Migrating Dinosaurs

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IN RECENT YEARS THERE HAS BEEN A GROWING BODY OF EVIDENCE TO SHOW THAT DINOSAURS, THOSE magnificent creatures that ruled the world for 160 million years,were capable of behavioral responses ascomplicated as those we normally attribute only to the highest living vertebrates, mammals and birds. One type of behavior that seems to have been widely practiced by dinosaurs is migration.

Many people think of migration as the movement of animals (including humans) between countries or continents. Others conjure up an image of birds flying south for the winter, and returning north each spring. Both views are correct in that the word migration comes from the Latin *migrare,* which simply means "to move from one place to another." We can be more specific by referring to either dispersal (including intercontinental migration), or to annual migration cycles. These two types of migration are not mutually exclusive, and it is not difficult to find modern examples of annual migrations between continents. And, of course, the disruption of a migratory pathway can also lead to dispersal.

Intercontinental Migration

There are many examples of intercontinental migration in the fossil record, although analysis of the evidence is much more complicated than simply looking at the distribution of dinosaur fossils. For one thing, our knowledge of dinosaurian history is very sketchy, in part because there are so many gaps in the fossil record. Imagine, if you can, trying to understand the history of humankind if your only source of information was a history book missing most of its pages.

Another consideration is the position of the continents. Continental drift is a phenomenon that is now well understood. The continents are not stable masses of rock. They are in fact constantly moving like flotsam on the surface of an ocean. Measurements made by satellite confirm, for example, that North America is drifting westward at a rate of about two centimeters a year. That may not sound like very much, but when it is extended over periods of millions of years, the distances covered can be quite substantial.

As continents change positions, mountains are built and destroyed, and coastlines change. When dinosaurs ruled the planet, much of the central part of North America was covered by inland seas that at times stretched from the Gulf of Mexico to the Arctic Ocean. And the continental masses are not moving in the same directions or at the same rates, so their present relationships have little meaning for our understanding of animal distribution in the remote past. Little can be said about dinosaur dispersal without referring to geological interpretations of geographical changes through time. For example, the faunal similarities between Upper Jurassic (165 to 145 million years ago) dinosaurs of the western United States and eastern Africa (Tanzania) are striking. *Brachiosaurus, Barosaurus, Elaphrosaurus* and *Dryosaurus* are known from both areas, and there is some fragmentary evidence to suggest that *Allosaurus* and

Ceratosaurus were also present in Africa. Whereas one would initially be tempted to use this as an example of intercontinental migration because of the tremendous separation between Africa and North America today, in fact these continents had direct land connections at that time through Europe and South America, and the Atlantic ocean was just starting to open up.

Better documented examples of intercontinental migrations are to be found in northern hemisphere Cretaceous rocks, which are 145 to 65 million years old. Between 1922 and 1930, the Central Asiatic Expeditions of the American Museum of Natural History sought evidence in the deserts of China and Mongolia to show that Asia was the dispersal center for land-dwelling animals of the northern hemisphere. The expeditions became most famous for their dinosaur discoveries, including the first unquestionable nests of dinosaur eggs. The fossil riches of central Asia subsequently attracted other ambitious international expeditions, right up to the present day. This intensive collecting activity has revealed that almost every family of dinosaurs from North America had representatives in Asia. North America and Asia were separate for a long period of time before the Cretaceous, which allowed the dinosaurs to evolve along different pathways. Sometime during the Early Cretaceous Period (more than 100 million years ago), these two continents contacted each other in the arctic regions and faunal exchange was initiated. The similarity of the dinosaur fauna at the end of their history clearly demonstrates that a land link had been established between the two areas. This allowed Asian dinosaurs to migrate to North America, and vice versa.

Paleontologists, like all scientists, have insatiable curiosities. Once we knew that dinosaurs were migrating between continents, we started to wonder which dinosaurs evolved where, and when the migrations actually took place. But more complicated problems almost always have more complicated solutions, and things are not always what they first seem to be. *Protoceratops* is one of the more celebrated dinosaurs recovered from Mongolia by the Central Asiatic Expeditions. Anatomically, it appeared to be the perfect ancestor for the magnificent horned dinosaurs of North America. Its remains were also found in rocks that are older than any of the known horned dinosaurs. Therefore, it seemed obvious that ceratopsians evolved in Asia and migrated to North America, where they produced the spectacular horned species. Or is it obvious? The Museum of the Rockies in Bozeman, Montana, has now collected protoceratopsians from rocks in Montana that seem to be very close to the same age as those from Mongolia. And modern analysis of the anatomy of protoceratopsians has shown that *Leptoceratops* from Alberta is in fact more primitive than *Protoceratops*!

