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their natural environment. I do not think this happened. Some of the animals never spent the winter in their natural habitat, yet they showed the hibernation pattern typical of the population. These animals were the ones from each population which were caught at the end of the summer, when they were only a few months old. The similarity in fattening and torpor patterns of the inexperienced and the experienced animals suggests that it was indeed genetic differences between the populations that caused the hibernation differences in the laboratory.

Differences between populations of a species, such as these in the Golden-mantled Ground Squirrels, are examples of evolutionary changes that can take place. The two populations of ground squirrels are descended from a common ancestor, but in the process of descent, the genetic make-up of one, or more likely of both, populations has been altered. The result is that today there are genetic differences between the Gothic and the Lost Lake ground squirrels. These differences came about through natural selection as the ancestors of these ground squirrels moved into various localities and as the climates of these localities changed. The result of the selection was that each population became best adapted to its own distinctive environment. The ground squirrels at Gothic are now better adapted to surviving long winters than are the Lost Lake ground squirrels. Evolutionary changes which eventually result in new groups of plants or animals can start in just this way, through the small genetic changes which adapt the population to small changes in the environment.

The Superiority of Dinosaurs

by *Robert T. Bakker*

A new emphasis is permeating the science of paleontology. For more than a century paleontologists have been discovering fossils, describing them, and attempting to show how one ancient organism is related to another. Once a reasonable family tree had been sketched for a particular group, the classical student of ancient life usually considered his examination finished and went on to the family tree of some other group. In contrast, today it is the reconstruction of the details of the lives of extinct animals — what they ate, how they reproduced, how they defended themselves — that is capturing the interest of more and more paleontologists.

Usually only the hard parts (bones and teeth) of vertebrate animals are preserved as fossils. However, muscles, tendons, nerves and blood vessels, and occasionally other soft organs and tissues, leave marks on the surfaces of bones. Detailed analyses of the anatomy of various living vertebrates reveal how these soft organs affect bone surfaces. From this it is possible to interpret the marks preserved on fossil bones. From these interpretations it is possible to infer something about the activity, physiology, and even the behavior of animals that are known only from fossilized bones.

This new approach to studying fossil vertebrates is producing some evidence that challenges many of the theories about the habits and ecology of one of the most popular groups of extinct animals, the dinosaurs. These great beasts were reptiles whose closest living relatives are the modern crocodilians. Generally, paleontologists have assumed that in the everyday details of life, dinosaurs were merely overgrown alligators or lizards. Crocodilians and lizards spend much of their time in inactivity, sunning themselves on a convenient rock or log, and, compared to modern mammals, most modern reptiles are slow and sluggish. Hence the usual reconstruction of a dinosaur such as *Brontosaurus* is as a mountain of scaly flesh which moved around only slowly and infrequently.

Dinosaurs vs. Mammal-like Reptiles

This classical view of dinosaurs presents a perplexing problem. The group of vertebrates which dominated the land before the rise of the dinosaurs were the synapsids, the mammal-like reptiles (see Hopson's article on this group in *Discovery,* vol. 2, no. 2). During their 100-million-year history the synapsids evolved from a few early, very primitive reptiles into many highly specialized herbivorous and carnivorous types. Most paleontologists have believed that the locomotion and physiology of these mammal-like synapsids were more similar to those of active, warm-blooded mammals than to sluggish modern lizards or alligators.

Surprisingly, though, when the first dinosaurs and their near relatives appeared in the Triassic period (Figure 1), the synapsids began to decline and soon became extinct. The dinosaurs then ruled the land unchallenged for over 100 million years while the early mammals, the surviving descendants of the synapsids, remained very small in size and number. Only after the dinosaurs suddenly disappeared about 70 million years ago did the mammals develop into the great variety of dominant land vertebrates we have today. The problem is this: if the later synapsids were such splendidly advanced

DISCOVERY 3 (2). Spring 1968.

