NEW APPROACHES TO STUDYING DINOSAURS IN DINOSAUR PROVINCIAL PARK

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No area of equivalent size has produced a larger number of articulated dinosaur skeletons of such diversity than Dinosaur Provincial Park in southern Alberta. This led to its designation as a UNESCO World Heritage Site in 1979. The documentation of specimens collected from the Judith River (Oldman) Formation of the area has been good, and Dinosaur Park figured prominently in the earliest taphonomic, paleoecological, and physiological studies on dinosaurs. Although the strata are Campanian, the park has also been important to research on dinosaur extinction because it represents a peak of diversity not seen in later faunas.

After almost nine decades of collecting in this area, the park continues to yield new information. Nearly 350 articulated skeletons have been collected. As many as half a dozen new skeletons have been found each year during the past five years, and the supply is constantly renewed because of the high rate of erosion in the badlands. It takes a long time to find and collect skeletons, however, and often they represent a restricted regime of depositional environments. In recent years, more emphasis has been placed on other types of collecting programs, with the result that data is being collected at an accelerated rate. Thousands of specimens can be collected in a single day from microvertebrate sites. For every skeleton collected in the park there are probably ten bone beds, and some of these are enormous lag deposits with millions of bones. Isolated bones have been

an important source of information on smaller dinosaurs, both small species and juveniles of larger ones. Dinosaur footprints, egg shell, and insects in amber have rounded out the story. Long ignored because of the complexity of three-dimensional modeling, sedimentological studies are finally underway and now provide a framework of depositional environments to which to relate the fossils. Slowly patterns are emerging that will provide a much firmer data base for all dinosaur studies. A multidisciplinary research team has developed to work in the park and is centered on a core of staff from the Tyrrell Museum of Palaeontology, Drumheller, Alberta, Canada. The construction of a research field station this year will insure the continuation of work in this area.

Ever since the first discovery of dinosaurs, people have tried to imagine what it must have been like when these magnificent animals were alive. Illustrators have reconstructed scenes that included not only the dinosaurs but also depictions of their possible environments. One of the earliest artists, and without doubt the most successful, was Charles R. Knight. His reconstructions have been reprinted countless times, and his influence can be seen in the work of the majority of artists who have reconstructed dinosaurs. Knight was a master of composition and color, and it takes little imagination to step back in time while gazing at his paintings. One of my favorites, and a significant influence on my decision as a child to become a paleontologist, is his mural for the Field Museum of Natural History showing a confrontation between *Triceratops* and *Tyrannosaurus* (Fig. 1). The painting has the same impact on me now as it did when I was young. But I sometimes wonder today how it would look if a contemporary artist were to repaint it. There would be some anatomical differences in both animals, and this would be most noticeable in the poses they assumed. There would be no grass in the foreground, as this type of plant did not appear until the Paleocene. Although the climate would have been warm temperate, these animals are best known from Montana, the Dakotas, and Alberta, where broad-leafed, deciduous trees were more common than palms and cycads. And perhaps there would be small creatures—frogs, salamanders, lizards, or even shrewlike mammals—scurrying underfoot because they greatly outnumbered the dinosaurs. Birds and pterosaurs would have dominated the air.

Knight had a tremendous influence not only on other artists but on scientists as well. Although there had been some early speculation that sauropods were terrestrial animals, some scientists believed that they were too heavy to support their own weight and that they must have spent most of their life in the water. As more people had seen pictures of sauropods in the water than had read about the controversial subject, Knight's paintings had a profound effect on common knowledge. It is taking a great deal of work to change this idea in the public mind. Anatomical and environmental evidence now strongly suggests that sauropods like *Opisthocoelicaudia,* a camarasaurid from the Nemegt Formation of Mongolia (Fig. 2), spent most of their time on land.

Dinosaurs have never escaped the public eye, thanks to the works of artists like Knight and the spectacular dinosaur displays in places like the American Museum of Natural History. However, somewhere between the two world wars, funds dried up for the collection and preparation of dinosaurs, and dinosaur research dwindled to a trickle.

By the mid-1960s there was a resurgence of research interest in dinosaurs. Like most sciences, paleontology had matured during the intervening years. Research problems were broader in scope. Whereas the majority of paleontologists who had worked on dinosaurs previously were geologists, most of the new workers brought with them more extensive training in the biological sciences. The public had a perception that scientists knew all there was to know about dinosaurs, but our ignorance soon became evident on all fronts. Not only was our knowledge of anatomy and taxonomy at a preliminary stage, but almost all of our concepts of how these animals lived were tainted by the belief that dinosaurs approximated modern reptiles.

Robert T. Bakker rode on the crest of the dinosaur renaissance. His controversial ideas about dinosaur physiology, suggesting that they were warm-blooded, had been proposed by some earlier workers but had never been backed by such a body of evidence (Bakker 1975). Interestingly enough Bakker is also an accomplished illustrator (Fig. 3), and this certainly helped attract attention from both the public and the scientific community (Thomas and Olson 1980). And everyone loves a good controversy, so it was not surprising that the public soon developed a heightened awareness of dinosaur research. As with any science, the closer one looked at these emerging problems, the more questions they spawned. But the key factor was a total shakedown of the traditional concepts of what dinosaurs were.

As the dinosaur renaissance developed, Peter Dodson was completing one of the earliest taphonomic studies in the Western world, based on the dinosaurs of Dinosaur Provincial Park, Alberta, Canada (Dodson 1971). Taphonomy is the study of what happens to an animal between its death and ultimate burial and is a powerful tool for understanding how animals lived and interacted, both with each other and with their environments. Other ecological studies on dinosaur faunas were undertaken by James Farlow (1976), who also coauthored a paper with Dodson suggesting how anatomical features could be used to understand dinosaur behavior (Farlow and Dodson 1975). Computer-based studies by Dodson (1975, 1976) explored the problems of understanding variation in dinosaurs and its bearing on analysis of what constitutes a dinosaur species. Specimens that had once been considered as distinct species turned out to be males, females, and juveniles of the same species. Finally dinosaur extinction continued to attract considerable attention. It seems incredible that such a successful life form could have become extinct in what appears to be a relatively short period of time. A new generation of extinction theories developed during the dinosaur renaissance, and another dinosaur paleontologist, Dale Russell, was at the center of some of the most heated controversies.

