

THE THUNDER LIZARDS

In December, the American Museum of Natural History will unveil its reconstruction of the dinosaur *Barosaurus* in the newly renovated Theodore Roosevelt Memorial Hall. This month's cover painting and special section on sauropods mark the opening of this permanent exhibition.

On the way to greener feeding grounds, a seasonally migrating herd of Diplodocus moves through a landscape sparsely vegetated with cycads.

© John Gurche, from John Reader's *The Rise of Life*, 1986

Life Styles of the Huge and Famous

The giant sauropods led superlative lives

by Peter Dodson

Sauropods, as paleontologist Walter Coombs observed, were beasts the size of whales, on legs of elephants, with tails of lizards, necks of giraffes, heads of horses, and nostrils of tapirs. In any description of these beasts, superlatives abound. Sauropods had the smallest brains relative to body weight of any group of dinosaurs, yet they were among the most successful of all dinosaurs. The first sauropods appeared in the Early Jurassic, almost 200 million years ago. They reached the peak of their worldwide diversity in the Late Jurassic, about 150 million years ago, and a few persisted to the dying moments of the Late Cretaceous, 66 million years ago. So far, their remains have been found on every continent except Antarctica. There were more genera of sauropods than of any other major group of dinosaurs. (A genus comprises a group of closely related species.) About ninety genera of sauropods have been named, but fewer than fifty are probably valid. Few sauropods are known from essentially complete remains, and skulls are especially rare. This is a problem of taphonomy, or burial: these animals were so large that, most likely, the tail, head, and feet rotted away before the whole carcass was buried. Complete burial could easily have taken several years.

Indeed, sheer size is the most remarkable characteristic of the sauropods. Even a small sauropod was thirty feet long and weighed six or more tons. And the biggest? We're still trying to figure that one out. The largest, almost complete *Diplodocus* skeleton found so far is about ninety feet long. Very incomplete remains discovered by "Dinosaur Jim" Jensen, of Brigham Young University, in the famous Dry Mesa Quarry in western Colorado in the 1970s suggest that the tallest sauropod was *Ultrasaurus*, perhaps some 55 feet high, and the longest was *Supersaurus*, which may have stretched 125 feet from nose to tip of tail. A recent contender for top honors, at a possible 140 feet, is *Seismosaurus*, discovered in 1985 in New Mexico and currently under excavation by Utah paleontologist David Gillette. Typical sauropods ranged in weight from ten to thirty tons. *Barosaurus* was a

heavily built sauropod, although perhaps only eighty feet long.

How did these giants live? What they lacked in brains, they made up in brawn. Gigantism was obviously part of their formula for success. But did they become too big for their own good? Could they support their bulk on land or did they languish in swamps, submerged up to their chins in water? What did they eat and how many hours a day did they spend eating it? Were they warmblooded? How did they reproduce? And how long did they live? Thinking about questions like these puts flesh on the bones and brings our heroes to life.

Sauropods were long thought to have been too large to move about freely on land and to have required water to help support their bodies. In 1971, after studying the anatomical structure of the creatures' limbs, feet, and rib cages, Robert Bakker, a paleontologist in Boulder, Colorado, made a strong case that sauropods were thoroughly adept, elephantlike terrestrial animals, not short-limbed, barrel-chested, aquatic beasts.

Bakker and I decided to examine the colorful outcrops of the Upper Jurassic Morrison Formation in Utah, Colorado, and Wyoming, where the remains of the ancient behemoths have been found in abundance. Along with our colleagues Kay Behrensmeyer, now of the Smithsonian Institution, and John McIntosh, of Wesleyan University, we discovered that the sauropod fossils were by no means confined to rocks that indicated the presence of ancient swamps or lakes. At the Cleveland-Lloyd Quarry in central Utah and again at Sheep Creek in southern Wyoming, we found that skeletons had come from limy pond deposits. At the beautiful tilting bas-relief of Dinosaur National Monument in Utah (where the American Museum's *Barosaurus* came from, as well as three other kinds of sauropods and five other kinds of dinosaurs) and in the picturesque cliffs of Garden Park near Cañon City, Colorado, the ancient bones are closely associated with river channels that flowed across the Jurassic landscape. But bright red and maroon sediments near Cañon City, near Fruita, Colorado, and at Como Bluff, Wyoming, all attest to dry sa-

vannalike conditions. We concluded that sauropods roamed across a broad spectrum of environments, going essentially where they pleased.

Furthermore, to our surprise, we found plant remains to be very uncommon. While large quantities of plant fodder were required to fuel sauropod bellies, little evidence of this verdure remained, having been oxidized to dust during the withering dry seasons. The bright hues of the Morrison sediments and the scarcity of plant remains contrast strongly with the pale colors and abundant plant remains in the Late Cretaceous beds of Alberta and Montana, where I have worked for the past ten years. During the Late Cretaceous, the lush lowland plains were awash with water. Seventy million years earlier, during the Late Jurassic, climates of western North America were dry and strongly seasonal. Sauropods may have wandered long distances following the rains in search of fresh salad.

But how much salad did a sauropod require? This depends on many things, but especially on body size and metabolic rate. A convenient size unit is elephant size, roughly five tons. The smallest Morrison sauropod, *Haplocanthosaurus*, weighed about one and a half elephant units. Slender *Diplodocus* weighed two or three elephant units, stocky *Camarasaurus* six elephant units, and bulky *Barosaurus* and *Apatosaurus* as much as eight elephants. The giants weighed in at ten to twenty elephants. Relative to their huge bodies, most sauropods had small heads, more or less the size of horse or giraffe heads. Also, the teeth, although robust and often heavily worn, particularly in the camarasaurids, are simple in structure.