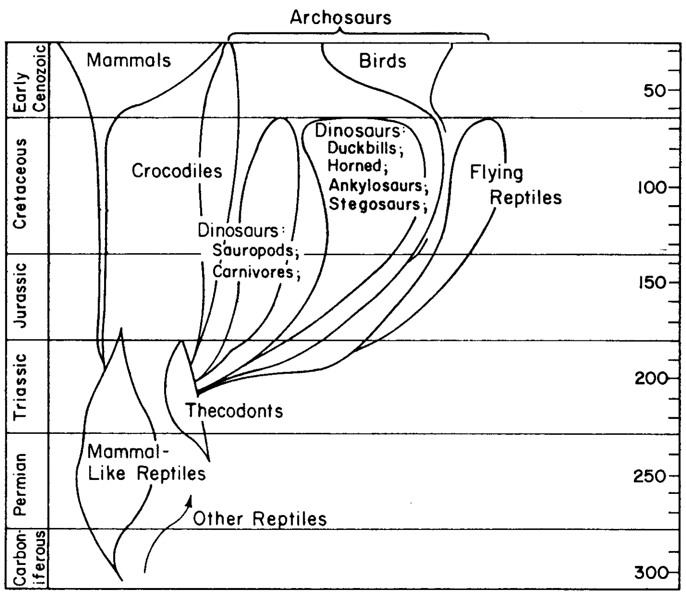


Fig. 1. Relationship of dinosaurs and their relatives to the mammal-like reptiles and early mammals. Numbers at right indicate millions of years before present. Names at left are the periods of earth history. Note that the mammal-like reptiles became extinct as dinosaurs and other archosaurs appeared, and that the true mammals did not expand until after the dinosaurs' extinction.

animals with the improved physiology of mammals, and if dinosaurs were slow and sluggish, why were the mammal-like synapsids exterminated in competition with the first dinosaurs? And why didn't the mammals achieve a more significant diversification during the dinosaurs' reign? To answer these questions, we must consider the physiology, anatomy, and ecology of dinosaurs.

Posture

One of the most significant clues to the level of activity that can be attained by a vertebrate is its posture. Modern birds and mammals are very active animals, and nearly all living birds and mammals have an erect posture with the limbs held vertically, straight under the body (Figure 2B). In contrast, lizards and salamanders have a sprawling gait and posture with the thigh and upper arm bone held sideways, horizontally, out from the body (Figure 2A). These sprawling vertebrates are relatively slow and inactive.

Dinosaurs and birds are quite closely related, and paleontologists long have recognized that the hind limbs of dinosaurs were held in an erect, bird-like posture. However, the dinosaurian forelimb almost invariably has been restored in a lizard-like position with the upper arm bone (the humerus) sticking out sideways. The resulting restorations of dinosaurs, as seen in most museums and textbooks, is very peculiar: the hindquarters are held high like those of mammals, but the forelimbs are sprawled close to the ground (Figure 3). This

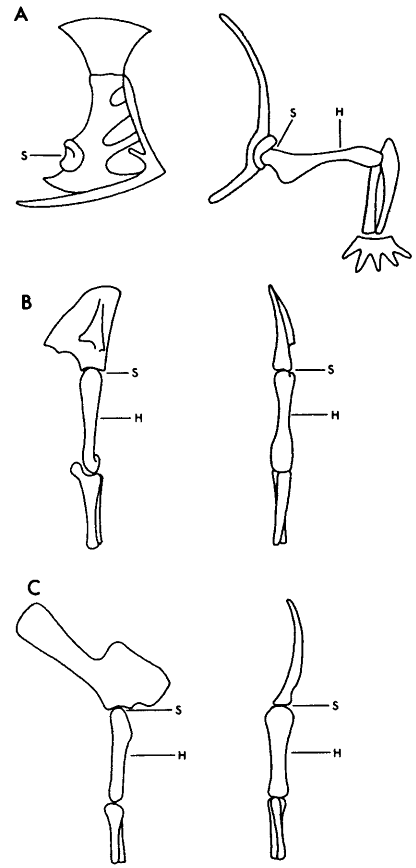


Fig. 2. Comparison of sprawling and erect forelimbs. Left: side views of right shoulder bones and forelimb. Right: rear views of same. A) lizard B) elephant C) sauropod dinosaur. Humerus (upper arm bone) and forearm omitted in side view of lizard. Note that in erect limbs the shoulder socket faces downward; in sprawling limbs it faces sideways. H = humerus; S = shoulder socket.

uniquely awkward posture resembles more than anything else a man cheating at push-ups. The impression one gets from mounted skeletons and drawings is that dinosaurs must have been very clumsy.

For the last two years I have been studying the anatomy and mechanics of the forelimbs of living vertebrates and trying to interpret the forelimb movements of fossil forms, especially dinosaurs, mammal-like reptiles and early reptiles. The evidence from the limb bones and the inferred muscle and joint action strongly suggests that the accepted restorations of dinosaurian posture are incorrect. In lizards and other sprawling animals which hold the humerus horizontally, the shoulder socket faces mostly outward from the side of the body (Figure 2A). In mammals which have a vertically-held humerus the shoulder-socket faces downward. The dinosaur shoulder joint was 100% mammal-like in functional arrangement — the socket faced downward, and very little if at all backward or sideways (Figure 2C). Consequently, these extinct reptiles must have had a posture fully as erect and graceful as that of a mammal, both fore and aft.