The ideas developed during the early years of the dinosaur renaissance were all characterized by multidisciplinary influences. The prefix *paleo-* was attached to most of the names of scientific disciplines. New tools, new approaches, new perspectives. But the data were not new. Predator-prey ratios were based on the data published by Sternberg in 1950, and there were accusations that these figures were despoiled by collecting biases (Beland and Russell 1979). Even the work of Peter Dodson, based on field observations, centered on the quarries of earlier collectors.

Some arguments could not be resolved on the basis of existing information. Knowledge of the kinds of problems being argued was used in initiating field programs in Dinosaur Provincial Park on an unprecedented scale. In 1982 the Tyrrell Museum of Paleontology put eighteen staff, three professional associates, and fifty-four volunteers in the park. Other collecting parties were organized in Crowsnest Pass and north of Drumheller. And although most of this effort was directed toward the acquisition of specimens, a tremendous amount of data was collected as well.

When the original collectors came to Alberta for dinosaurs, they were looking for high-quality specimens for display that would attract attention to their institutions and generate research support funds. Approximately five hundred major specimens were collected in the Drumheller and Dinosaur Provincial Park regions of Alberta, and these found their way into more than thirty-five institutions around the world (Fig. 4). The collectors who came had difficulty in dealing with all the available resources and ended up collecting only the best specimens. Not only were they selective about the kinds of dinosaurs they collected, but sometimes they were even selective about what parts of the skeletons were excavated, taking skulls from skeletons and leaving the rest in the field.

Although we are still in a position to choose only the best specimens discovered and collect only articulated skeletons, we now realize that there is a tremendous amount of information available

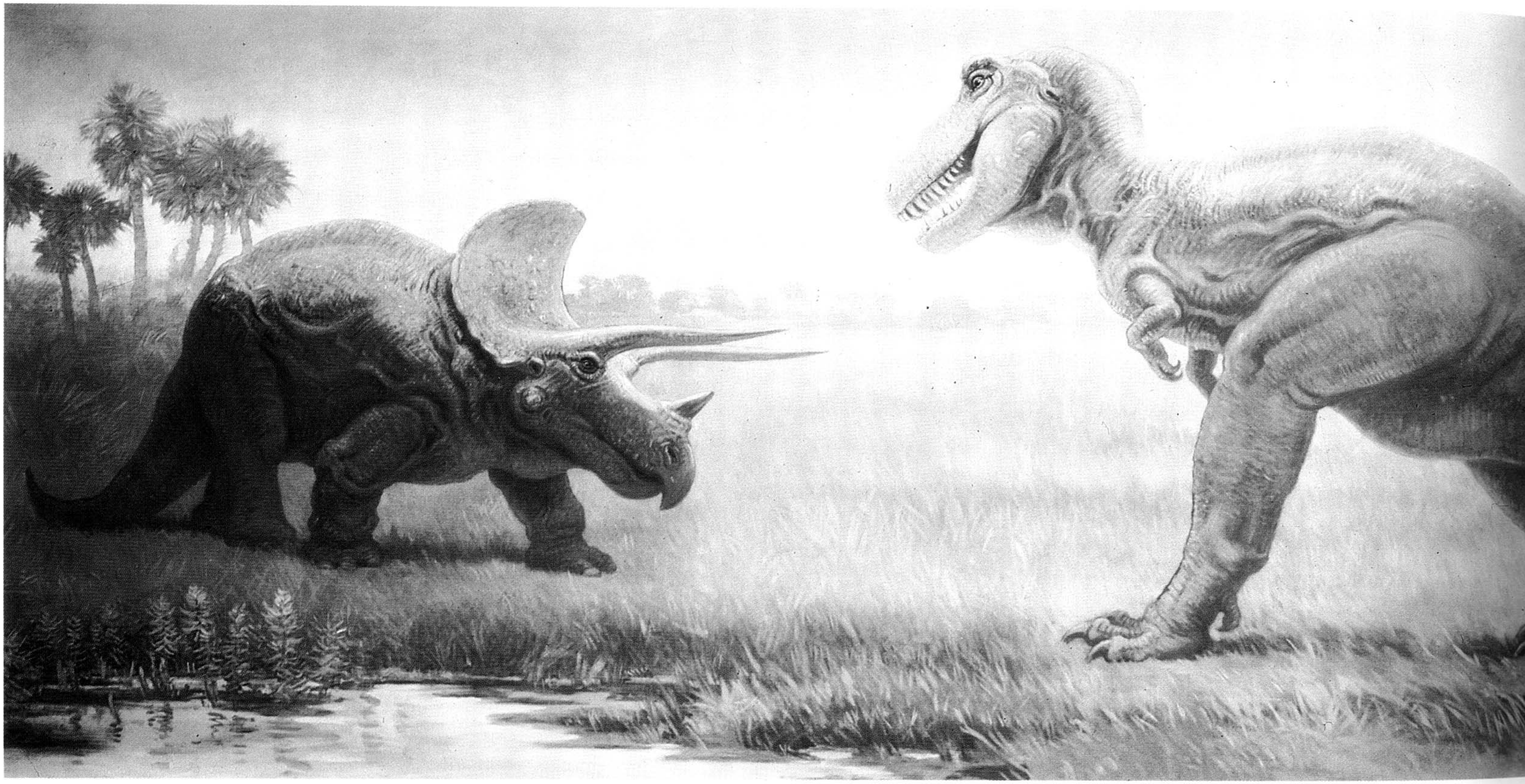


Figure 1. *Triceratops* and *Tyrannosaurus* mural by Charles Knight. Courtesy Field Museum of Natural History, Chicago.

Figure 2. *Opisthocoelicaudia skarzynskii*, by Vladimir Krb. Checklist 95.

through other types of paleontological resources as well.