How could a beast this big, with a relatively small head, have gathered enough food in a day to keep alive, much less thrive? Basically, the jaws and teeth were used simply to rake in foliage, which may have been reduced to small particle size internally in a gizzard. Sauropods may have also swallowed stones for grinding plants, but proof has been maddeningly difficult to come by. The West is almost paved with polished, egg-sized, sometimes brightly colored stones, which are com-

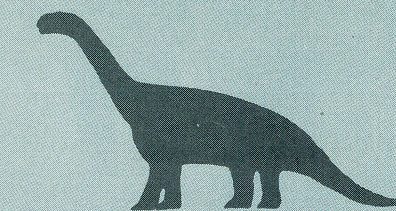
THE SIX SAUROPOD FAMILIES

VULCANODONTIDS

Remains of vulcanodontids have been found in rocks of Early Jurassic age in Zimbabwe and India, and some sauropods from Europe and China may also have belonged to this family. In size, vulcanodontids ranged from the diminutive twenty-foot-long *Vulcanodon* to the sixty-foot-long *Barapasaurus*. Much about this family remains unknown. We do know that they had distinctive spoon-shaped teeth covered with coarse projections, or denticles, that are unknown among other kinds of sauropods.



lightly built, and the teeth were spoon-shaped. Also known from Europe and Asia, camarasaurids first appeared in the Middle Jurassic, in the heyday of sauropods, but one member of this family, *Opisthocoelicaudia* from Mongolia, if correctly identified, lived in the Late Cretaceous, near the very end of the age of dinosaurs.



CETIOSAURIDS

Of moderate size, these sauropods ranged from forty to sixty feet in length. Most lived in the Middle and Late Jurassic, and fossils have been found on all continents except Antarctica. Cetiosaurid necks were not greatly elongated, and their front legs were just a little shorter than their hind legs. The Chinese *Shunosaurus*, the best preserved of all cetiosaurs, was equipped with a tail club. The only cetiosaur skull known belonged to *Shunosaurus*. It is long, with many spoon-shaped teeth; the nostrils, situated near the eyes, pointed sideways.

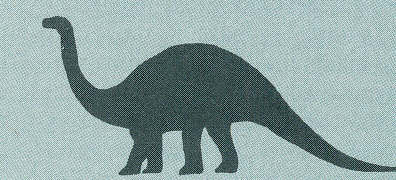


BRACHIOSAURIDS

Late Jurassic *Brachiosaurus* is the only thoroughly known member of this family. One of the heaviest of all dinosaurs, *Brachiosaurus* is famed for its long front legs and elevated shoulder region, which gave its back a sloping, giraffelike appearance. Its large nostrils sat in a bulge above the eyes. Its relative *Ultrasaurus* was large even for a brachiosaurid; it had an estimated vertical reach of fifty-five feet.

DIPLODOCIDS

This family includes the familiar giants *Diplodocus* and *Apatosaurus*, as well as *Barosaurus*. Most of these sauropods had extremely long necks and tails. *Diplodocus* was rather slender in build and reached a length of about ninety feet. The recently discovered sauropod record holders, *Supersaurus* and *Seismosaurus*, were members of this family and stretched to estimated lengths of 125 and 140 feet, respectively. *Barosaurus* had a longer neck than *Apatosaurus*, but the record neck was that of the Chinese *Mamenchisaurus*. At thirty-five feet long, its neck measured half the total length of its body. The diplodocid skulls known so far are long and low, with slender, peglike teeth that jut from the front of the mouth only. The nostrils were situated at the top of the skull, above the eyes. The last diplodocid appears to have been the Mongolian *Nemegtosaurus* from the Late Cretaceous.

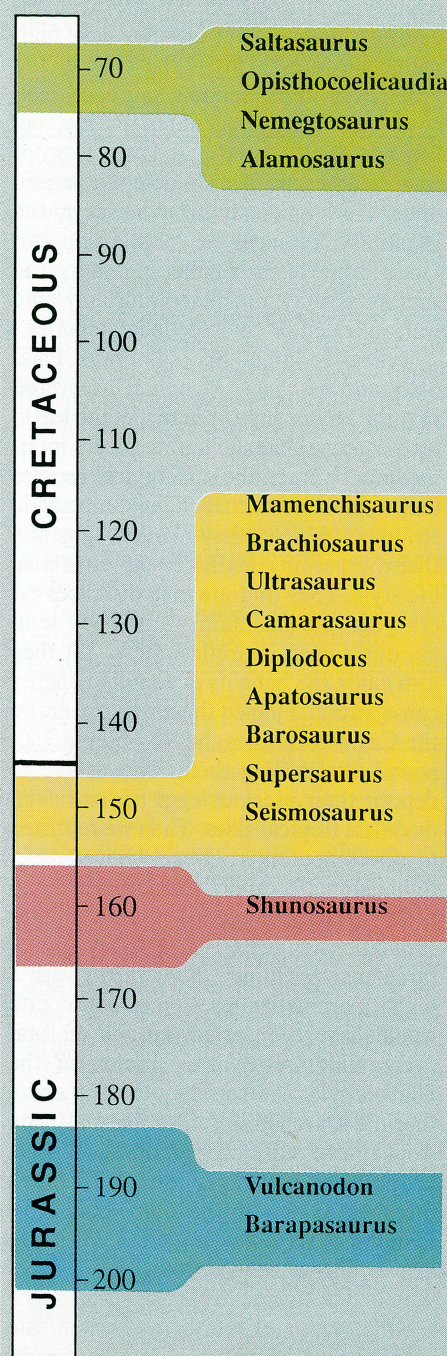


TITANOSAURIDS

The most complete titanosaurid, *Alamosaurus*, with just one-quarter of its bones found, is also the only member of the family found in the United States. The best titanosaurid hunting grounds to date are in South America and India, where fragments of skeletons, many of Cretaceous age, have been excavated. Many members of this family were rather small; *Magyarosaurus* from Romania was a dwarf at only about thirty feet long. The Argentinean *Saltasaurus*, the only known armored sauropod, had a coat of bony scutes on its back.

