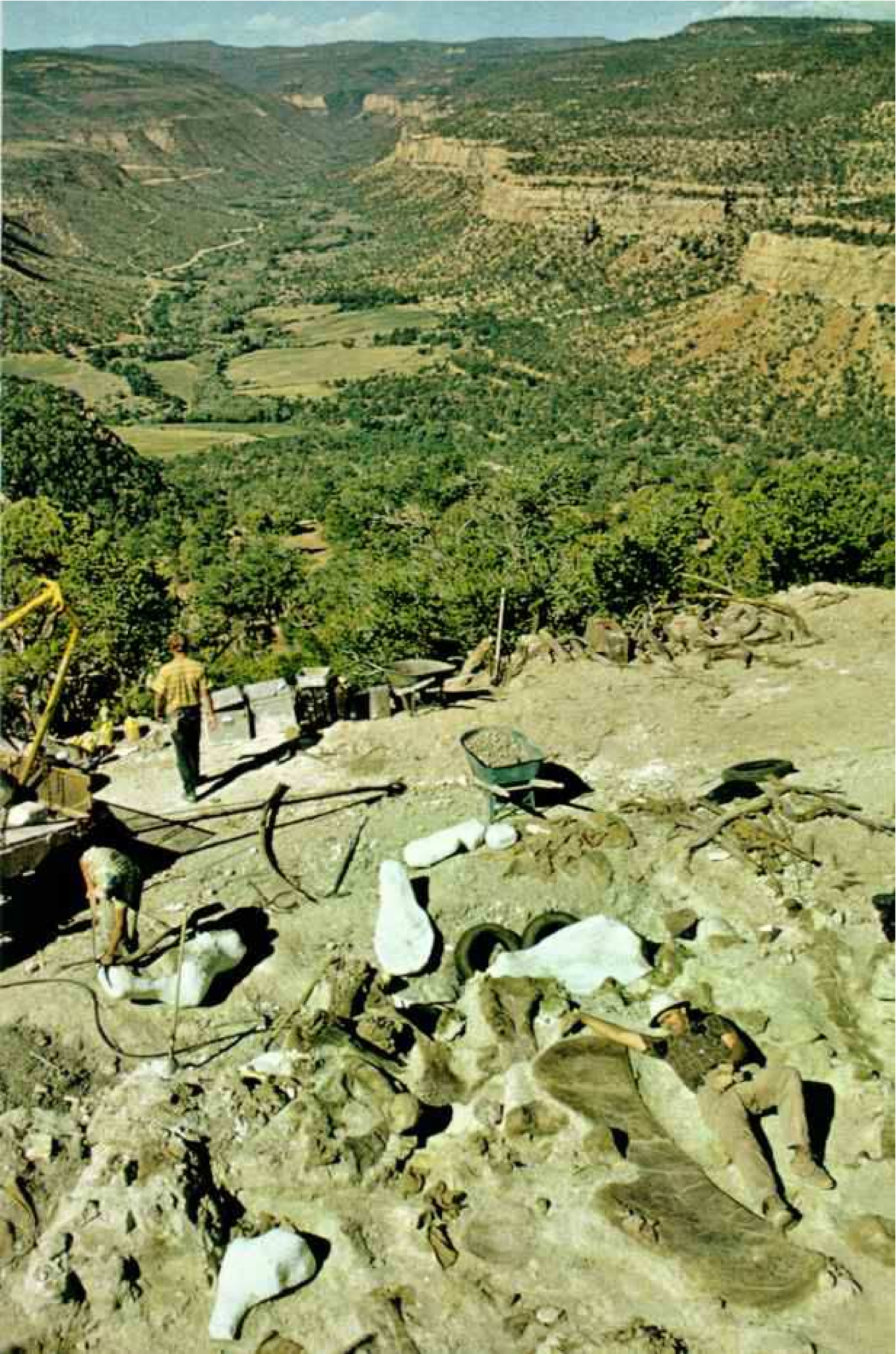
Professor Rosner, an expert on heat transfer, carried out experiments on a simulated *Stegosaurus* model and concluded that the double row of staggered bony plates *could* have functioned as convective heat-loss fins to cool *Stegosaurus* off (page 183). Projecting high above the back, the bony plates, perfused with "overheated" blood after strenuous activity, would be cooled by the breezes—functioning much like the vanes and baffles of an automobile radiator. The staggered, or alternating, arrangement of *Stegosaurus*'s plates, never satisfactorily explained before, happens to be a more effective cooling arrangement than plates symmetrically paired. Though this investigation does not prove *Stegosaurus* was endothermic, it does suggest a frequent need