Since the late 1970s the Tyrrell Museum has worked with sedimentologists in the badlands of both Dinosaur Provincial Park (Koster and Currie 1986) and Drumheller (Rahmani 1981). The sedimentologists provide information on the environments in which those animals lived and the depositional environments in which the bones were buried. This work provides the artist with basic information on the size of rivers and the presence of lakes and marshes and other geographic features that can be incorporated into a painting.

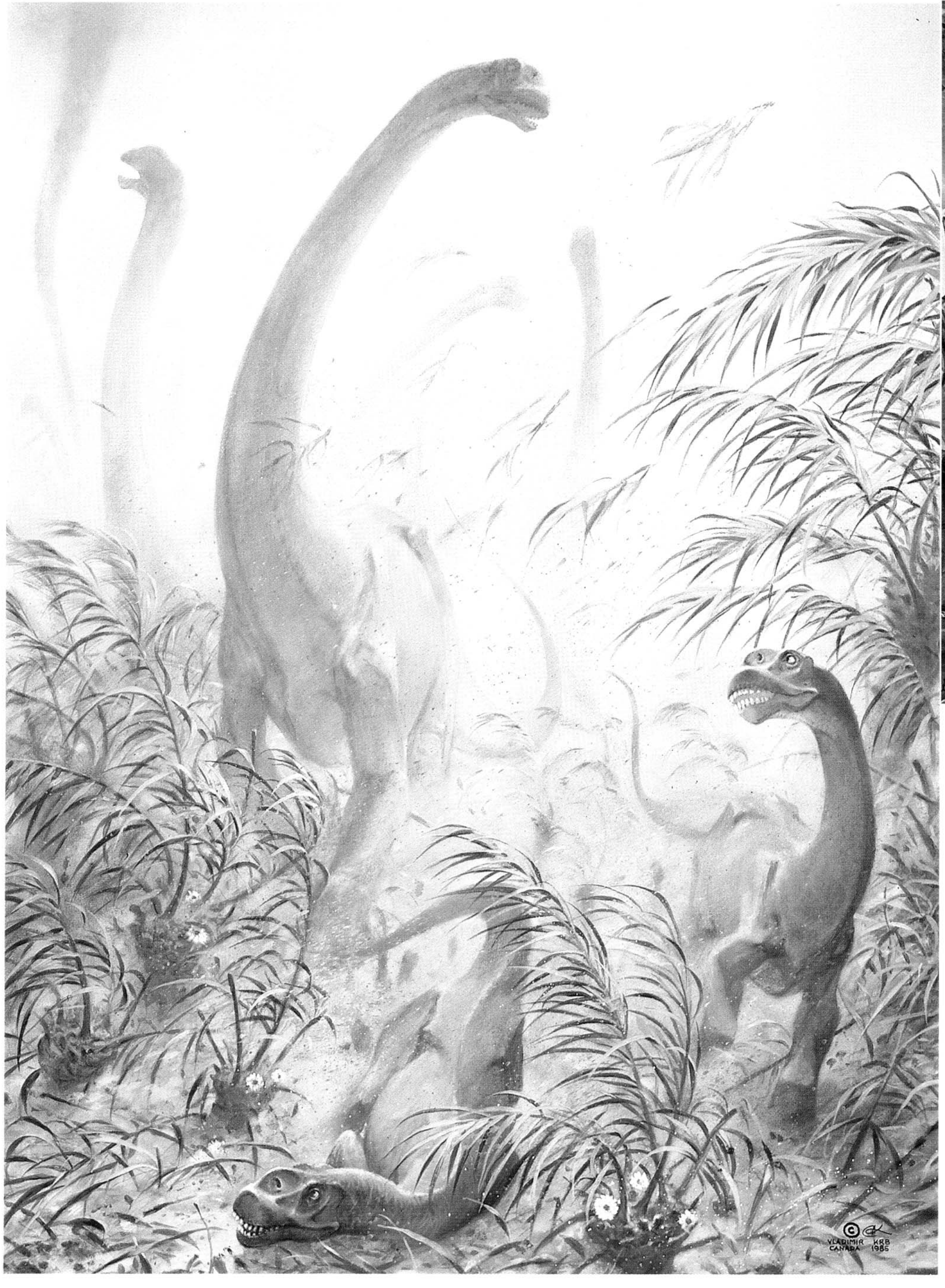
Leaf fossils are not very common in Dinosaur Provincial Park and are generally badly broken up. Nevertheless, they show us that a large number of modern genera of coniferous and deciduous trees lived in the Cretaceous of North America. Fossil logs and stumps are far more common in this part of the world, but until recently nobody has taken the time to do thin sections for identification of the wood. Most specimens are turning out to be coniferous, again of genera that are still extant. One exceptional type of preservation is found in the tar sands of Fort McMurray, where Cretaceous logs are actually pickled in oil. Once the oil is removed, it is very difficult to distinguish the specimens from modern wood.