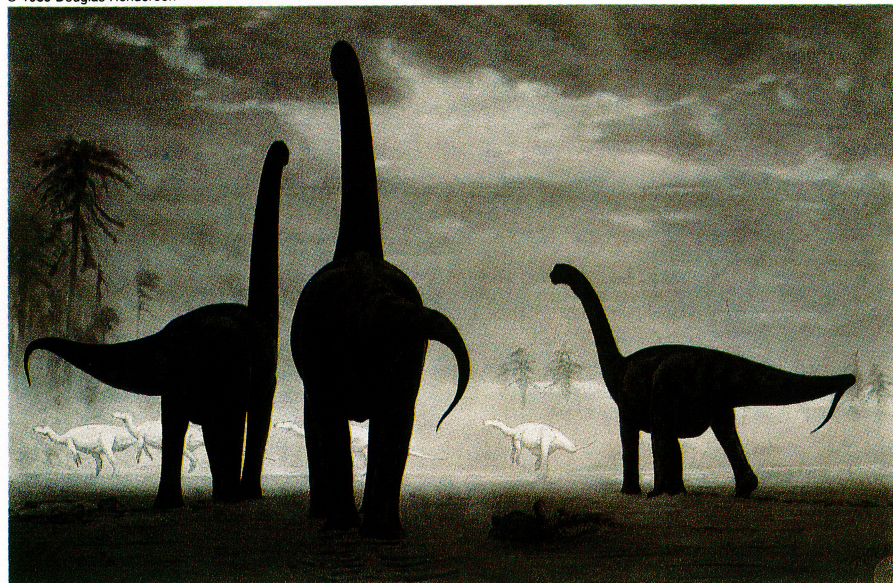


Millions of years ago



Approximate dates for some representative genera of sauropods are given. Based on studies of their shared anatomical characteristics, sauropods are divided into at least fifty genera, which belong to six families.

Sauropod silhouettes adapted from D. Norman's *The Illustrated Encyclopedia of Dinosaurs* (Crescent Books, 1985) and D. Lambert's *A Field Guide to Dinosaurs* (Avon, 1983).



Camarasaurus stride across a mud flat as a Camptosaurus herd passes in the distance. This painting is based on a trackway found in Colorado.

monly identified as "stomach stones"—even when dinosaur bones haven't been found within a hundred miles of them. Rarely are such stones found with sauropod skeletons.

Unlike mammals, sauropods did not waste time chewing. After being processed in the stomach, food was slowly digested in the intestine. *Barosaurus* may have had six tons of fermenting plant material in its huge gut at any given time. Elephants in the wild ingest about 375 pounds of fodder over a twelve-hour day. For sauropods the setting sun may not necessarily have curtailed feeding. The need to consume many hundreds of pounds of greenery a day may have made sleep a luxury. We have learned from studies of mammals that large animals are generally unselective feeders. Everything goes down the hatch: scratchy leaves, woody twigs, and chewy bark, as well as tender shoots and fleshy fruits. In the Jurassic, flowering plants did not exist. Available plants included cycads, cycadeoids, conifers, ginkgoes, horsetails, and especially ferns. Prairies of ferns were essential features of middle Mesozoic landscapes, and ferns probably constituted a major component of sauropod diets.

Did sauropods also feed at the treetops, beyond the reach of other beasts? However appealing this image may be, it presents several problems. *Brachiosaurus* was built like a giraffe and may have fed like one. But most sauropods were built quite differently. At the base of the neck, a sauropod's vertebral spines, unlike those of a giraffe, were weak and low and did not provide leverage for the muscles required to elevate and maintain the head in a high

position. Furthermore, the blood pressure required to pump blood up to the brain, thirty or more feet in the air, would have placed extraordinary demands on the heart (see opposite page) and would seemingly have placed the animals at severe risk of a stroke, an aneurysm, or some other circulatory disaster. If sauropods fed with the neck extended just a little above heart level, say from ground level up to fifteen feet, the blood pressure required would have been far more reasonable. The long neck may simply have served as a feeding boom for a stationary mountain of flesh. They could have lifted their heads with occasional graceful sweeps, blackout being prevented by using the carotid sinuses near the brain as reservoirs for blood. Sauropods were certainly capable of rearing up, or procreation would have ceased. But such a posture probably did not play a role in daily feeding activities.

Fossil footprints, sometimes arrayed in vast trackways consisting of hundreds or thousands of prints, attest to the herding behavior of sauropods. Fine examples of these have been found in Arkansas, Texas, and Colorado. Some of these have been studied by James Farlow, of Indiana University/Purdue University at Fort Wayne, and by Martin Lockley, of the University of Denver. The Davenport Ranch site in Texas is particularly informative. Here a few young individuals (with feet twelve inches across) were led by older individuals twice as large.

Their long legs would have made sauropods excellent walkers. Because the same kinds of sauropods are found over and over again from New Mexico to Montana, and because the Late Jurassic climate was

strongly seasonal with long dry periods, I believe that sauropods migrated widely on an annual cycle to follow the pattern of rainfall and plant regeneration.

Were sauropods warmblooded? Their temperatures were both high and almost constant. Climates of the Jurassic were warm, and sauropod body temperatures responded only very slowly, on a time scale of several weeks, to external temperature changes. But did they have high metabolic rates? This is the crux of the problem of understanding sauropod biology. Arguments about dinosaur metabolism are usually based on the physiology of tiny ectothermic lizards or endothermic mice. At large body size, however, the familiar differences begin to disappear. Unlike some of the smaller dinosaurs, the sauropods may not fit comfortably into warmblooded or coldblooded categories.

Biologists James Spotila, Frank Paladino, and Michael O'Connor discovered that the largest living sea turtle, the leatherback, has a metabolic rate nicely intermediate between those of typical reptiles and typical mammals. This metabolic strategy, which they called gigantothermy, permits leatherbacks an active life style. They migrate long distances every year and maintain warm body temperatures even in arctic waters. Yet they also enjoy the benefits of reptilian energy conservation. I joined these researchers on the Costa Rican beaches to observe 750-pound turtles drag themselves ashore to deposit their precious eggs under velvet, moonless tropical skies. Then we returned to our computers at Drexel University in Philadelphia to apply leatherback metabolic rates to sauropods. Our computer simulations suggest that a thirty-ton, or three-quarters grown, *Barosaurus* with a high mammalian-level metabolic rate would have been at severe risk of fatal overheating. As Warren Porter, of the University of Wisconsin, put it, an endothermic sauropod in full sunlight at noon would have suffered meltdown. With a leatherback metabolic rate, only maximum blood flow to the skin would have maintained the body temperature in a safe range. Our model and those of others working independently suggest that only a reptilian metabolic rate offered a safe physiological strategy for large sauropods, especially those living in warm, dry climates. The large size of sauropods is probably in itself an indication of low metabolic rate, life in the slow lane.