OTIS IMBODEN (RIGHT)

A MONSTER OF MONSTERS, whose shoulder blade alone is longer than discoverer Dr. James Jensen (**right**), was unearthed at Dry Mesa quarry in Colorado. Although only this bone and several others have been found, they justify its nickname, "Supersaurus."

If, as seems probable, Supersaurus was a four-footed herbivore built along the lines of *Brachiosaurus*, it thus becomes the biggest of all dinosaurs, as shown in a conjectural drawing (**above**) with a *Brachiosaurus* and a man for comparison.

Supersaurus may have weighed as much as a hundred tons—equal to a herd of 15 African elephants. If so, it becomes the largest land animal of all time and outweighs most great whales.



to shed excess heat—and that is one critical aspect of temperature regulation.

These various lines of evidence have led some paleontologists, especially Robert Bakker, to conclude that dinosaurs might have been true endotherms. If that were the case, they would have been free of one of the constraints that all living ectotherms must deal with—dependence upon external heat sources to warm up to optimal temperatures. The major stumbling block in this, though, is that an endotherm requires more fuel to generate that heat. And that leads to improbable daily food consumption for an endothermic Supersaurus-size animal, as we have already learned.

Personally, I doubt very much that all dinosaurs were endothermic. Many, or most, probably were warm-blooded as a consequence of subtropical climates and thermal inertia imposed by their large size. The theropods, however, and especially the smaller kinds like *Compsognathus*, *Deinonychus*, and the struthiomimids, I suspect may have been true endotherms. Notice that the theropods are the only dinosaurian group to which all the above lines of evidence apply. And add to that the evidence that *Archaeopteryx* and other birds evolved from a small theropod dinosaur.

The "Great Dying": Why Did It Occur?

The possibility that birds are surviving dinosaur descendants raises the ultimate question: Why did their ancestors and all the other dinosaurs become extinct? What caused the "great dying"? One theory that appeals to me is that of Professor Loris Russell of the Royal Ontario Museum in Toronto. He postulated that the dinosaurs were warm-blooded, but that unlike birds and mammals, they lacked an insulative covering such as hair or feathers. This conclusion has been borne out by fossil specimens showing impressions of dinosaur skin.

According to Professor Russell, as earth temperatures declined from near-tropical levels toward the end of the Cretaceous Period and became more seasonal, dinosaurian temperatures also declined. Without insulation, dinosaurs could not retain their blood heat in the longer and colder winters, and so perished. All reptiles that survived the crisis at the end of the dinosaur era, such as lizards and snakes, were cold-blooded. Mammals and birds may have survived because they were endothermic *and* insulated.

But why didn't the dinosaurs simply migrate to more hospitable environs as the climates deteriorated? Tropical conditions must have persisted somewhere at low latitudes. Perhaps some did migrate; perhaps they were able to survive for a time in tropical latitudes.

Professors Leigh Van Valen of the University of Chicago and Robert Sloan of the University of Minnesota believe that in North America, at least, dinosaur extinctions may have occurred slightly later in the south than in the north. But they, along with Dr. Nicholas Hotton of the Smithsonian Institution, attribute extinction to gradual replacement by mammals, rather than directly to cold weather.