A great many striking similarities between dinosaurs and mammals are evident in the forelimb; at every joint — shoulder, wrist, and elbow — the dinosaurian forelimb was perfectly adapted to an efficient, erect posture and gait totally unlike that of modern lizards. For example, mammals have a muscle (the teres) running from the posterior edge of the shoulder blade to the humerus. This muscle is very important in the backward swing of the arm. The teres is hardly ever developed in lizards, but the marks left on the forelimb bones of dinosaurs indicate that the teres was an exceptionally powerful part of the locomotory musculature. Thus the evidence for dinosaurian locomotion suggests that these great Mesozoic reptiles were much more active than most scientists have believed.

The Dinosaur Heart

The surviving next-of-kin of the dinosaurs, the birds and crocodiles, give us a few more bits of information for inter-

Fig. 3. Posture of a horned dinosaur, *Chasmosaurus belli,* as usually restored in museums and textbooks. The hindlimbs are erect, but the forelimbs are sprawling. Drawing made from a model by L.S. Russell. Compare with cover picture and with Figure 7.

preting dinosaurian physiology, especially the circulatory system. Birds have a very efficient, four-chambered heart. The three-chambered variety common to lizards, snakes, and turtles is far less sophisticated and advanced. Since mammals also have a four-chambered heart, we can say that this feature is probably vital to a high level of activity. Alone among modern reptiles, the crocodiles have a four-chambered heart, although it is not nearly as refined as that of birds. Secondly, the posture of crocodilians is somewhat more erect than that of other living reptiles. Thus in two areas—circulation and locomotion—crocodiles show the beginnings of improvements which characterize the active vertebrates, birds and mammals.

The immediate ancestors of dinosaurs were the extinct thecodont reptiles, and some early thecodonts had skeletons very similar to those of living alligators and crocodiles. In many thecodonts the limb structure shows that a more erect posture was being acquired just as in the crocodilians and some probably were bipeds. We can conclude that probably in these thecodonts the heart was also becoming improved in a crocodile-like manner. As described above, dinosaurs had a fully erect posture. Indeed, in all the details of their skeletons, dinosaurs were far more advanced than either thecodonts or crocodiles, and I believe that the dinosaurian circulatory system must have been refined far beyond the crocodilian level. Dinosaurs may well have had four-chambered hearts fully as efficient as those of birds and mammals.

Flight demands a very high level of continuous activity. The great group of reptiles to which the dinosaurs belong, the Archosauria, produced two separate groups of flying vertebrates—the birds and the flying reptiles, the pterosaurs. The evolution of these two groups from archosaurian ancestors is another indication of the physiological level attained by the archosaurs, including the dinosaurs.

Thus, although much work remains to be done on dinosaur functional anatomy, the mammal-like posture has convinced me that these rulers of the Mesozoic were fast, agile, energetic creatures that lived at a high physiological level reached elsewhere among land vertebrates only by the later, advanced mammals.

The Largest Dinosaurs: The Sauropods

Having considered the evidence for interpreting the physiology of dinosaurs and advanced archosaurs in general, we now can take a look at the ecology of two of the kinds of dinosaurs: first, the sauropods. *Brontosaurus* and *Barosaurus* (Figure 4) are typical of the huge, long-necked, longtailed sauropods which were very common throughout the Jurassic and Cretaceous. Up until the present these dinosaurs, the largest of land vertebrates, have been pictured as slow-moving swamp dwellers which fed on masses of soft water vegetation. The evidence cited for these habits is the following: sauropods had "weak" teeth; their nostrils indicated aquatic habits; and their limbs were probably not strong enough to support their great weight on land for long periods. All of this evidence is very shaky.

Strong Teeth

First of all, sauropod teeth were not weak. These dinosaurs had teeth only at the front of the jaws for plucking off vegetation, and thus sauropod teeth were the functional equivalent of the incisors of mammals. The incisors of deer and horses are strong enough to pull up grass or break branchlets off trees, and yet are tiny compared to the teeth of sauropods. Although sauropods did not have any grinding, molar-like teeth, the mechanical breakdown of the food may have been