Were these giants long-lived? In general, longevity correlates positively with body size: large animals live longer than smaller ones, but coldblooded ones live longer than warmblooded ones of the

SAUROPODS AND GRAVITY

by Harvey B. Lillywhite

Gravity is a pervasive force in the environment and has dramatically shaped the evolution of plants and animals. For animals, life on land required muscular and skeletal adaptations to allow movement and mobility. Then, as some land animals evolved large body size and adopted an erect posture, cardiovascular specializations were needed to help them withstand the weight of blood in long vertical vessels. Perhaps nowhere in the history of life were these challenges greater than among the gigantic, long-necked sauropods.

The long-held view of sauropods as lumbering, aquatic swamp dwellers has been questioned on physiological grounds. In 1951, Kenneth Kermack pointed out that breathing would have been difficult or impossible for a sauropod up to its head in water, because pressure on the neck and chest, far under the water's surface, would not have allowed the creature to expand its lungs to inhale. Nonetheless, sauropods continued to be pictured almost completely submerged.

In the 1970s, Robert Bakker, following an idea first proposed by Elmer Riggs as early as 1904, reexamined sauropod anatomy and came up with a new vision of the creatures as enormous, giraffelike tree browsers, more graceful and agile than the sluggish giants popular in earlier depictions. In spite of their size, sauropods were conceivably well adapted for fully terrestrial locomotion and erect posture, although amphibious habits were perhaps equally likely, with wading sauropods sometimes using water for support. What remains unclear is whether sauropods on land held their head and neck erect or carried them lower, at the level of the body, as in the depiction of *Mamenchisaurus* mother and young below.

The farther away the head is from the heart, the more force must be exerted to pump blood up to it. An upright *Barosaurus* stood as tall as thirty-eight feet and had a neck length of some twenty-five feet. Consequently, in a *Barosaurus* with its head held high, the heart had to work

against a gravitational pressure of about 590mm of mercury (Hg). In order for the heart to eject blood into the arteries of the neck, its pressure must exceed that of the blood pushing against the opposite side of the outflow valve. Moreover, some additional pressure would have been needed to overcome the resistance of smaller vessels within the head for blood flow to meet the requirements of brain and facial tissues. Therefore, hearts of *Barosaurus* must have generated pressures at least six times greater than those of humans and three to four times greater than those of giraffes. (In a standing human the average arterial blood pressure is 95mm Hg at heart level.)

An animal contending with such high blood pressure would have needed strong arteries and greatly thickened heart muscle. Giraffes, for example, have the highest blood pressure measured in living vertebrates; compared with humans, they have relatively muscular arteries and thick-walled, enlarged hearts. Using a model that took into account heart wall stress and blood pressures, zoologist Roger Seymour estimated the heart size of large, erect sauropods to have been more than 1.6 metric tons, or eight times heavier than that of a similar-sized whale having a comparable internal heart volume. This may be an overestimate, however, because the structure of reptilian hearts allows a smaller wall thickness for a given stress than does a mammalian heart. Nonetheless, in most large dinosaurs, the ribs around the heart are long, suggesting that the cardiac compartment was indeed capacious.

If we look at living snakes, we see that arboreal or climbing species have evolved both high arterial blood pressure and heart positions that are closer to the head than in nonclimbing species. Proximity of the heart to the head presumably insures that blood flow to the head is adequate, regardless of body posture, and minimizes the height to which blood must be pumped when the snake's head is up. The anatomy of sauropods, however, did not allow anterior or

vertical migration of the heart into the neck. Therefore, natural selection for elongation of the neck must have outweighed the cardiovascular disadvantages, unless it preceded terrestrial habits.

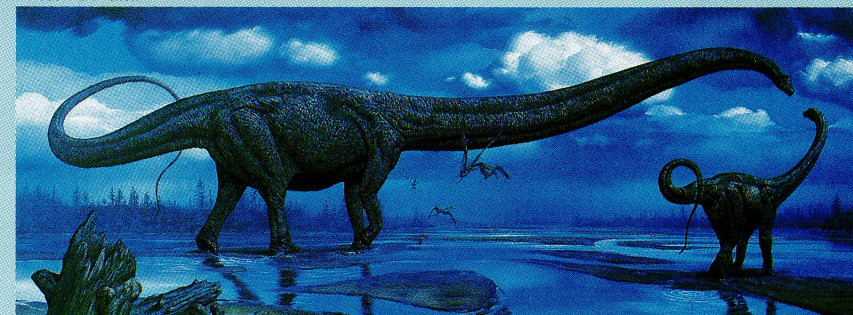
Because pressure increases with depth in any continuous fluid system, such as that in arteries, pressure in the legs of *Barosaurus* must have been greater than at heart level and could conceivably have reached 900 to 1,000mm Hg in the lower legs and feet. Such tremendous pressures pose serious dangers of tissue swelling due to excessive leakage of fluid from capillaries. Capillary pressures in the legs of *Barosaurus* were probably adjusted by muscular constriction of smaller arteries, which reduces downstream pressures. (Similar adjustments must have been required to regulate blood pressure in the brain whenever the head was lowered, for example, when the animal was drinking.) In giraffes, swelling is counteracted by the tight leg skin, which acts somewhat like support hose to raise pressures in underlying tissue fluids surrounding the capillaries and small vessels. The expansion of arteries can be partly counteracted by thickened, muscular walls. Other mechanisms that regulated the level of plasma proteins, rates of lymph flow, and placement of valves in veins might also have helped prevent swelling in the pillarlike legs of sauropods.