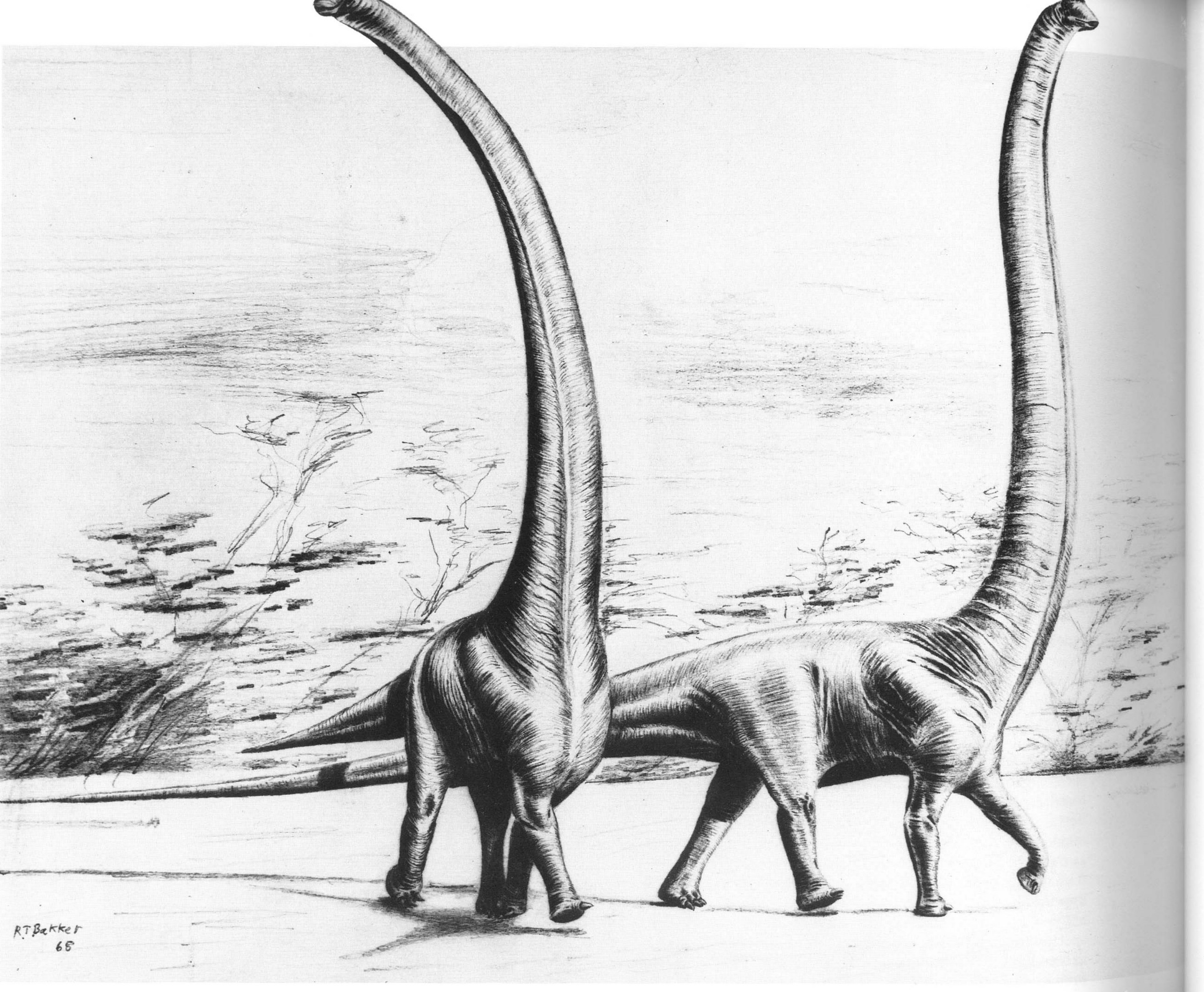
A far better source of information on plants from the Cretaceous of Alberta comes from study of the palynomorphs (pollen and spore fossils) (Jarzen 1982). These have diagnostic shapes that can be used to identify the kinds of plants that were in the region. More than seventy-five types have been identified from the Judith River Formation of southern Alberta, and this number is expected to

more than double over the next few years.

The information collected from all sources of plant fossils shows Cretaceous floras of Alberta that are characteristic of warm temperate or subtropical environments. The vegetation would have been lush, and the habitats would have been numerous and varied.

Another type of plant fossil is amber, the fossilized remains of tree resin. Several sites in Alberta are so productive that thousands of specimens can be collected in a single day. Preparation and study of amber frequently yields the remains of fossil spiders and insects. On the average one insect appears in every fifty pieces of amber. The insects are very similar to modern genera, and in fact some species are indistinguishable at present from living descendants (McAlpine and Martin 1969) The fauna now includes spiders, pseudoscorpions, bit-

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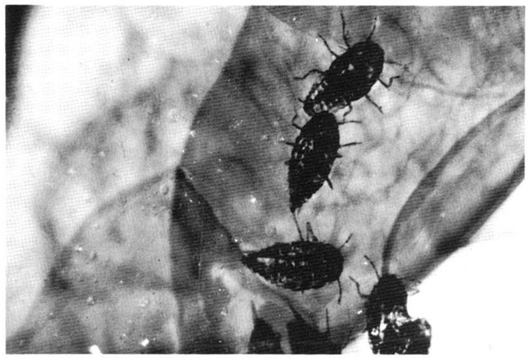
ing flies, mayflies, and aphids (Fig. 5).

There is not much diversity among freshwater invertebrates known at present (Russell 1964). Clam beds include thousands of specimens, generally representing only two or three different species. Recent study of these beds has shown that they may have other value. Some freshwater invertebrates are quite sensitive to environmental changes and can help determine the Cretaceous depositional environments. One site in Dinosaur Provincial Park displays a sequence of clam beds that were drowned by sand and mud, presumably carried by flood waters. Many of the clams died trying to dig out of the mud. The overlaying sands reveal that gas from the rotting bodies of the clams rose through the sediments. These types of sites can indicate the amount of sand accumulated in single flooding events.

More attention has been paid recently to isolated dinosaur bones. It is very difficult to walk far in any direction in Dinosaur Provincial Park without finding isolated bits of dinosaur bone, and millions of bones are exposed. If one attempted to collect all of these specimens, one would soon run out of space to store them. Although most are left in the field, it has been profitable to identify these isolated bits and pieces because approximately one percent of them are diagnostic enough to identify the species.

There are strong biases in Dinosaur Provincial Park against the preservation of small animals. Large skeletons stayed together after the animals died because of the greater weight of the bones and because of the strength of the soft tissues holding them together. Small specimens decomposed faster, were completely destroyed by scavengers, or were broken up by the action of the rivers. The net result is that very few animals weighing less than fifty kilograms are represented by articulated skeletons. By studying the isolated dinosaur bones, both baby dinosaurs and adults of small species have been recovered and identified.