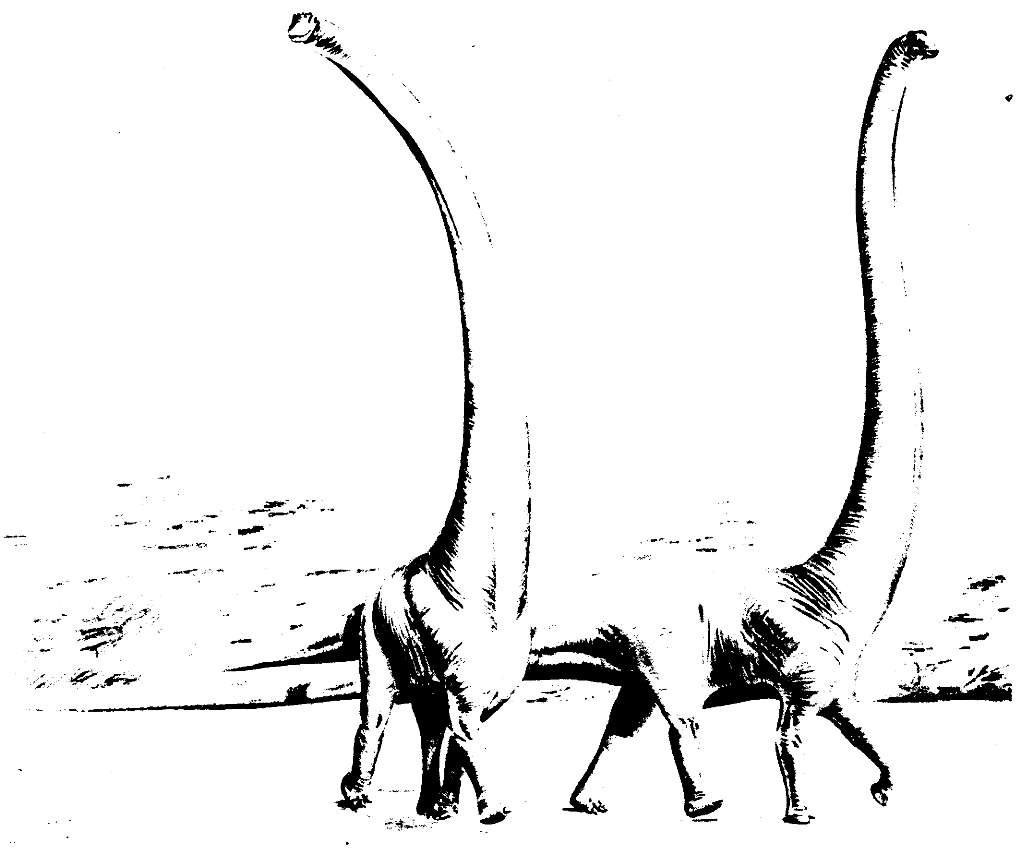


Fig. 4. Restoration of the longest-necked sauropod, *Barosaurus.* Length of this animal was about 85 feet, height about 40 feet. Restoration by author.

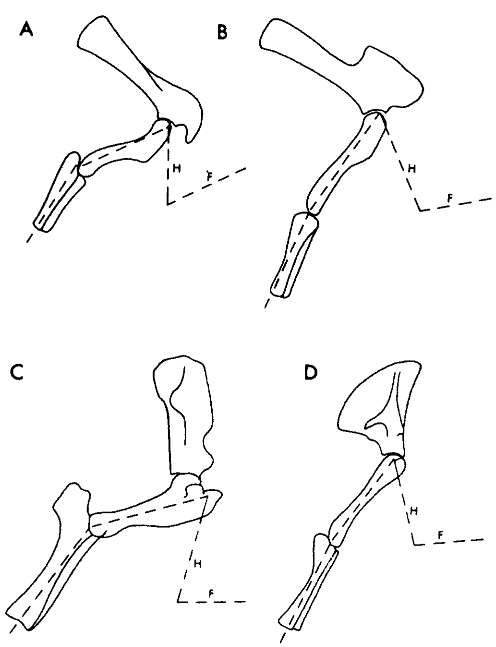


Fig. 5. Galloping (left) and ambling (right) limbs. Side views of right shoulder and arm bones, with humerus swung fully back and forearm straight. H = axis of humerus swung fully forward; F = axis of forearm fully flexed. A) horned and B) sauropod dinosaurs; C) rhinoceros; D) elephant.

carried out somewhere in the digestive system, perhaps in a gizzard like that of certain birds. Modern crocodiles have powerfully muscled stomach walls capable of violent contractions. Masses of pebbles swallowed and emplaced along the stomach walls apparently help crocodiles to tear food apart. A skeleton of a small herbivorous dinosaur, *Psittacosaurus,* was found with over a hundred pebbles in the rib cage, indicating a stomach system something like that of crocodilians. Stomach stones, usually called gastroliths, have also been found in or near sauropod skeletons; these archosaurs may have had some mechanical breakdown of food in the stomach.

Secondly, some of the sauropods have nostrils in an unusual position. Many modern and extinct aquatic vertebrates had nostrils high up on the skull, near the eyes. *Diplodocus* and some other sauropods have nostrils similarly placed, but such a position is not necessarily indicative of aquatic habits. Crocodiles, for instance, are aquatic but have their nostrils at the end of the snout. On the other hand, some living mammals (elephants and tapirs) and some fossil genera (*Macrauchenia* and its kin) have high nostrils, but otherwise are adapted to a fully terrestrial life. The functional significance of the position of the nostrils in *Diplodocus*-like sauropods is not yet clear, but this feature alone cannot prove aquatic habits.