If dinosaurs were migrating between the continents, then it would be logical to assume that some of the species found on each continent should be identical. This has proven to be difficult to assess, however. There are of course the obvious gaps in the fossil record. And sometimes new species are described without adequate comparison with known species; that is just one of the many reasons why dinosaur names change from time to time. (One of the best examples of changing names is that of one of the most famous dinosaurs, *Brontosaurus*, the "thunder lizard." In this case, two specimens from the same species of animal were given different names, *Apatosaurus* and *Brontosaurus*. When it was discovered that these were in fact the same dinosaur, the correct name became *Apatosaurus*, because it was described first. Nevertheless, the name "*Brontosaurus*" has persisted in the popular literature, even though it is incorrect.) To date, *Saurolophus* is the one of the few dinosaurs that

Preceding page: Iguanodons *migrating up the Clayton trackway, on the lookout for predators. By Doug Henderson.*

has the same generic name in both North America and Asia. Detailed study may eventually reveal that *Tyrannosaurus* and *Tarbosaurus* are the same animals, and in fact many scientists already believe this. Many other examples could be cited here, but there seem to be at least subtle differences to distinguish the North American and Asian forms at the subspecies or species level.

The differences we see in the species may in part be explained by differences in the ancient environments. Then, as now, animals were specialized for living in certain habitats, and one would not expect to find the remains of a forest-dwelling dinosaur in rocks formed from the sands of a prehistoric desert. Identifying these environments is a major aspect of the work of the Sino-Canadian expeditions going on today. To pursue its objectives, the Dinosaur Project has multidisciplinary teams of scientists and technicians doing fieldwork in China (under the guidance of the Institute of Vertebrate Paleontology and Paleoanthropology, Beijing), the arctic islands of Canada (under the National Museum of Natural Sciences, Ottawa) and in Alberta (under the Tyrrell Museum of Palaeontology, Drumheller). Dr. Tom Jerzykiewicz (Geological Survey of Canada) was a unique addition to the team because he has studied the dinosaur-bearing sediments in both Mongolia (as part of the Polish-Monogolian team of 1965 to 1971) and Alberta. Logistic support from the Ex Terra Foundation (Edmonton) has made it possible to include representatives from all three institutions in the expeditions to all regions.

The environments utilized by dinosaurs also played an important role in the distribution of these animals. Paleontologists have often found it quite remarkable that large horned dinosaurs similar to *Triceratops* did not seem to have dispersed from North America to Asia during the Cretaceous. At least it seemed that way until 1989 when two Russian scientists described *Turonoceratops tardabilis* from Soviet Central Asia. The absence of horned ceratopsians from most Asian localities can no longer be attributed to geographic separation. The Sino-Canadian expeditions are analyzing the environmental and faunal changes that took place in Asia throughout the Jurassic and the Cretaceous using paleontological and geological evidence. Overall, it appears that the majority of Jurassic and Cretaceous sites were quite dry in Asia, whereas the traditional collecting sites in North America represent relatively wet, well-watered habitats. The absence of horned dinosaurs from traditional collecting sites in Central Asia can be attributed to the fondness of those animals for wetter environments; so understanding the environments of the sites being compared is also critical if we want to understand intercontinental migration patterns.

Bayan Manduhu has proven to be one of the most useful sites in China for comparing Late Cretaceous dinosaur fauna. Literally hundreds of skeletons of dinosaurs (*Protoceratops*, *Pinacosaurus*, *Oviraptor*, *Velociraptor*, and others), lizards, crocodiles, and even mammals were found. Five types of fossilized eggs were identified, and many of them were found in nests. None of the eggs seem to contain embryos, although a skull and partial skeleton of an embryonic *Protoceratops* were found outside of an egg. In spite of the hundreds of specimens recovered, the diversity of this fauna is much lower than that of Dinosaur Provincial Park in Alberta or the Nemegt Basin in Mongolia. The reasons for this were evident from the study of the sediments, which showed that this area was arid during the Cretaceous, just as it is now. And looking across the modern Gobi Desert, one is often surprised by the amount of life that is there, even if it does lack variety. This similarity between past and present environments gives us a unique opportunity to make direct comparisons. We were surprised by the number of fossilized burrows made by ancient insects beneath the feet of the dinosaurs. But when we dug into the modern sand dunes, which appeared to be totally sterile on the surface, we found many living invertebrates feeding on layers of wind-blown plant remains that had been buried by the shifting sands.