The animals that lived in environments adjacent to stream beds had a greater chance of being buried and fossilized as complete skeletons than did animals that lived and died between the streams in forests, marshes, or other habitats. Many of the



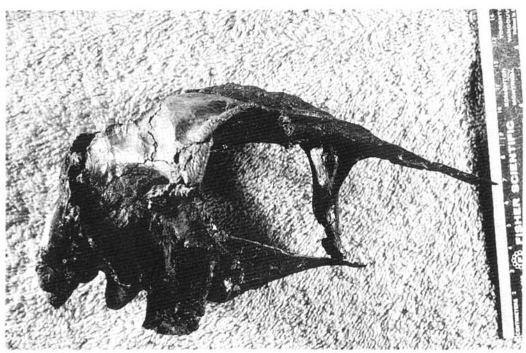


Figure 4. Fossils collected by Barnum Brown for the American Museum were hauled out of the badlands of Alberta by horse-drawn wagon; photograph circa 1912. Specimens taken from the Drumheller and Dinosaur Provincial Park regions of Alberta by the early dinosaur hunters found their way into more than thirty-five institutions around the world.

Figure 5. Amber, which is abundant at several sites in Alberta, frequently contains the remains of spiders and insects. These aphids are among a line of twenty-seven preserved in an amber specimen 3 millimeters long.

Figure 6. This isolated braincase of Troödon, a small dinosaur (3 meters or less in length), was discovered in Dinosaur Provincial Park in 1982. Study of the specimen has revealed it to be very similar in general morphology to the braincases of modern birds.

Opposite
Figure 3. *Barosaurus*, by Robert Bakker. Checklist 90.

Figure 8. *Centrosaurus* herd crossing a stream; restoration by Gregory Paul. Checklist 87.

small forms, such as *Troödon*, are almost entirely represented by isolated bones from the skull or skeleton. Comparison with articulated specimens of closely related species from Asia allows the identification of these forms and gives us a good idea of what the animals looked like. In 1982 the value of isolated bones was shown when a braincase of *Troödon* (Fig. 6) was discovered in Dinosaur Provincial Park. Study of this specimen showed that the braincase, including the well-preserved middle-ear region, of *Troödon* was very similar in general morphology to that of modern birds and emphasizes the fact that small carnivorous dinosaurs and birds are closely related (Currie 1985).

Over the past few years approximately one new dinosaur species has been discovered annually in Alberta, primarily on the basis of isolated bones. It is now known that some genera that were previously known only from the western United States or Asia were in fact living in Alberta as well. At one

Opposite
Figure 7. *Kritosaurus incurvimanus*, by Vladimir Krb. This restoration is based on information obtained in the recovery of a specimen found entangled in the roots of a fossilized tree in Dinosaur Provincial Park. When the hadrosaur died seventy-five million years ago, its carcass floated downstream in a river until it came to rest against the tree at the bank. The dinosaur's skin left impressions in the mud under the body, which are preserved in the fossil rock. The upper part of the skeleton began to disarticulate as the body decomposed, and some of the bones were washed further downstream before becoming buried in the sand. Checklist 93.

Figure 9. A *Styracosaurus* bone bed discovered in Dinosaur Provincial Park in 1984. About five percent of the bone beds in the park seem to be monospecific; see also Fig. 11.

time it was thought that differences between the Asian and North American faunas were related to differences in time and/or distance. However, it is now apparent that many of the differences were ecological and that if we were sampling the same types of environments, we would expect to find more faunal overlap. Many of the isolated bones in Dinosaur Provincial Park were probably washed in from drier, more upland regions to the west that may have been equivalent to environments in Asia.

Articulated specimens are still the most valued prizes. The majority tend to be partial skeletons of hadrosaurs (the "headless wonders" of C. M. Sternberg) of known species, but the skeletons of new species of dinosaurs continue to appear occasionally (Sues 1978).

It takes a great deal of effort to find a dinosaur skeleton. On the average in Dinosaur Provincial Park it requires about eighty man-days for each major prospect found (Beland and Russell 1978). In 1986 more than thirty prospects in southern Alberta were waiting to be excavated by the Tyrrell Museum. Some consist only of a few articulated bones sticking out of the exposures. But unless time is taken to actually uncover the specimens, it is impossible to know how complete they are. Two dinosaurs collected in 1982 were in fact rejected by earlier field parties who had decided that the skeletons probably did not include skulls. In each case, however, the specimen turned out to be nearly complete, lacking only parts of the tail and limbs. In contrast, it is more common to expend a great deal of time, effort, and money taking down a hillside only to discover that little more of the specimen was present than was exposed.

During an excavation, accurate records are kept of the orientation of the individual bones, and the skeletons as a whole. Many of these records tell interesting stories (Fig. 7).

Collecting biases still exist. Many hadrosaur skeletons have been found in recent years, but only the best are excavated. The articulated skeletons of other animals, however, are always collected. Furthermore, we are starting to understand some of the preservational biases. For example, theropod bones are hollow, but the laminar bone is much denser than that of herbivorous dinosaurs. Consequently the bones of carnivores can lie on the surface for much longer periods of time before being destroyed by weathering.

Articulated dinosaurs continue to be exposed in Dinosaur Provincial Park at an impressive rate. Three or four skeletons are collected each year, and with the use of sophisticated equipment such as helicopters between ten and twenty metric tons of material are removed annually. Because so many specimens are being found, it has become necessary to take only the most significant. Nevertheless, accurate records are kept of all specimens that are discovered so that we have a more complete and less biased census than has been possible until now.

Bone beds represent another type of resource that had been largely ignored in Alberta. Bone beds contain a large number of specimens in which the bones of individuals have become so juxtaposed that generally it is not possible to learn which bone belongs to which individual. In many cases it is even difficult to identify which species the isolated bones come from. Nevertheless, techniques have been developed in other parts of the world to excavate bone beds. When we started the major projects in Dinosaur Provincial Park, we felt that it would be useful to apply some of these techniques to bone beds there. In 1978 two Park naturalists reported a large bone bed in the core area of the park to staff of the museum. This bone bed was interesting in that it did not have much overburden, there was a tremendous amount of bone exposed on the surface, and the bones that could be identified all seemed to be from ceratopsian dinosaurs. Once the broken and eroded bone was removed from the surface, between twenty and sixty bones per square meter were found. A minimum of 85 percent of these could be identified as horned dinosaurs. The census taken of articulated skeletons and specimens recovered from normal bone beds suggests that ceratopsians only comprised 25 percent of the fauna in this region. Therefore the high percentage of ceratopsian bones found at this particular site is unusual. Furthermore, all of the ceratopsians from this bone bed are identified as *Centrosaurus*. Hadrosaurs, which normally make up more than forty percent of the dinosaur fauna in