Finally, terrestrial sauropods would have required complex lungs, similar to those of living active reptiles or perhaps mammals. In all vertebrates studied so far, lung function depends on blood flow that is at uniformly low pressures (relative to the pressures in other parts of the animal). Sauropods, then, most likely had hearts capable of producing large differences in blood pressure between the lungs and other circuits of the body. This would have required either extreme modification of the resistance to blood flow somewhere between the heart and lungs or the evolution of a four-chambered heart as in crocodiles, birds, and mammals.

Perhaps no analogy with living animals will ever give us a true picture of exactly what was involved in such a monumental blood-delivery system as that of *Barosaurus* and its long-necked relatives. Nonetheless, paleophysiology can add to our understanding of the variety of animal designs possible, as well as evoke a richer picture of how the mammoth dinosaurs might have lived.

Harvey B. Lillywhite, a professor of zoology at the University of Florida at Gainesville, studies the physiology of snakes and other long-bodied animals.

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The longest-necked sauropod, Mamenchisaurus, crosses a mud flat.

Barosaurus on Central Park West

Old bones, shrewd deals, and engineering feats result in a new display at the American Museum

by Mark Norell, with Lowell W. Dingus and Eugene S. Gaffney

The time is about 150 million years ago; the place, a sparsely forested plain in an area that will one day become the arid mountains and deserts of western North America. A female *Barosaurus*, one of the largest animals ever to have walked the earth, and her offspring are peacefully feeding on plants. Suddenly, their foraging is cut short by the appearance of a hungry carnivore, *Allosaurus*. The lone hunter knows better than to attack the sixty-ton mother; pivoting, it rushes instead at the terrified baby. The young quarry attempts to hide behind its mother, dodging both her lashing tail and the *Allosaurus*'s deadly teeth and claws. In a final effort to protect her young, the *Barosaurus* rears up to a height of some fifty feet to fend off the attacker with her powerful forelegs or crush it under the weight of her immense body.

What is the sequel to this Jurassic drama? Maybe the giant *Barosaurus* mother is lucky and repels or kills the predator. Or perhaps the agile *Allosaurus* rips into the baby and proceeds to devour it as the mother flees in panic.

The effort to imagine dinosaurs as living organisms, facing challenges similar to those that confront animals today, was the inspiration for the new exhibit in the Theodore Roosevelt Memorial Hall, or Rotunda, of the American Museum of Natural History in New York. A mother *Barosaurus* towers above the Rotunda's floor, protecting her young from a predator. The dramatic and controversial pose gives viewers an idea of the dynamism that can reside in fossil relics. The effect produced by the most modern fabrication and fossil-mounting methods heightens both the romantic history and the grandeur of the fossils.

The story of how the *Barosaurus* came to the American Museum starts almost a hundred years ago. Much of the Museum's huge collection of dinosaur remains was assembled in the late 1800s and early 1900s, during what has been called the golden age of dinosaur exploration. When a mother lode of fossils began to emerge in the American West, the Museum and other natural history institutions in North America, competing openly to acquire ex-

tensive collections and discover new species, began a "bone rush."

Under the direction of Henry Fairfield Osborn, the first chairman of the Museum's Department of Vertebrate Paleontology, veteran bone hunters Walter Granger, Barnum Brown, and William Diller Matthew sent tons of fossils to New York. During the golden age, so much material was excavated that many specimens collected as long as a century ago still have not been thoroughly studied, prepared, or placed on public exhibition. Huge bones, some of them in their original wooden shipping cases, remain stored in the Museum's labyrinthine basement.

The dinosaurs in the Rotunda mount were found in the Morrison Formation, a fossil-rich rock unit stretching from New Mexico to Montana. This formation has yielded many remains of sauropods—the huge quadrupedal plant eaters, including *Barosaurus* and its relatives, that lived mainly in the Jurassic period, some 213 to 144 million years ago. *Barosaurus* is one of the rarest of all North American dinosaur fossils, and the adult and young on display are the only publicly exhibited specimens of these dinosaurs. The reconstructed adult, which is unusually complete for any dinosaur specimen known—80 percent of the material is original—is also the most complete specimen of a *Barosaurus* ever collected.

The adult was unearthed between 1912 and 1914 in what is now Dinosaur National Monument in Utah. It might have ended up as spare parts divided among three different institutions if not for the foresight and perseverance of Barnum Brown, the American Museum's foremost dinosaur collector.

About 1919, the heyday of collecting at this Utah site was drawing to a close when the principal excavator, Earl Douglass, of Pittsburgh's Carnegie Museum, discovered two remarkably well preserved sauropod skeletons. One of the skeletons went to the Smithsonian Institution, the other to the University of Utah. Later, when the University of Utah needed parts of a *Diplodocus* for a display, it traded a section of the *Barosaurus* tail to the Carnegie Museum for neck parts. The neck eventu-

Sauropod bones are embedded in rocks of the Morrison Formation in Dinosaur National Monument, Utah. A vast rock unit, the Morrison Formation is especially rich in sauropod fossils, many of which have not yet been excavated.