Thirdly, the sauropod limbs were very finely adapted to a fully terrestrial existence. Among the modern mammals with the advanced, erect gait, two different functional types of limbs can be found: a fast-acting type permitting galloping and great speed; and a slow-acting, ambling type giving less speed but more efficient in supporting heavy weight (Figure 5). The chief difference between the two types is that during locomotion in the slow-acting, ambling type, the upper arm bone swings farther forward and less backward, the forearm flexes less, and the whole limb is held straighter than in the fast-acting type. Advanced thecodonts and all the earlier dinosaurs had limbs constructed for fast galloping. However, in the sauropods the limbs became modified for slow-acting, ambling locomotion and became very elephant-like. Some of the similarities between elephant limbs and those of sauropods are incredibly detailed. Obviously this type of limb evolved to carry a very heavy animal over firm, hard ground.

Not only the limbs, but the whole body configuration of these great dinosaurs is totally unlike that of aquatic herbivores. Modern hippos have short legs, short necks, and wide, barrel-shaped bodies. The Indian rhinoceros frequents ponds and swamps, and rhinos in general are rather squat and short legged. Some extinct rhinos had very hippo-like configurations and were probably even more aquatic. Even the water-loving carnivores and insectivores, represented today by many different types, have an otter-like body shape—short legs and round bodies. In very sharp contrast, sauropods had short bodies with usually quite long legs and deep, slab-sided chests (Figure 6). The back muscles and ligaments of sauropods were extremely strong. Elephants have a body shape much like that of sauropods—relatively long legs, and short, deep bodies.

Long Necks

In addition, sauropods had a feature never associated with a swamp-dwelling, herbivorous mammal or reptile—a very long neck. The hippo can browse along the bottom of a swamp by simply submerging; a long neck is unnecessary. On the other hand, long-necked mammals invariably are adapted to browsing high in the shrubbery and tree tops. Such adaptations can be highly advantageous, since long-necked animals can reach food supplies unavailable to other herbivores. The modern giraffe is a good example of this configuration, and the giraffe-like shape has evolved a number of times among mammals. Several fossil camels were very long-legged and long-necked. The largest land mammal ever to have lived, *Baluchitherium,* was a huge, long-legged, long-necked browsing rhinoceros. Very probably the ability to browse high in the trees was a major factor in the evolution of this giant mammal. Likewise, elephants have the functional equivalent of a long neck, since with their trunk they can reach very high up into the foliage and pluck vegetation. Thus modern elephants always have a greater vertical range of food to choose from than nearly all other mammals. In times of drought, when the underbrush dries out, this advantage can be critical. The great reach of the trunk was probably signficant in the success of the elephant family. Sauropod necks were extremely long — *Barosaurus* and *Brachiosaurus* could browse at the 40 foot level—and a greater vertical choice of food probably gave these dinosaurs advantages which contributed to the great success the group enjoyed.

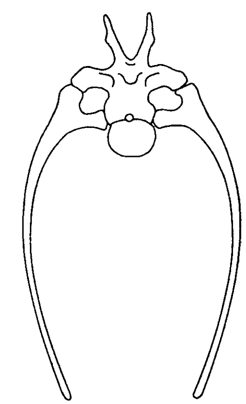


Fig. 6. Front view of vertebra and ribs of the sauropod *Diplodocus* (redrawn from W. Holland). Note that the chest is deep.

Environment

The plant fossils from the sauropod-containing rocks definitely refute the swamp theory. Sauropods are most common in the Morrison Formation of western America, Late Jurassic in age. In this formation no recognizable swamp deposits are known, and the plant fossils almost invariably represent terrestrial conifer trees and cycads. Today paleobotanists who are well acquainted with the Morrison flora believe that it represents not a swamp or even a lush, tropical jungle, but rather an open upland, with conifers and a low, rich undergrowth of ferns and cycads. Very significantly, the commonest trees are conifers which often bore leaves only at the top of a tall trunk; thus these leaves would be available only to sauropods.

In contrast to uplands, swamps are poor places for large herbivores. First of all, swamps produce far less weight of fodder per acre per year than plains or forests. Secondly, the unsure footing of swamps is dangerous; elephants, especially juveniles, sometimes get mired and die of starvation. Only a few modern large vertebrate herbivores are specifically adapted to swamps—the hippos and the Sitatunga Antelope are the best examples—and even rodents are far less common in soggy ground than in the woods or on the plains.

Defense

Many writers have thought that sauropods fled to the swamps to escape from carnivores. However, the contemporary carnivorous dinosaurs, such as *Allosaurus,* probably could swim better than the sauropods. Although stiff toward the end, the long, powerful tails of these carnivores were flexible enough at the base to permit the whole tail to be swung as a skulling organ. Moreover, although the toes were not webbed, the hind limbs and feet were very large in proportion to the body and probably could give very powerful and effective kicks for swimming. If a sauropod did enter water to escape big allosaurs, the predator probably swam right in after it to make the kill, much as a pack of hyenas will drive a gnu into a river where they will kill it.