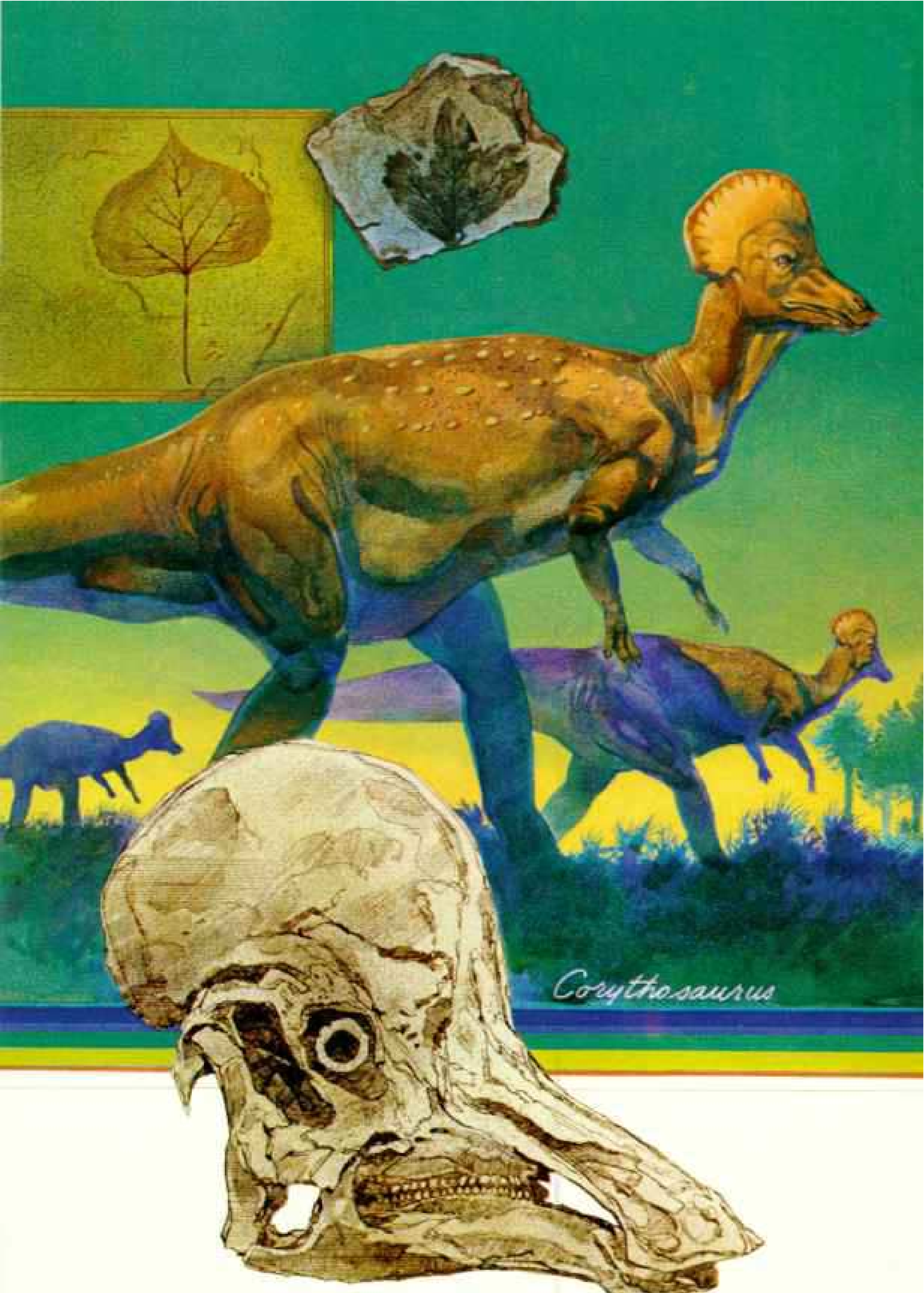
At the same time that the dinosaurs were dying out, a dramatic extermination of other life forms occurred. In the sea the reptilian sea monsters disappeared, together with the coil-shelled ammonites, relatives of the modern squid and nautilus. Massive extinctions occurred in the sea's microscopic planktonic life. On land certain plants vanished, and the flying reptiles disappeared.