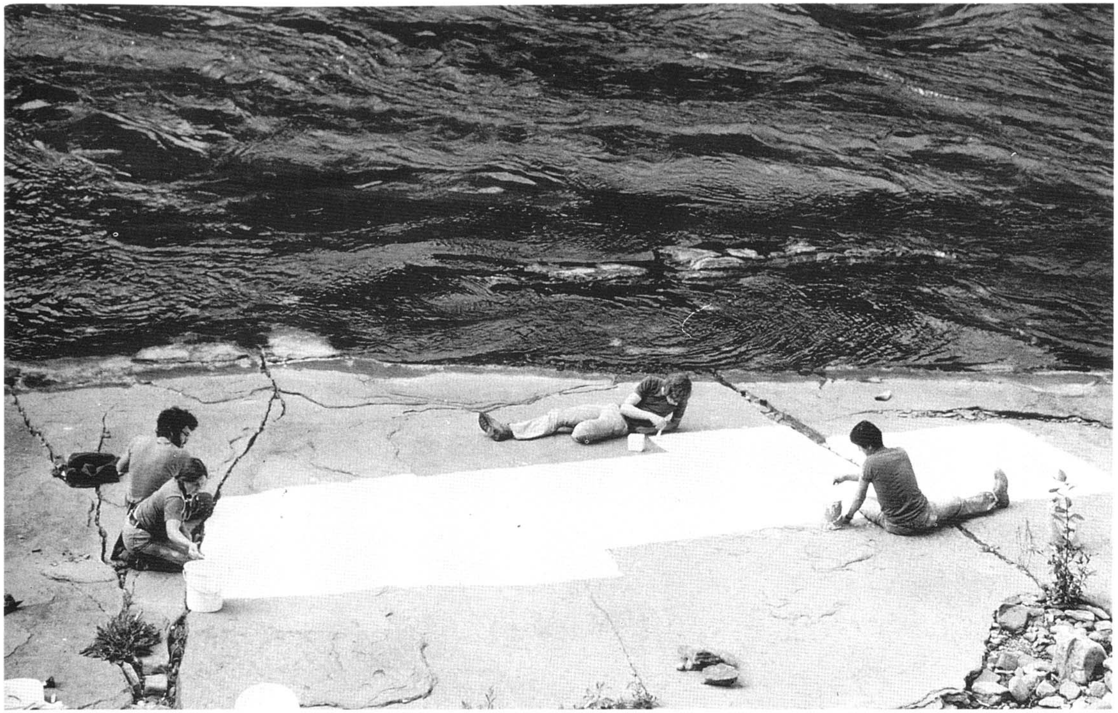


Figure 10. Casts of fossilized trackways along the Peace River were made to preserve a record of the site. The tracks contain the earliest known fossilized bird footprints as well as the prints of seven species of dinosaurs (Currie 1981).

the park, only account for three and a half percent in this particular bone bed and were outnumbered by carnivorous dinosaurs.

Study of the distribution pattern of bone size proved to be quite interesting. Normally a comparison between numbers of specimens and size (or age) of specimens represented in a particular fossil assemblage results in a bimodal distribution, with large numbers of very young and very old animals. The medium-sized, young adults tend to be underrepresented in the fossil record. This is because in normal populations the weakest animals are the hatchlings and juveniles, and these are more susceptible to death by predation, accident, or disease. Only the fittest survive and grow to be young adults. These become the strongest individuals in the population and do not die as frequently and therefore do not enter the fossil record. As the animals become older and larger, they become weaker and are more susceptible to death once again. In the *Centrosaurus* bone bed, on the other hand, the majority of animals are medium sized, presumably sexually mature adults. This strongly indicates that some catastrophe befell these animals and wiped out individuals of all ages indiscriminately. Three major size classes of animals were found in the *Centrosaurus* bone bed, again supporting the suggestion that there was a catastrophe of some sort. Three individuals are small in size and probably were animals less than a year old. The next size class is more than double that of the first, and the remaining animals are fifty percent or more larger than these. The discrete size classes can be explained by the following hypothesis. During the first year of life growth is extremely rapid in most animals and there is a considerable difference in size between one and two year olds. Growth rates slow down in the second year of life, and consequently there is not as marked a difference between the two- and three-year-old animals. The size difference, however, is still significant enough to distinguish the two ages. Finally older animals have growth rates that are slow enough to be masked by individual variation. For example, a three-year-old

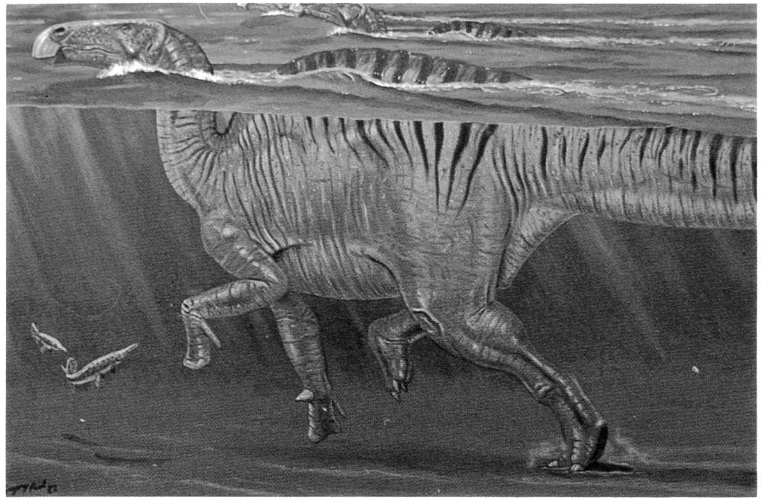


Figure 12. Swimming ornithopod restoration by Gregory Paul. Trackways show that as some dinosaurs swam, they poled with their feet to change speed or direction. Courtesy Tyrrell Museum of Palaeontology.