For defense, the sauropods could swing their tails like enormous whips. Modern crocodiles and long-tailed lizards use their caudal appendages defensively, and the huge muscular processes on the anterior tail vertebra of sauropods shows that this tail was enormously powerful in these dinosaurs. In some sauropods *(Brontosaurus, Diplodocus)* the tail ended in a very long, slender whiplash. A blow from the tail of a ten-foot-long crocodile can lift an adult man completely off his feet; the tail of a 90 foot-long sauropod probably could break a leg or fracture the skull of a contemporary carnivore like *Allosaurus.*

In addition, sauropods probably could rear up on their hind limbs to strike out with their forefeet or come crashing down to crush an attacker. Most modern mammals including the elephant can rear up even though the fore limb normally supports more weight then the hind. In the fossil trackways of sauropods, the hind prints were twice the size of the fore, so that the hind feet must have normally supported two-thirds of the total body weight. Thus the sauropod must have been able to shift all the weight to the hind limbs fairly easily. Of course such a posture would have enabled the animal to browse even higher among the trees, as well as to defend itself.

Although illustrations usually show sauropods dragging their tails behind them, the fossil trackways of dinosaurs almost never show any trace of tail marks. Since in a closely packed herd a 30-foot-long tail would have been stepped on frequently if the owner dragged it along, sauropods probably held their tails high off the ground. The pelvic-tail musculature was certainly powerful enough to hold up this appendage (Figure 4).

Ecological Force

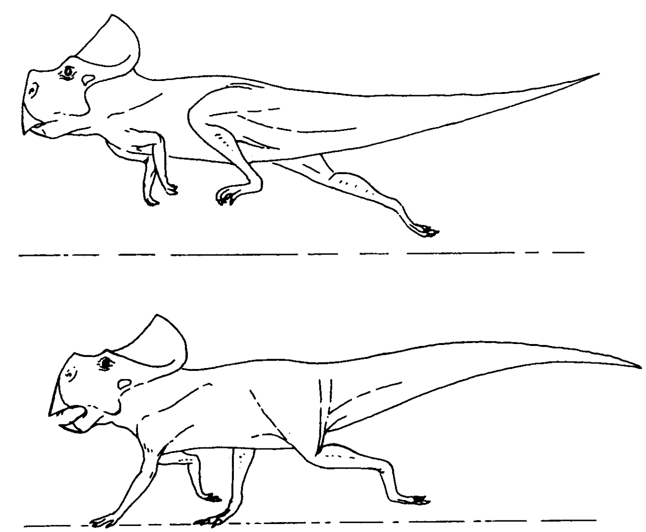
The big sauropods must have been a tremendous ecological force. Uprooting undergrowth and breaking down trees to get at the soft, edible inner bark, herds of modern elephants in Africa can quickly change a forest into an open savannah woodland. The African elephant is obviously a key agent in checking the spread of thick forests across the continent. Today, only one species of elephant roams Africa; during Morrison times no less than six distinctly different genera of sauropods were alive in Colorado, Wyoming, and Montana: *Barosaurus, Brachiosaurus, Brontosaurus, Camarasaurus, Diplodocus,* and *Haplocanthosaurus,* and up to five of these have been found in a single quarry.

The weight of a large individual sauropod probably ranged from 20 to 60 tons depending on the genus, compared to 5 tons for a large African elephant. The trackway evidence indicates that sauropods traveled in herds, and the amount of fodder that must have been consumed by the combined herds of all six sauropods is almost beyond imagination. When leaves were scarce these dinosaurs probably used their feet, armed with stout claws, to tear into the edible portions of tree trunks. Only a very productive woodland could support such a great population of herbivores. The herds of sauropods must have been constantly on the move as they thinned out the forests and underbrush.

Social Behavior

It might seem too much to hope for evidence about sauropod social behavior and yet a unique fossil trackway gives us just such information. First of all we must note that the young of modern crocodiles and lizards generally live in environments different than those of the adults. Adult reptiles have no concern for their young. They compete with them for food, and often display cannibalistic tendencies towards bite-sized juveniles. In contrast, in most modern birds and mammals the whole clan, herd, or flock looks after the youngsters, at least to some extent.

Fig. 7. The early horned dinosaur, *Protoceratops,* from Mongolia, about six feet long. Above: running bipedally at full speed. Below: trotting in a quadrupedal gait.