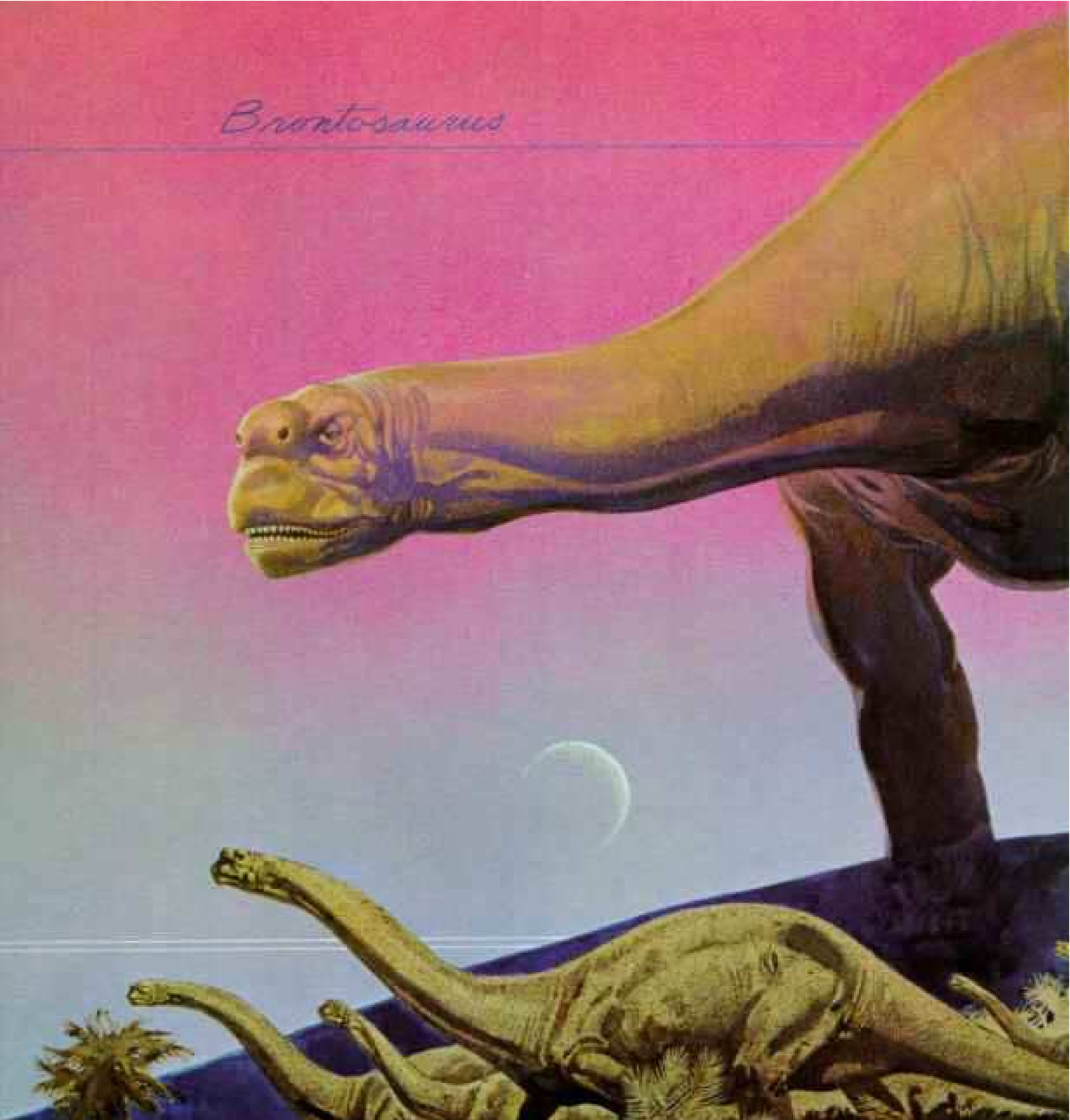
Some experts attribute these exterminations to sudden, severe cold weather—which seems to *(Continued on page 182)*