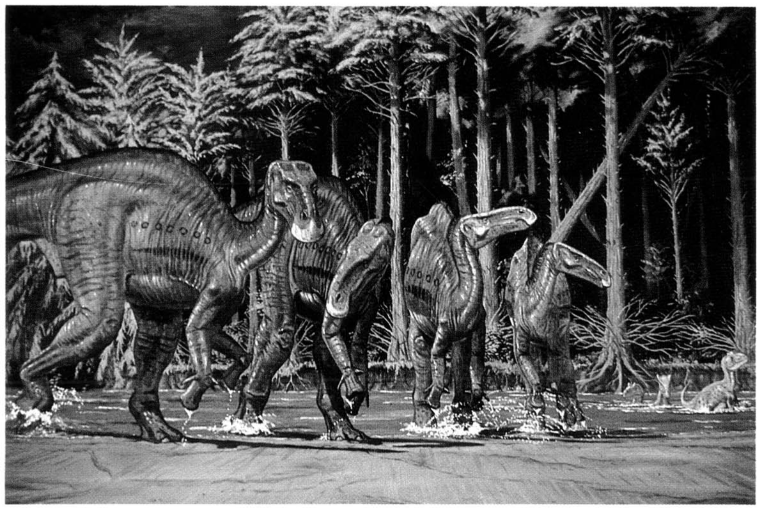


Figure 13. Traveling ornithopods, a restoration by Gregory Paul suggested by a set of tracks showing at least ten ornithopods moving together in one direction. A portion of the trackway indicates that at one point one animal lurched sideways and bumped into a second, creating a domino effect of stumbling that involved four animals; the animals apparently then recovered and resumed their original course. Courtesy Tyrrell Museum of Palaeontology.

Opposite
Figure 11. A restoration of *Styracosaurus albertensis*, the dinosaur occurring in the bone bed shown in Figure 9, by Vladimir Krb. Checklist 94.

male may be as big as a four-year-old female. The fact that we have distinct growth stages in the *Centrosaurus* bone bed suggests two things: first, that the species probably bred at a certain time each year and, second, that these individuals died at the same time.

Almost all of the carnivore remains in the *Centrosaurus* bone bed are isolated shed teeth. Dinosaurs replaced their teeth throughout their life and probably lost most of their loose teeth when they were eating. When we find large numbers of shed carnivore teeth, then we look for other evidence that they were feeding. A great number of *Centrosaurus* bones are broken in such a manner as to suggest that they were still fresh, or "green," when they were trampled by a heavy animal. Finally there are many specimens where the teeth left impressions on the bone when they scraped the flesh off.

Putting together all the information collected to date (Currie and Dodson 1984) suggests that a herd of *Centrosaurus* attempted to cross a river in flood (Fig. 8). As individuals they may have been able to swim quite well, but crowded by other members of the herd many of them were drowned. This sort of event is common even now with herds of herbivorous mammals. For example, in the winter of 1984/1985 more than four thousand caribou drowned when they tried to cross a river in flood along their migration route in Quebec. As in the modern tragedy hundreds of carcasses of *Centrosaurus* were washed downstream onto sand bars, point bars, or the banks of the river itself. Carnivorous dinosaurs scavenged the cadavers along the river, dropping their loose teeth and breaking much of the bone. The skeletons then lay in the sun for the rest of the dry season, while the remaining soft tissue (muscles, ligaments, tendons, and so on) decomposed, and the bones separated. When the river once again flooded its banks, perhaps a year later, many of the small bones were washed downstream and the larger bones were buried in sand and mud. After seventy-three million years they are being dug up by paleontologists of the Tyrrell Museum. This is not the only possible explanation, of course, but it is the hypothesis that we have been working toward for five years. To date we have found little evidence to suggest any alternate story that is as reasonable.

Accurate records are kept of each bone bed discovered in Dinosaur Provincial Park, and there appear to be as many as ten bone beds for every articulated specimen. Whereas most bone beds in Dinosaur Provincial Park seem to include a broad sample of the Judith River fauna, about five percent of the bone beds seem to be monospecific. In 1984 a new bone bed was discovered in silt stone (mudstone), suggesting that the animals died in a quiet-water environment (Fig. 9). The dinosaur occurring here is *Styracosaurus* (Fig. 11), once considered to be a rare dinosaur in the park region. This site will be excavated in the near future. Bone beds for other ceratopsians are known, including *Anchiceratops*, *Chasmosaurus*, *Monoclonius*, *Pachyrhinosaurus*, and *Triceratops*. None of the more common hadrosaur bone beds of Alberta have been excavated to date, and it is unknown whether some of these are monospecific as well.

Microvertebrate sites are a special type of bone bed. All of the specimens are small, including the dinosaur teeth. Microvertebrate sites are worked either by collecting the specimens concentrated on the surface of the ground by water erosion or by shoveling the matrix into sacks, subsequently washing it through screens and sorting the concentrate under a microscope. At one time more than ninety percent of the animals known from Dinosaur Provincial Park were dinosaurs. Through the study of microvertebrate sites, however, it is now known that most animals were small animals much as in modern ecosystems. Many are still living today, including gar, sturgeon, frogs, salamanders, soft-shell turtles, alligators, crocodiles, birds, and small mammals. Microvertebrate sites can yield thousands of specimens in a single day, giving good, statistically viable samples for paleoecological studies.

At one time there were only two vertebrate-dinosaur footprint localities known in western Canada. The best of these was the Peace River Canyon of British Columbia, where staff now at the Tyrrell Museum worked from 1976 to 1979. About seventeen hundred Lower Cretaceous dinosaur footprints have been found in more than one hundred trackways. These were mapped and measured, nearly two hundred were cast (Fig. 10), and one hundred were excavated. In addition to giving us information on the soft anatomy of the foot, trackways show how the animals stood and walked and whether some species were facultative or obligatory bipeds. Footprints identify general types of dinosaurs that were living in the region, and some species are represented by growth series. The speed of the dinosaur may be calculated using a mathematical formula (Alexander 1976). The majority of herbivorous dinosaurs from the canyon were moving at between four and six kilometers per hour (Currie 1983), whereas the carnivores were averaging a much faster speed (up to seventeen kilometers per hour).