At Davenport Ranch in Texas, preserved in rocks of Early Cretaceous Age (about 120 million years old) is a field of trackways left by thirty brontosaur-like dinosaurs traveling together. However, these animals were not merely a disorganized mob of reptiles, but rather they were socially arranged in what appears to have been a true herd. The very largest footprints were made only at the periphery of the herd; the very smallest were made only in the center of the herd. It appears that the fully grown, powerful males were the lookouts and escorts for the whole group, while the youngest and most vulnerable juveniles were sheltered in the center of the herd. Such social structure is unknown in modern reptiles, but is very common among the great herding mammals of the African, Asian, and American plains. The survival value of such a structured herd is great, since the newly born and immature individuals, usually easy marks for predators, are guarded by the fully developed and strongest members of the group.

Horned Dinosaurs

The second type of dinosaurs whose ecology we will discuss here are the ceratopsians, the horned dinosaurs. They were the last dinosaur group to appear—their whole evolution is restricted to the latter part of the Cretaceous period. The earliest genera, such as *Protoceratops* from Mongolia, were rather small dinosaurs, only about five or six feet long (Figure 7). The front and hind limbs of these early horned dinosaurs were adapted to galloping, and since the hind limbs were much larger than the fore, *Protoceratops* and its near relatives probably could run bipedally when they were traveling at full speed. The ceratopsian limb joints indicate that the humerus swung as in a rhino—not as in an elephant—and the amount of forearm movement was rhino-like.

The tail of *Protoceratops*-like horned dinosaurs was quite long, very broad and heavy, and probably counterbalanced the large head when these reptiles moved on their hind limbs alone. Although these animals were probably completely herbivorous, the front of the jaws was modified into a deep beak which probably was an excellent defensive weapon as well as an organ for plucking plant food. The early ceratopsians were practically hornless. Although probably built for more speed than most herbivorous dinosaurs, the little ceratopsians almost certainly were far slower than the strictly bipedal carnivorous dinosaurs. For defense the protoceratopsians may well have acted much like the modern wild boars and peccaries which often charge their enemies and slash with their tusks. Thus, when sight or smell revealed that a predator was stalking, the small horned dinosaurs may have charged into the carnivore, snapping with their powerful beaks to rattle the enemy and break up the assault before it started.

Many of the later ceratopsians grew to very large size. *Chasmosaurus* (see cover) was as large as a modern rhinoceros, and *Torosaurus* (Figure 8) and *Triceratops* may have reached lengths of up to 30 feet and weights approaching ten tons. However, the limbs of even the largest ceratopsians were built for very fast, quadrupedal galloping. The retention by these dinosaurs of the galloping habit probably was related to a bellicose defensive behavior. Unlike *Protoceratops*, the later ceratopsians were armed with long horns in various patterns on the head. In reconstructions these horns usually are shown too short. The bony horn cores of ceratopsians were very similar to those of bison and other heavy bovids. In bovids the horny cover sheathing the core is often twice the length of the core itself and also makes a very slender, sharp point.

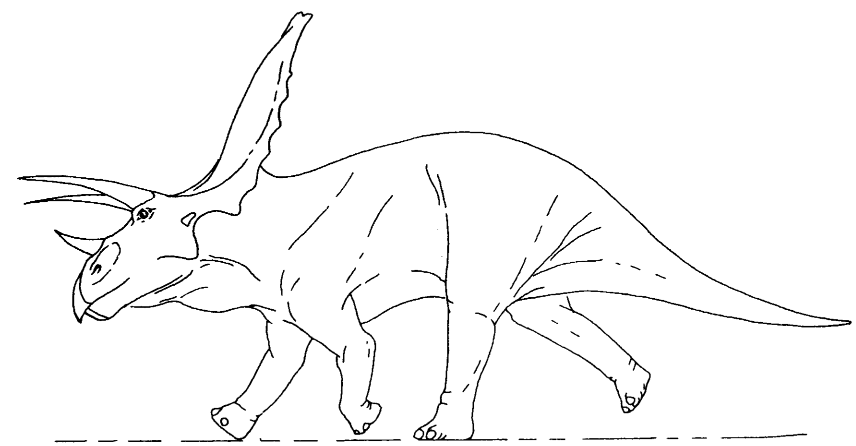


Fig. 8. One of the last horned dinosaurs, *Torosaurus*, about 30 feet long.

The joint between the neck and the skull of horned dinosaurs was a ball-and-socket articulation permitting the animals to move their huge heads very quickly in any direction. Armed with long horns on a highly maneuverable head, strong beaks, and the ability to gallop at speeds probably up to 30 mph, these large ceratopsians must have been some of the most dangerous terrestrial herbivores ever to have evolved.