Willard Clay



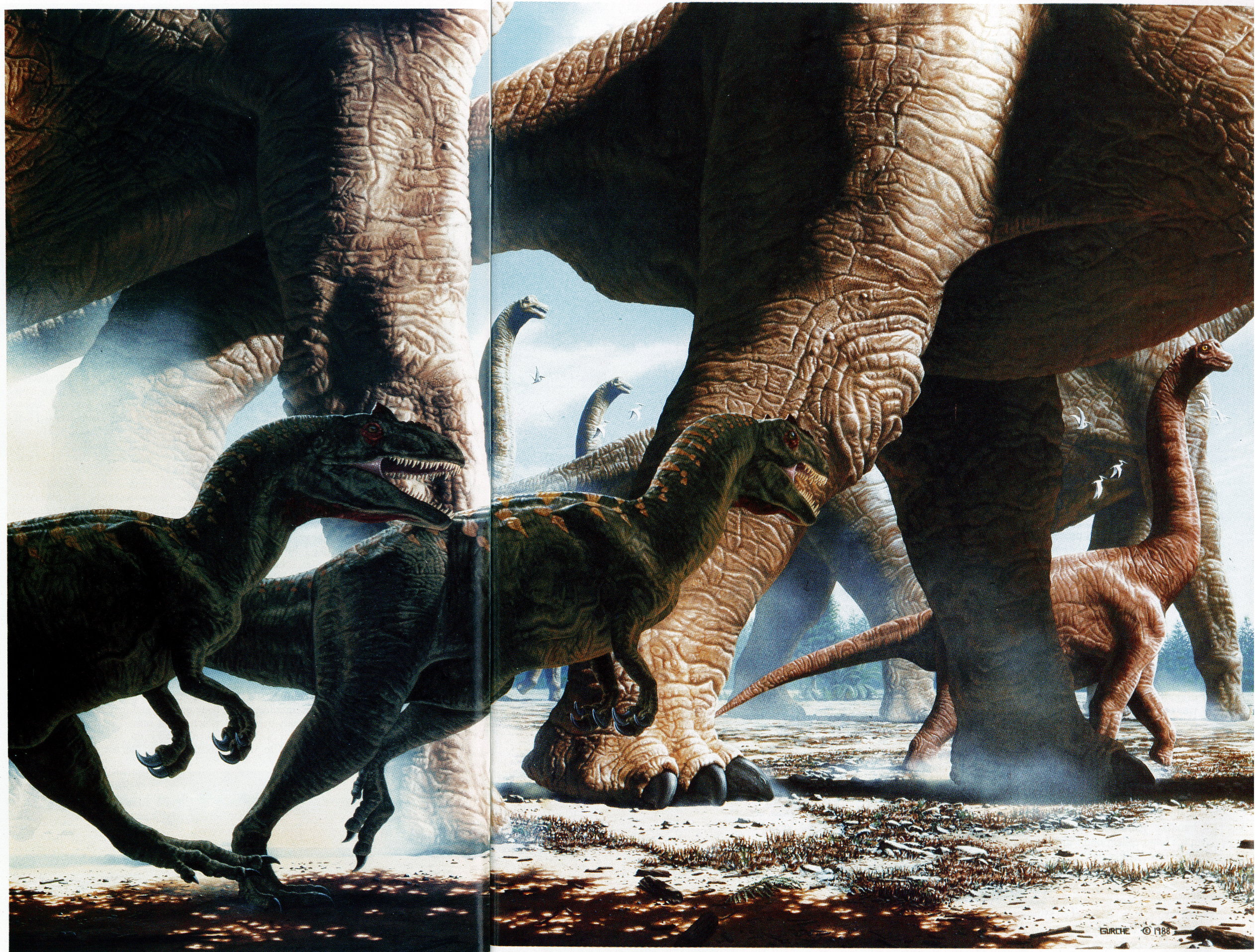
Two *Allosaurus* pursue a young *ultrasaur* buffered by the pillarlike legs of adults. *Sauropods*, like elephants, may have traveled with the vulnerable young in the middle of the herd.

© 1988 John Gurche

same size. If sauropods had mammalian levels of metabolism, they probably grew quickly to maturity and had life spans of fifty to one hundred years at most. If they had reptilian metabolic rates, life spans would conceivably have been measured in centuries. Arthur Dunham, of the University of Pennsylvania, and his colleagues argued against warmbloodedness, but they believe that all dinosaurs were reproductively mature by the age of twenty at the latest, otherwise survival rates of the young would have to have been impossibly high to maintain the population.

Did *Barosaurus* lay eggs? As far as we know, *all* dinosaurs laid eggs. But we really don't know very much. Eggs and nests have been found in association with very few kinds of dinosaurs. The largest dinosaur eggs known, from southern France, have the volume of two-liter soda bottles and have been attributed to a small sauropod, *Hypselosaurus*. We have absolutely no direct evidence yet of the size of the eggs of the great sauropods. Eggs of the extinct elephant bird from Madagascar have five times the volume of the supposed *Hypselosaurus* eggs, so presumably no physiological reason prevented the development of even larger dinosaur eggs.

I view sauropods as somewhat stately, slow-moving titans. Others will disagree. Far from the pinnacle of dinosaur success, they were, I believe, archaic herbivores. Their large sizes, small heads, simple teeth, and tiny brains served them well for millions of years. But in the Cretaceous, more progressive, large-headed, larger-brained dinosaurs appeared, and vegetation changed. The moist lowlands of the Late Cretaceous, some 70 million years ago, had fast-growing, weedy, flowering plants and deciduous trees of small stature. In the drier habitats of the Jurassic where the sauropods thrived, the dominant plants grew more slowly. The teeth of Cretaceous duck-billed and horned dinosaurs were far more complex than those of sauropods and processed the food of the new flowering plants far more efficiently than sauropods ever could. The old giants retreated to southern continents, where the newcomers did not flourish. Nonetheless, some kinds of sauropods straggled on to the close of the age of dinosaurs. Skeletons such as the Museum's towering *Barosaurus* give testimony to one of nature's grandest extravagances. □



FOSSIL HORSE TRADING

The following confidential memorandum from the archives of the American Museum of Natural History provides details on some of the exchanges that brought the widely dispersed Barosaurus skeleton to the American Museum:

REPORT ON BAROSAURUS

Supplementing my report of July 26, 1929. I again visited Salt Lake City in December and secured the following agreement from Dr. [Frederick J.] Pack who has authority from the President and Trustees of the University to act in their behalf in this negotiation.

Value of specimen agreed upon \$5000. Terms \$2,500 in cash, balance in trade.

Specimens desired by University of Utah: a three-toed horse skeleton (we can supply a composite skeleton), and other mammal material to make up difference. American Museum to box, ship and pay transportation charges on *Barosaurus*.

This agreement I consider fair with full value coming to the American Museum providing we can secure the remainder of this skeleton.