Interactions between some trackways help us understand dinosaur behavior. Many of the ornithopod tracks were made by swimming animals (Fig. 12). One spectacular set of trackways shows a herd of possibly ten ornithopods moving in one direction (Fig. 13). Four of these trackways suggest that one animal lurched sideways and bumped into another, who bumped into the animal next to it, and who in turn affected the course of a fourth animal. These animals then resumed their original courses and proceeded without any of the trackways intersecting.

In recent years more than a dozen footprint sites in western Canada have been investigated, although only two footprints have been found in Dinosaur Provincial Park.

Within a radius of two hundred kilometers of the Tyrrell Museum almost ten million years of dinosaur history are represented by three successive faunas. These are preserved in the Judith River Formation at Dinosaur Provincial Park, the Horseshoe Canyon Formation near Drumheller, and the Scollard Formation north of Drumheller. The Scollard is interesting in that it includes the Cretaceous-Tertiary boundary, marked by both a palynomorph change and a concentration of iridium (Sweet and Jerzykiewicz 1985). Dinosaur extinction remains a much contested area of research that produces far more theories than results. Alberta is one of the places that may answer some of the questions. There were thirty-five species of dinosaurs at Dinosaur Provincial Park, twenty known species of dinosaurs in the Horseshoe Canyon Formation, and fewer than half a dozen in the Scollard Formation. In the Scollard Formation the last dinosaur occurrence is almost six meters below the Cretaceous-Tertiary boundary. These facts suggest that in Alberta the dinosaurs died out before the end of the Cretaceous, after a long period of declining diversity. This underscores that two areas of research are particularly critical: Did dinosaurs die out rapidly or over a long period of time? And did they die out at the same time everywhere? Until these questions are answered, no one can arrive at a conclusive theory for the extinction of dinosaurs and their contemporaries.

The Tyrrell Museum has attempted to communicate the excitement of paleontological research to the general public. The building itself is located in the badlands (Fig. 14) so that the visitor can take advantage of the surrounding strata to learn how sedimentologists and paleontologists interpret and collect data and specimens. Along one of the nature trails is a bone bed that is actively worked during the summer months.

Inside the building many of the dinosaur skeletons are mounted on badland topography (reproduced in fiberglass) as a link to the badlands outside. Specimens of smaller fossilized plants and animals are displayed in cases in the foreground. All of this information is assimilated in the painted reconstructions. The oil paintings were done at one eighth natural size by Vladamir Krb and were enlarged using computer-controlled airbrushes that painted them onto canvas. The dinosaur mural, which is nearly 131 meters wide and 6 meters high, displays life-sized restorations corresponding to the skeletons in the foreground.

The dinosaurs are displayed in faunal associations; the Morrison Formation for the Jurassic, and three Cretaceous groupings for Alberta representing the Judith River, Horseshoe Canyon, and Scollard formations. In one area, the museum has gone one step further. A three-dimensional restoration was created by cutting and assembling a skeleton of steel to match the mounted skeleton of *Albertosaurus*. The framework was covered with

Figure 14. The Tyrrell Museum of Palaeontology, located in the fossil badlands near Drumheller, Alberta. The new museum and its associated field station make up the largest exhibition and research center for dinosaurs in North America.

steel mesh and styrofoam, giving the rough body form. Styrofoam was then cut and shaped into muscle structure and covered with a skin of fiberglass. The animal was then painted with some artistic license. Finally "scales" were added one at a time using hypodermic needles. Just before the textured skin was added, it was discovered that there were skin impressions on one of the *Albertosaurus* specimens in the collections of the National Museum of Natural Sciences in Ottawa, and this information was incorporated into the model. Because of the technique used the colors are deep and change when the direction and intensity of lighting are changed. An environment was constructed using artificial plants blended into the background mural. Two other animals joined *Albertosaurus* in this grouping. The first good restoration of an ankylosaur, *Edmontonia,* was completed using information recently published by Ken Carpenter (1984). Earlier paintings and restorations of ankylosaurs tended to mix several species into a single, superankylosaur that never really existed. Finally the sculptors Brian Cooley and Mary Ann Wilson completed the first restoration of the pachycephalosaurid *Stegoceras.*

The progression of interpretation continues through the use of aquaria and a "paleoconservatory" in the display area. The aquaria include living representatives of fossil animals; and displayed in front of the aquaria are both fossil and modern skeletons of the living animals. When the museum opened in 1985 soft-shell turtles, fresh-water rays, sturgeons, gars, and a selection of salamanders were displayed. The paleoconservatory—an area of about 1220 square meters—includes many of the plants that flourished in Alberta during the Cretaceous, including ginkgo, dawn redwood, katsura, magnolia, and other trees that can be found today in other parts of the world. It is hoped that people walk away with the impression that dinosaurs did not live all their lives in tropical swamps nor in the badlands.

Although the Tyrrell Museum has only been open since September 25, 1985, changes have already been introduced in the galleries to keep abreast of new discoveries in the field. Ten audiovisual theaters and twenty computer terminals offer opportunities to change programs quickly. Additional information on specimens is available on the terminals. There are sixteen interactive exhibits, where the visitor has an opportunity to push buttons and pull levers to see what kinds of reactions result. There is also a public-viewing window into the research section of the building, where visitors can watch dinosaurs being prepared and mounted.

In April 1986 construction began in Dinosaur Provincial Park on a relatively small field station that will include a 610-square-meter dinosaur display and an equivalent amount of laboratory and office space. The tendency is toward the development of regional programs stretching from Dinosaur Provincial Park to Drumheller and north along the Red Deer River to Dry Island Buffalo Jump, where a skeleton of *Tyrannosaurus* was recently excavated.

The collection, research, and display of dinosaurs in Alberta are continuing and should foster interest in the subject worldwide. And more than ever before, there is a close working relationship between artist and scientist that will intensify the public appeal of the dinosaur.

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