The framework for the Dinosaur Project is now well established, and future expeditions in China will concentrate on acquiring more detailed information on the timing of intercontinental migration.

EVIDENCE FOR ANNUAL MIGRATION CYCLES

The idea that dinosaurs may have had annual cyclic migratory patterns is not a new one. In 1928, Frederick von Huene speculated that more than 200 million years ago the European prosauropod dinosaur *Plateosaurus* was migrating between regions of winter and summer rainfall. This speculation has often been repeated, usually on the basis of evidence showing that some dinosaurs were gregarious animals that moved in large herds.

I first started thinking about dinosaur migration in the late 1970 s when working on dinosaur footprints in the Peace River Canyon of British Columbia. Previously, sites had been reported where there were numerous parallel dinosaur trackways moving in the same direction. However, in the Peace River Canyon, one layer of rock showed a large group of bipedal herbivores moving together in one direction, and changing the trend of direction as they went along. Four trackways were close together, and one can see where one animal slipped and lurched sideways, thereby affecting the path of his neighbor. In turn, this affected (to a lesser degree) the path of the next animal, and so on. These four trackways show sinuous, S-shaped paths that do not intersect, and the probability is extremely high that the four trackmakers were moving side by side. It is evident from the trackway sites that some of the plant-eating dinosaurs were moving in great herds.

One of the best lines of evidence to show that dinosaurs were gregarious comes from bone beds (extensive, concentrated layers of mixed-up bones from many individuals). Dinosaur bone beds are more common than dinosaur skeletons, and when studied properly can provide information that is not available from any other source. Most bone beds were formed in stream channels, and contain representative bones of all the animals that lived in the area. These animals generally died on land, where their bones were scattered by carnivores and scavengers. As meandering streams cut their banks, the bones would fall into the stream channels and sink to the bottom, where they would be concentrated. Eventually they would be buried by the sand and mud being carried by the water. Occasionally, scientists find bone beds that are dominated by a single species of animal. One such accumulation discovered in Dinosaur Provincial Park (southern Alberta) has been worked for more than ten years by staff of the Tyrrell Museum of Palaeontology. The bone bed is completely dominated by *Centrosaurus apertus*, a horned dinosaur that is distantly related to *Triceratops*. The paleontological and geological evidence suggests that a herd of 400 or more of these 4-ton animals attempted to cross a river in flood. They may have been good swimmers as individuals, but many of them appear to have drowned when they interfered with each other as they tried to swim across as a group. Although this may sound like a rather fantastic explanation, it still happens today with large herds of herbivorous mammals. For example, ten thousand caribou drowned in the Cani-

Sauropod dinosaur tracks – Glen Rose trackway of Jurassic Texas. Photo: American Museum of Natural History.

apiscau River of Quebec in 1984, and there are many examples of mass drowning of wildebeest and bison. As in the modern examples, the carcasses of *Centrosaurus* floated downstream, coming to rest on the banks, point bars, and sand bars of the river. There they were scavenged by large and small carnivorous dinosaurs, who left trampled, tooth-marked bones and the crowns of their loose teeth as evidence of their grisly repast. What was left lay on the surface of the ground until all of the remaining muscles and ligaments had rotted away, at which point the river went into another flood phase and buried the bones in a new layer of sand.

There are other bone beds like that of *Centrosaurus*, which appear to represent catastrophes that befell herds of other horned dinosaurs (including *Anchiceratops*, *Pachyrhinosaurus* and *Styracosaurus*) in different places at other times. Flood waters, drought, forest fires, and disease are just a few of the potential causes for mass mortality, although few of these bone beds have been studied enough to establish the probable causes of death. A tremendous bone bed of the duck-billed dinosaur *Maiasaura* was found near Choteau, Montana, an area that is most famous for its dinosaur egg sites. Preliminary analysis of this site suggests that a herd of ten thousand or more duck-billed dinosaurs may have suffocated in a volcanic ashfall!