TOWARD THE END of the reign of dinosaurs, there flourished a group of large duck-billed plant eaters bearing a great variety of bony skull crests. In *Corythosaurus*, an air passage ran from the nostrils through the bill, up into the crest, and exited in the back of the mouth. The passage may have allowed breathing while eating. This would have been an advantage had the animal been a constant feeder, as the large battery of teeth suited to grinding suggests.

The passage may also have contributed to an acute sense of smell—to warn of predators or, as with the shape of the crest, to aid the animal in recognizing others of its own kind.

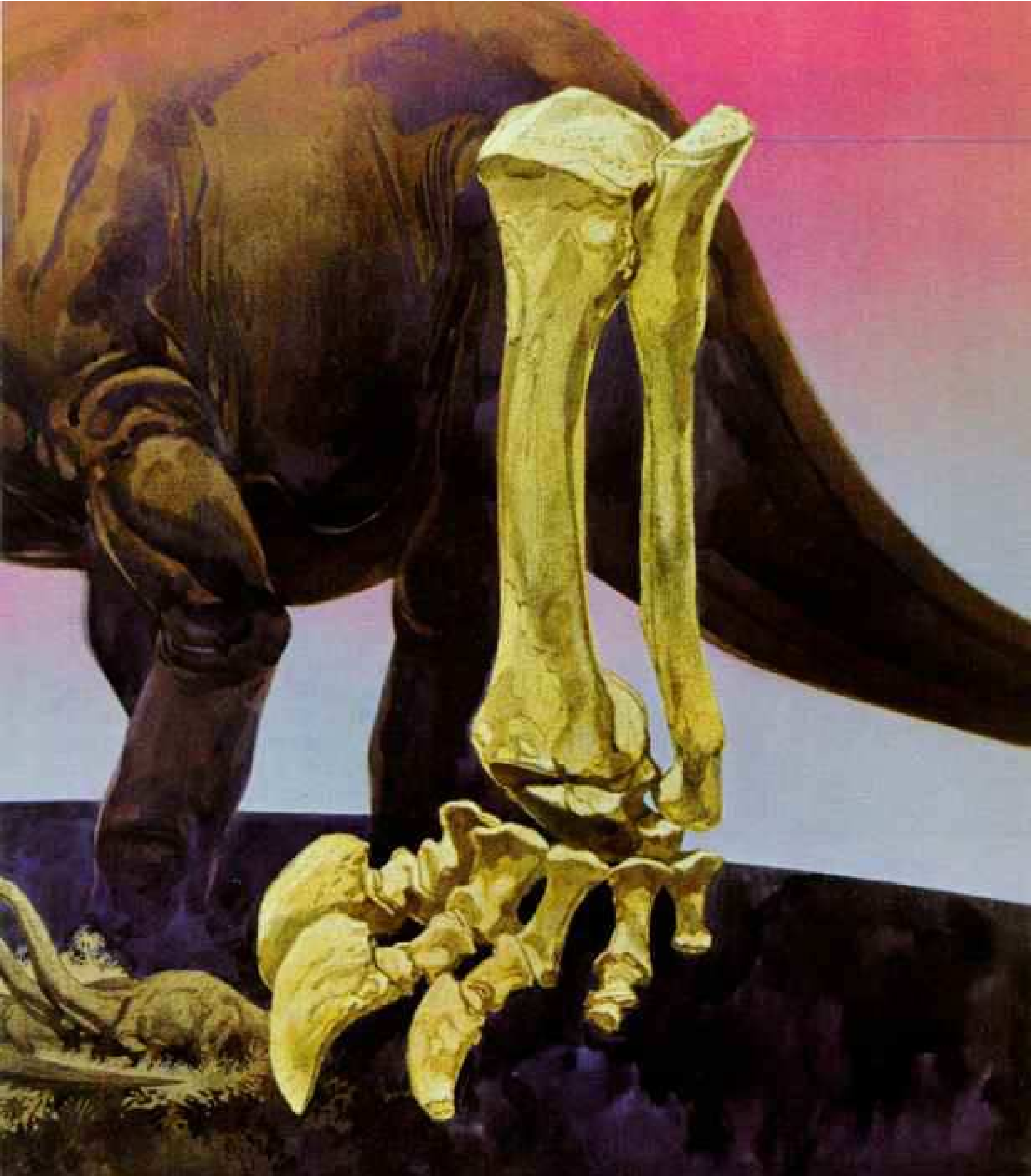
Once thought to be strictly aquatic, the duck-bill dinosaurs may have been land browsers, perhaps favoring riverbank habitats, with a taste for pine needles.