The part of this *Barosaurus* skeleton in the National Museum consists of the last ten cervical vertebrae with

ribs; three anterior dorsals; left scapula and humerus. It has cost \$3,400 to clean and restore it (Laboratory records).

[Charles W.] Gilmore (confidentially) favors an exchange and desires a free mountable skeleton of *Gorgosaurus*. Dr. [Alexander] Wetmore does not favor disposal of this *Barosaurus* neck (from conversation reported by Gilmore).

American Museum can offer the following specimen in exchange: *Gorgosaurus* No. 5434. Skull and jaws, all cervicals, and dorsal vertebrae, all ribs, forelimbs, one femur. Sacrum, hind limbs, except one femur, will be cast.

Cost of preparing and casting hind limbs and part of tail \$4,123. To finish tail and sacrum \$450.—total cost \$4,573. (Cost taken from Laboratory time sheets and exclusive of collecting and transportation charges).

The caudal series of this skeleton nine or ten vertebrae in the Carnegie Museum are preserved in two blocks, 348/A and 349/B according to their quarry charts.

So far no negotiations have been undertaken to secure this part of the specimen.

A.M.N.H.
Dec. 31, 1929

Barnum Brown

AMNH



Bone collector Barnum Brown and his wife, Lilian, at Howe Quarry in 1934

ally proved to belong not to a *Diplodocus* but to a *Barosaurus*.

As a result, the bones of the rare *Barosaurus* were dispersed to three different institutions. Barnum Brown, recognizing the skeleton's importance, came up with a plan to unite the bones in New York, even though the American Museum owned none of the material and had not even participated in its excavation and preparation. In 1929, Brown negotiated with the three institutions in an effort to consolidate the specimen in New York. According to some of his original correspondence, the deal called for a combination of fossil trades and cash payments between the American Museum, the Carnegie, the University of Utah, and the Smithsonian. In the end, Brown's bargaining helped the American Museum acquire the bones for far less than it would have cost to collect them in the field.

The Roosevelt Rotunda mount reflects the legacy of many early paleontologists and the efforts of contemporary scientists and fossil preparators. During our lunches here at the American Museum, Gene Gaffney, Lowell Dingus, and I—members of the Department of Vertebrate Paleontology—developed the idea of mounting a sauropod on its hind legs. The first drawings were blurry sketches made on damp napkins. In the beginning, none of us really believed that our wishful speculation would eventually lead to the reconstruction in the Rotunda.

After developing a preliminary design, we got to work. All the original bones, stored in the collection for sixty years, had to be cleaned and repaired. Many of their glue joints had cracked, and some of the pieces were scattered. Only about a fifth of the skeleton was missing, but each of these pieces, including the skull, several limb bones, and part of the tail, had to be modeled to complete the skeleton.

The replacement parts were modeled in Toronto, Canada, by Research Casting International, an organization that specializes in fabricating and mounting dinosaur casts. Under the direction of Peter May, the technicians at Research Casting sculpted each individual missing bone in clay, basing the shapes on the remains of more completely known close relatives of *Barosaurus*, in particular, its contemporary *Diplodocus*. According to John S. McIntosh of Wesleyan University, the premier scholar of sauropod relationships, this better-known Jurassic sauropod so closely resembles *Barosaurus* that many partial skeletons and isolated bones long considered by paleontologists to be the remains of the rather common *Diplodocus* may actually belong to *Barosaurus*.



The Museum's adult *Barosaurus* was fabricated bone by bone by the technicians of Research Casting International in Toronto, Canada. Molds of each bone were cast, top, and then mounted, below.

Photographs by Paul von Baich



The weight of the original *Barosaurus* bones—a single vertebra weighs up to 200 pounds—would have made mounting the actual fossils impossible without thick structural supports. In addition, the pose of the adult *Barosaurus* in its rearing stance of fifty feet above the Rotunda floor demanded the lightest of materials. So, after the modelers had sculpted the missing elements, they made a duplicate of the *Barosaurus* bones by coating them with latex, which, when cured, formed a rubber mold. These molds were cast with polyurethane foam to provide sturdy but light replicas of the original fossils. Those that would stand near the ground were cast in higher-density and more durable materials, while those higher up were made of lighter substances. The weight of the neck vertebrae seems to have been a functional consideration even for the living *Barosaurus*. The sauropod solution was the development of large pleurocoels, or air spaces, in the vertebrae, which lightened the bones without compromising strength. The extreme complexity of these vertebrae made them the most difficult part of the skeleton to mold and cast.