Other Groups

Several other groups of primarily quadrupedal herbivorous dinosaurs produced species of large size, but their limbs, armament, and probably their behavior was strikingly different from that of ceratopsians. Stegosaurs had very slow-acting limbs much like that of sauropods. The armament of stegosaurs consisted of armor plates over the body and long, sharp spikes at the end of a stiff but still powerful and flexible tail. When attacked, stegosaurs must have relied on their body armor for protection while they maneuvered for a blow from their deadly tails. However, stegosaur limbs were built for even less speed than those of sauropods, and the stegosaurs certainly couldn't charge into a predator as the ceratopsians probably did. The ankylosaurs were similar to the stegosaurs in several ways. The ankylosaur limbs were modified for slow, ambling locomotion, and the tails were armed with spikes or club-like devices. The ankylosaurian body armor, made of many plates, was more complete than that of stegosaurs. Probably the ankylosaurs defended themselves in a stegosaurian fashion, waiting for the attack, then looking for a chance to deliver a devastating blow with the tail.

Only about three different genera of definite stegosaurs are known, all from the Jurassic. Ankylosaurs, restricted to the Cretaceous, were more diverse. However, neither of these groups produced the explosive radiation and great abundance which characterized the horned dinosaurs. The different armament and temperament of the ceratopsians may have been one key factor in their success. The largest known allosaur specimens from the Morrison Formation indicate animals 50 feet long; the carnivores of the Cretaceous, such as *Tyrannosaurus*, grew to similar lengths, and weights probably up to ten tons—as heavy or heavier than all of the herbivorous dinosaurs with the exception of sauropods. In contrast, many antelope, wild cattle, horses, and other herbivores are heavier than their largest predators, the lions and other big cats. Thus defensive armor and armament may have been far more important for the dinosaurian herbivores than for modern mammals. The plants of the late Cretaceous indicate an open woodland rather like that of the Morrison, although broadleaf plants had largely replaced the conifers and cycads of the Jurassic. In open ground big ceratopsians probably could have spotted the tyrannosaurs before the carnivores could make a surprise attack. Charging at full speed with its armed skull lowered, a big ceratopsian probably could rout even the largest tyrannosaur.

Anatomy, physiology, and behavior are all closely related in a living animal. The sauropods with their great size needed the ambling limb for support. Their huge size, long tails, and herding behavior provided protection from enemies. The other large, ambling herbivorous dinosaurs were not big enough to discourage attack, and armor was necessary. The horned dinosaurs probably used the combination of speed and a well-armed head to defend themselves very actively and aggressively.

Conclusion

We can now begin to answer the question posed at the beginning of this article: why did the mammal-like reptiles lose out in competition with the dinosaurs?

Even the most advanced mammal-like reptiles, although usually pictured as erect or semi-erect creatures, are constructed along lizard-like, sprawling lines. Never did these animals even begin to develop dinosaur-like, erect posture. Recently I had the opportunity to study the limb bones of the American Jurassic mammals, and these animals also had a sprawling build exactly like that of a lizard, or like that of the living Duck-billed Platypus. Apparently mammals did not acquire the more efficient, erect locomotion until late in the Cretaceous period, fully a hundred million years after the advanced thecodonts and early dinosaurs acquired it.

Today we think of mammals as active, agile creatures, and reptiles as sluggish sprawlers. However, the dinosaurs and their kin achieved locomotory advancements long before the mammals, and this superiority in limbs undoubtedly was a chief factor in the success of the archosaurs and the extinction of the mammal-like reptiles.

In Search of the "Insignificant"

by *A. W. Crompton*

The abundant collections of vertebrate fossils made during the last hundred years have given us a fairly good general picture of the evolution and diversification of life over a period of some 500 to 600 million years. The best known and most abundant collections document relatively slow changes within major groups of animals or plants, e.g., the evolutionary changes within the families of Tertiary (from 70 million to one million years ago) mammals. Less well represented in museum collections of fossil vertebrates are remains recording critical stages in the origin of fundamentally new types of animals, e.g., fossils documenting the steps involved in the change from reptiles to birds or from reptiles to mammals, etc. It appears that in most cases it was during the transitional stages that the essential features which were crucial to the success of the new group were acquired, or to use modern jargon, when the "fundamental break-throughs" were made. Usually these animals or plants bridging major groups formed an insignificant part of the total fauna or flora of the time. A major challenge to vertebrate paleontologists in future years, now that the main outline of the evolution of vertebrate life is known, is to find these critical stages in the evolution of vertebrates and to determine when, how and why several of the major groups of backboned animals came into existence. Rock strata that are known to date from periods when the early evolution of many of the major groups was taking place have often been neglected because they contain so few fossils; it is discouraging to take nothing back after a three-month field season.

A very important period in the history of life was the late Triassic (approximately 180 to 190 million years ago). It was at this time that several large animal groups came into existence, e.g., the dinosaurs, the birds, the crocodiles and the mammals. Triassic rocks containing the fossilized remains of terrestrial vertebrates are known from several areas of the globe, but most of them cover a very short time period or contain fossils representing only a narrow ecological