Corythosaurus



FAMILIAR BUT PUZZLING: For many it is *Brontosaurus,* also known as *Apatosaurus,* that springs to mind when they think of dinosaurs. For paleontologists, this 70-foot, 30-ton beast and its ilk present serious problems for thinking all dinosaurs could internally regulate their body temperatures as do mammals.

Brontosaurus had no special feeding

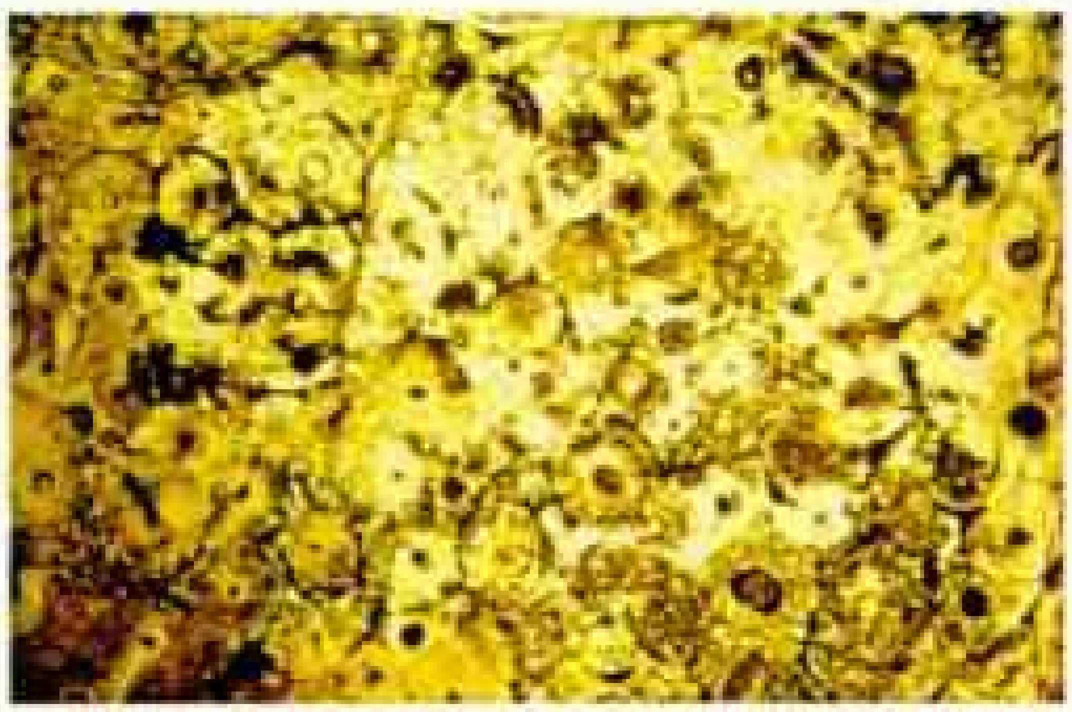


apparatus like an elephant's trunk. Its teeth were peglike and relatively small, as was its mouth. Even if it did nothing but feed, the intake would seemingly be too low to sustain elephant-style metabolism.