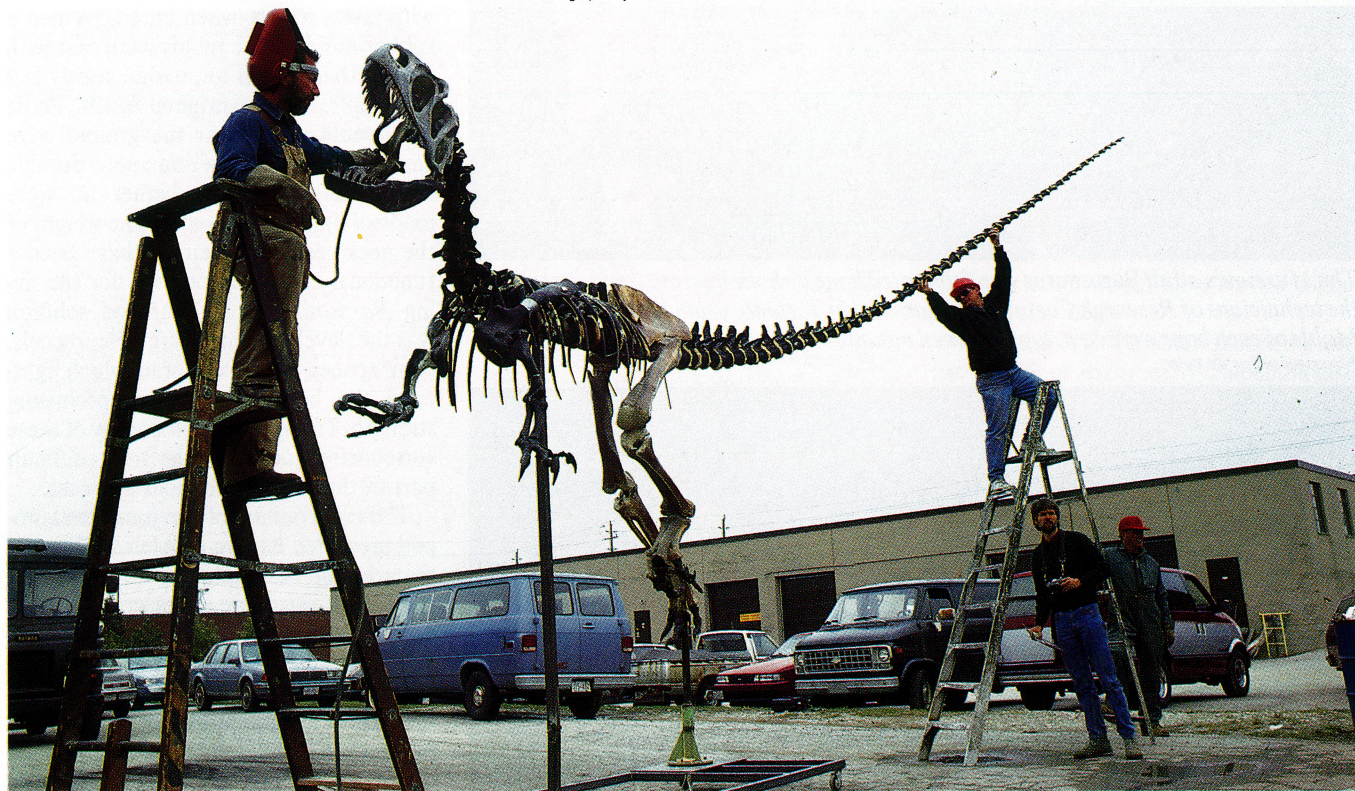
The construction of the juvenile sauropod presented its own problems. The only material in our collection consisted of some neck vertebrae and a crushed skull collected at Howe Quarry in north-central Wyoming. Discovered and excavated by Barnum Brown, Howe Quarry was one of the richest accumulations of dinosaur remains ever found. Unfortunately, most of the material found was disarticulated, lying in a large jumble of bones, so determining what bones belonged to what animal was problematic.

Because the juvenile *Barosaurus* is so fragmentary, most of the body needed to be sculpted in clay and then cast. Bone shapes and proportions were determined from more complete skeletons of closely related species. However, juvenile and baby animals are not just miniature adults; many of the differences that distinguish an adult *Barosaurus* from an adult *Diplodocus* may not be apparent in the young. In the process of growth, bones change not only in size but also in shape and in relation to other bones in the skeleton, much as puppies' bodies grow at a relatively faster rate than their paws. Structural transformations, such as the appearance of antlers in adult deer, may also arise at various points. To reconstruct the skeleton of the young *Barosaurus*, we have attempted to use what little information we have concerning the body proportions and anatomical structure of these animals.

The third animal in the grouping, the

After sections of the bodies of the dinosaurs were mounted, technicians, engineers, and paleontologists moved their shop to an empty parking lot to piece together the entire skeletons. The darting *Allosaurus*, below, was eventually balanced by steel strung from one ankle. A few vital vertebrae still missing, the adult *Barosaurus* rears next to a cherry picker, right.

Photographs by Paul von Balch



sprinting *Allosaurus*, was the easiest to fabricate. Thanks to the discovery of a remarkable deposit, the Cleveland-Lloyd Quarry in central Utah, almost every bone in the skeleton is known. During the thirty years that it has been excavated by Jim Madsen, of the University of Utah, the quarry has produced the remains of scores of *Allosaurus* individuals of different size classes. Some paleontologists suspect that this *Allosaurus* graveyard is a remnant of a particularly dangerous river crossing or quicksand deposit that entrapped the agile carnivores.

Mounting the *Allosaurus* in its dynamic running posture was a more difficult task. Special steel, chosen in consultation with a structural engineer, was needed to create the armature, or supports. The steel at the ankle of the *Allosaurus* had to be strong so as to support the animal at an extreme angle from only a single point. The armature along the spine and the tail needed to be light but rigid. The finished product is an almost invisible framework strong enough to sup-

port fifty pounds hung from the tip of the tail with no deflection.

Finally, we had to choose what kind of base to mount the animals on. Because we do not know exactly what kind of terrain this battle may have been played out on 150 million years ago, we opted for a purely aesthetic choice. What better than a replica of actual fossil-producing rocks? During the summer of 1991, Gene Gaffney and Peter May located a likely site, a small hillock in the Paleocene Tullock Formation in eastern Montana. Moving a fragile clay section of land this size would have been a monumental effort, so a thin layer of latex rubber was sprayed over the terrain to form a large sheet mold. The mold was then sent to the shop of Research Casting International in Toronto, where it was cast and painted. This exact replica of a small piece of the Montana prairie now forms the base of the New York exhibit.

Probably the most controversial aspect of our mount is the pose of the dinosaurs themselves. Was *Barosaurus* capable of

standing on its hind legs? Would it have protected its young in this fashion? And would the *Allosaurus* have launched such an attack? Although much has been written recently about the behavior and capabilities of these Mesozoic giants, little actual evidence regarding their behavior and physical limitations can be determined from the bones themselves. While issues such as the diet, color, physiology, and behavior of various dinosaurs hold great appeal, any pronouncements on the habits of animals that went extinct more than 66 million years ago are highly speculative. Rigorous scientific tests of many current theories are not possible within the context of the available evidence—the fossils. So, while scenes like ours may seem spectacular and seductive, beware! They represent only one of the many possible scenarios that may have occurred 150 million years ago. Because they have long vanished from the earth, leaving no close living relatives that we can observe in the wild, the giant sauropods will always retain much of their mystery. □