In modern mammals, species that live in forests and other closed habitats tend to be relatively smaller, solitary browsers with camouflage coloration and short simple horns. In contrast, open-country species are the most gregarious, are often distinctly marked, tend to be larger with large and/or complex horns, are more mobile, and run away from danger. The most gregarious animals tend to have the highest population densities and are ecologically dominant. Using these as analogies, it seems possible that those relatively large dinosaurs with elaborate horns, frills and crests were animals that lived in open country, may have had distinctive skin markings, and had the most complex social structure. There is at least a good correlation among the horned dinosaurs in that those animals with the most elaborate display structures, such as *Styracosaurus* and *Pachyrhinosaurus*, provide us with some of the best evidence for herding.

The evidence to show that many dinosaurs were herding animals is pretty overwhelming, and is now accepted by most paleontologists who work on these animals. There is not as much agreement on why they might be herding, however. Migration is not an unusual phenomenon in the animal kingdom. Most major groups of mobile animals, including insects, fish, reptiles, birds, and mammals, have examples of species that find migration advantageous. In most cases, migration is linked directly to the search for food and/or water. Among larger animals, there is often a selective advantage in developing a gregarious herd structure as a means of protection from carnivores. However, the collection of groups of large animals is not compatible with remaining in a single area because food sources become depleted, and this in turn gives a selective advantage to large animals that move from region to region. The larger and denser the herd, the more essential it is for it to keep on the move. It is pretty easy to imagine how destructive to the environment a herd of several thousand dinosaurs, each animal weighing as much or more than an elephant, would have been, and how quickly they must have depleted the food supplies. Those animals that develop specific migratory pathways that allow them to be in areas with proven food sources at the right times of the year will of course have a selective advantage over those that wander randomly into regions that may not be able to provide sufficient food.

The study of dinosaur distribution, coupled with the evidence that we have for dinosaur herding behavior, is producing the most compelling evidence for seasonal migration. Although most people seem to believe that dinosaurs lived in tropical areas, the most diverse dinosaur fauna are in fact found at higher latitudes. Dinosaur Provincial Park (in Alberta) and the Nemegt Basin (in the Mongolian People's Republic) have yielded the two richest diversities of fauna, with 35 species of dinosaurs each. During the Cretaceous these animals would have been living at even higher latitudes than they are today. Although sites closer to the equator have produced good dinosaur fossils, the fauna found there are not as varied. This trend suggests that dinosaurs were animals that preferred temperate climates rather than the tropics. From what we now know about dinosaur physiology, it is evident that these generally large animals would have been able to function well in cooler weather, whereas they probably would have had difficulty in discarding excess body heat in the tropics.

Some of the most interesting and promising areas for dinosaur research today are in the polar areas. Work in southern Australia has shown that during the Early Cretaceous, when Australia was much farther south than it is today, several types of small herbivorous and carnivorous dinosaurs were living within the Antarctic Circle. In 1986, an armored dinosaur (ankylosaur) was discovered by an Argentinean party working in Antarctica, and the following year a British party recovered a hypsilophodont there. These south polar dinosaurs are relatively small, and our knowledge of the paleogeography of that time suggests that they may not have been able to migrate great distances to get out of the Antarctic region during the winter months. This shows that dinosaurs must have been capable of surviving adverse polar conditions.

On the other side of the world, however, dinosaurs have been found within the Arctic Circle in Spitzbergen (Lower Cretaceous footprints), the Northwest Territories and Yukon of Canada, and Alaska. Unlike the Antarctic conditions however, the north polar regions were connected by land to more southerly (warmer) areas, and the dinosaurs tend to be larger, more mobile forms.

Plants survive well in the Arctic summers today, in spite of the short growing season and permafrost. With up to twenty-four hours of daily sunshine in the summer, plants are incredibly productive, and even large trees are known to have lived in the Arctic until fairly recently. As these plants also had to deal with up to twenty-four hours of darkness each day in winter, they are all deciduous forms, including "evergreens" like the Dawn Redwood (which even today loses its needles in the winter months). Furthermore, the caloric density of plant tissues is much higher in temperate and arctic regions, and the fiber content is lower. Hence there is a superabundance of forage of a higher quality. In the case of large, modern plant-eating species, this translates into a far greater surplus of energy for fat storage or antler-horn growth than in tropical forms, and this may have been the case with dinosaurs as well.

Dinosaurs were extremely successful throughout their 160 million year history, partially because they were able to adapt and take advantage of a variety of ecosystems. Although it was natural that they would move into the polar regions during summer months to use that high plant productivity, most would not have had enough food during the winter months. The smaller, less mobile species would probably have remained in the north, surviving on seeds and low-grade plant fodder such as bark and dried leaves. Small carnivores could have survived, of course, by eating the plant-eating dinosaurs, plus mammals and any other animals that remained active. Some dinosaurs may even have hibernated as a way of surviving the winter. But the majority of large species had another option. With their long legs and efficient ways of walking, dinosaurs were as capable as modern mammals of moving great distances.