But, the author believes, they may have been warm-blooded in another sense. In a benign climate with little daily or seasonal temperature variation, their huge bodies may have acted as heat reservoirs. As with a large water tank, once heated, they would cool off slowly and so maintain operating temperature without need for internal heat regulation.

Brontosaurus has often been portrayed as too heavy to walk on land, but comparative bone studies proved its legs could support and move its vast bulk.

OTIS IMBODEN



ARMAND DE RICQLES, UNIVERSITY OF PARIS, VII

reinforce Loris Russell's hypothesis. But what could have triggered it, especially after tens of millions of years of nearly uniform subtropical climate?

Dr. Dale Russell of the National Museums of Canada in Ottawa (he is no relation to Loris) has a theory. He and other scientists have attributed these biologic disruptions to a supernova explosion—like that of the Crab Nebula witnessed by Chinese astronomers in the year 1054.

According to their theory, a closer supernova explosion, within one hundred or so light-years of our solar system, could flood earth with excessive cosmic radiation for several decades. This might be lethal for many creatures, especially the large forms unable to burrow or otherwise shield themselves. In addition, absorption in the upper atmosphere of high levels of X rays produced by the explosion—perhaps ten thousand times the normal influx—could result in extreme atmospheric turbulence along with severe temperature imbalance. Water-saturated air would be displaced into high altitudes, where ice crystals would form. The ice-laden upper atmosphere would reflect away much of the sun's heat, causing a sudden and perhaps long-lasting drop in earth temperatures.

Another view of the great dying relates to plate tectonics, or seafloor spreading. Realigned continental masses could have

TO BEAT THE HEAT, the ungainly-looking *Stegosaurus* (**right**) may have perfected a natural radiator. Laced with channels for blood flow, its back fins are placed alternately rather than in pairs. Wind-tunnel tests on a model showed this to be the most effective array for dissipating heat. The spiked tail's degree of mobility is uncertain. Perhaps its evil appearance was deterrent enough.

Dinosaur bone sections (**left, top**) shown under low magnification (**left, middle**) are perfused with pathways called Haversian canals similar to those found in human bone (**bottom**). There they play a critical part in blood chemistry and, perhaps, metabolism. Though such canals suggest high metabolism in dinosaurs, they do not prove it. Some reptiles have canals; some mammals lack them.


Stegosaurus

caused changes in oceanic and atmospheric circulation patterns, with disruptive effects on worldwide climates. Seafloor spreading could also cause fluctuations in sea level that would inundate or drain low-lying continental regions, changing their climates. I doubt, however, that this scenario fully explains the demise of the dinosaurs.

Robert Bakker has suggested that it was not really the climatic effects of sea-level changes that created havoc with the dinosaurs. It was rather the lack of diversity in the land habitat created by the withdrawal of the seas. As he sees it, this led to production of fewer descendants to carry on the lineages.

No one knows what did the dinosaurs in, but I favor the cooling-environment hypothesis, whether the cold was caused by shifting continents or by an exploding supernova—or a combination of both.

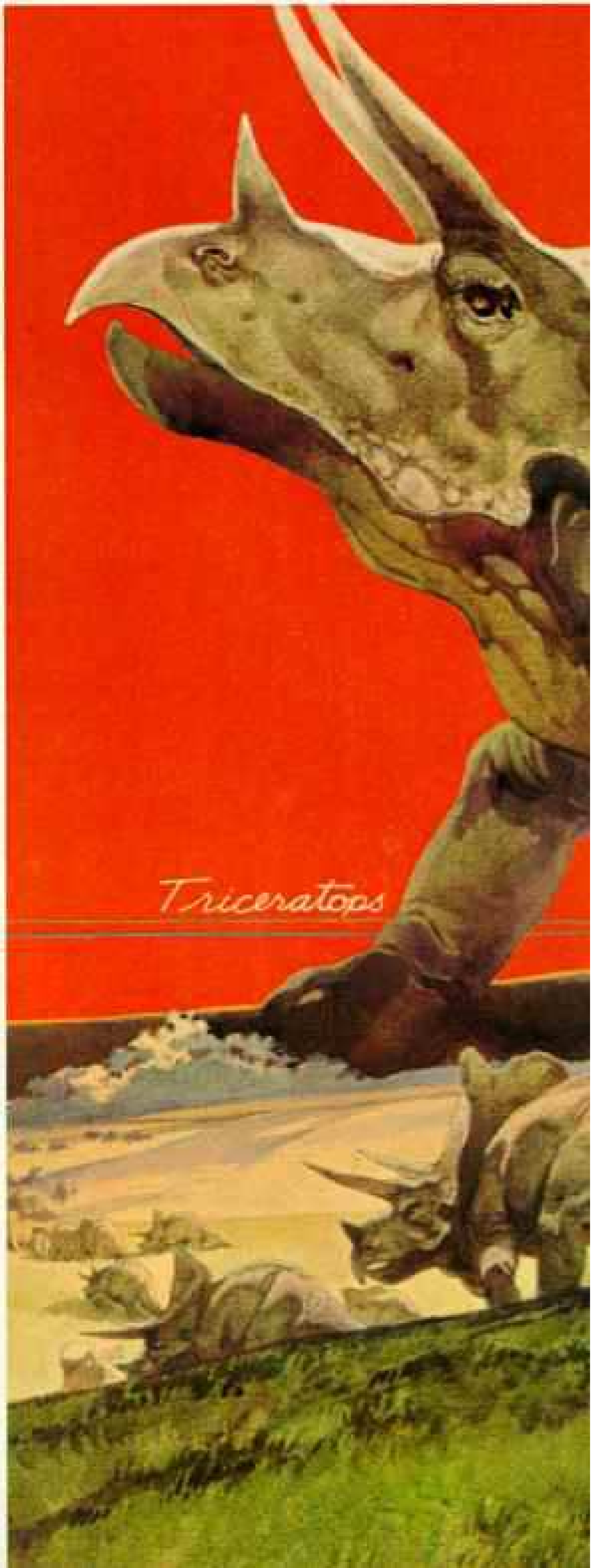
If Professor Loris Russell is right—that dinosaurs were warm-blooded but without insulation, and failed because of cooling climates—the early survival and ultimate success of birds is understandable. Feathered *Archaeopteryx* was likely warm-blooded and probably even endothermic—able to regulate its temperature internally. Insulation made the difference. While larger uninsulated dinosaurians perished, feathered descendants of the small theropods were fit to weather the rigors of "winter."

Flying Dinosaurs and Multi-ton Birds

The concept of birds as modern descendants of dinosaurs has provoked some amusing thoughts, though they have been offered in all seriousness. Two converts to the dinosaurian-origin-of-birds theory have proposed that our formal classification of birds and dinosaurs be changed: Birds, now in a class of their own (Aves), should be reduced in rank and made a subdivision of the class (new elevated rank) Dinosauria. The reason given is that birds are nothing more than "flying dinosaurs." Another suggestion is to include birds and their ancestors in a single class—that is, to classify all carnivorous dinosaurs as birds!

While I am delighted to have this support of my theory on bird origins, I prefer not to think of your canary as a dinosaur, or *Tyrannosaurus* as a bird. □

BEFORE WANDERING into oblivion, the armored *Triceratops* had emerged as an ambling fortress with mouth parts uniquely adapted to feeding on fibrous plants like palms. The turtle-like beak could rip fronds; then teeth



specialized for shearing could chop them fine enough to swallow.

Triceratops and other dinosaurs vanished about 65 million years ago. Final extinction may have taken several thousand or several million years. A cooling climate, sped by the effects of an exploding supernova, may have done them in.

Long suppressed, mammals began to fill the ecological niches vacated by dinosaurs. But birds, their insulating feathers adapted for flight, survived.