One of the dinosaurs found by the joint University of California (Berkeley)/University of Alaska expedition to the North Slope of Alaska in 1987 was a bizarre dinosaur known as *Pachyrhinosaurus*. This horned dinosaur has been known from southern Alberta for many years. Rather than having three horns on its face like its distant cousin *Triceratops*, *Pachyrhinosaurus* had massive growths of bone over the nose and the eyes. These may have formed a massive battering ram, although their similarity to the base of a rhinoceros horn suggests that the bony bosses may have supported a tough but lightweight horn derived from skin tissues (a rhinoceros horn is actually an agglutinated mass of hair). The frill over the neck was highly ornamented, with huge recurved horns (looking much like those of a Texas longhorn) and a unicorn-like spike rising above the center of the frill. Two bone beds in Alberta have already shown us that *Pachyrhinosaurus* was a herding animal, and with a range of more than 2,000 miles, this animal is one of the best candidates for annual migration.

Two thousand miles may be the known range for *Pachyrhinosaurus*, but it is doubtful that any individual moved the full extent of the species range. For example, North American caribou have a range of more than two thousand miles north to south, but no herd or individual is known to travel more than eight hundred miles in one direction within that range. Even at the maximum known range of *Pachyrhinosaurus*, if an individual moved at five miles an hour (a figure calculated from the trackways of slow-moving dinosaurs in the Peace River Canyon; the record is a Texas carnivorous dinosaur that moved at 25 miles per hour), it would be able to cover the maximum distance if it walked twelve hours a day for 33 days. Today wildebeest cover up to 50 miles a day, and caribou as much as 100 miles. In all likelihood, however, *Pachyrhinosaurus* herds were moving shorter distances and taking longer periods of time (caribou spend three to four months of the year migrating).

Pachyrhinosaurus is only one of the dinosaurs from Alberta that has been found in Alaska, but less is currently known about the herding behavior and possible movement of other species. Perhaps the greatest promise is shown by a bone bed of duck-billed dinosaurs from Alaska, because analysis of size distribution in the herd and comparison with southern specimens may give us some clues as to where and when these dinosaurs hatched from eggs.

Dinosaur behavior must have been as diverse as the dinosaurs themselves. Not all species would have moved in herds (in Africa today, 41 percent of the 70 antelope and other bovid species south of the Sahara are solitary and 59 percent are gregarious), and of the ones that herded, only some of them may actually have been migrating. The herds themselves are still poorly understood, although we know that they included males, females, juveniles, and babies. Today there are three basic social structures in the cattle (bovid) family: females with or without young (nursery herds), all-male bachelor herds, and solitary adult males. Modern herds are highly variable in organization, and can be composed of a dominant bull with his harem, or of females and their young (but no mature males), or all bachelor males, or almost any other combination you would care to think of. Different species of dinosaurs may well have had different herding strategies. *Pachyrhinosaurus* herds seem to have been simple in organization, composed of almost equal numbers of males and females. As in modern herding animals, migrating herds probably were only together at certain times of the year. They may well have collected into groups at the end of the Arctic summer and moved as a unit south to Alberta and Montana. Here the herds may have dispersed for the winter months, and only gathered together again when they started their migration north into the Arctic in the spring. This model provides an explanation for the rich diversity of plant-eating dinosaurs in places like Dinosaur Provincial Park, because many of them would only have been living there for part of the year.

Seasonal migrations would have provided opportunities for dinosaurs to disperse to other parts of the world. As previously mentioned, we know from studies of the continental positions during the Cretaceous that the connections between Asia and North America lay within the Arctic regions. Those dinosaurs that lived in or migrated to the Arctic would have had the opportunity to move easily between the continents. After all, if you were far enough north and wanted to go south again, turning slightly to the right could take you into Asia, or to the left into North America!

It must have been an amazing sight as ceratopsians and hadrosaurs collected into huge herds in the spring for their migration north. Carnivores large and small would have followed them for at least short distances, picking off the sick, the old or the incautious individuals. And perhaps it was somewhat prophetic that the dinosaurs shared the north with their own descendants, the birds who would one day migrate as much as 10,000 miles a year!