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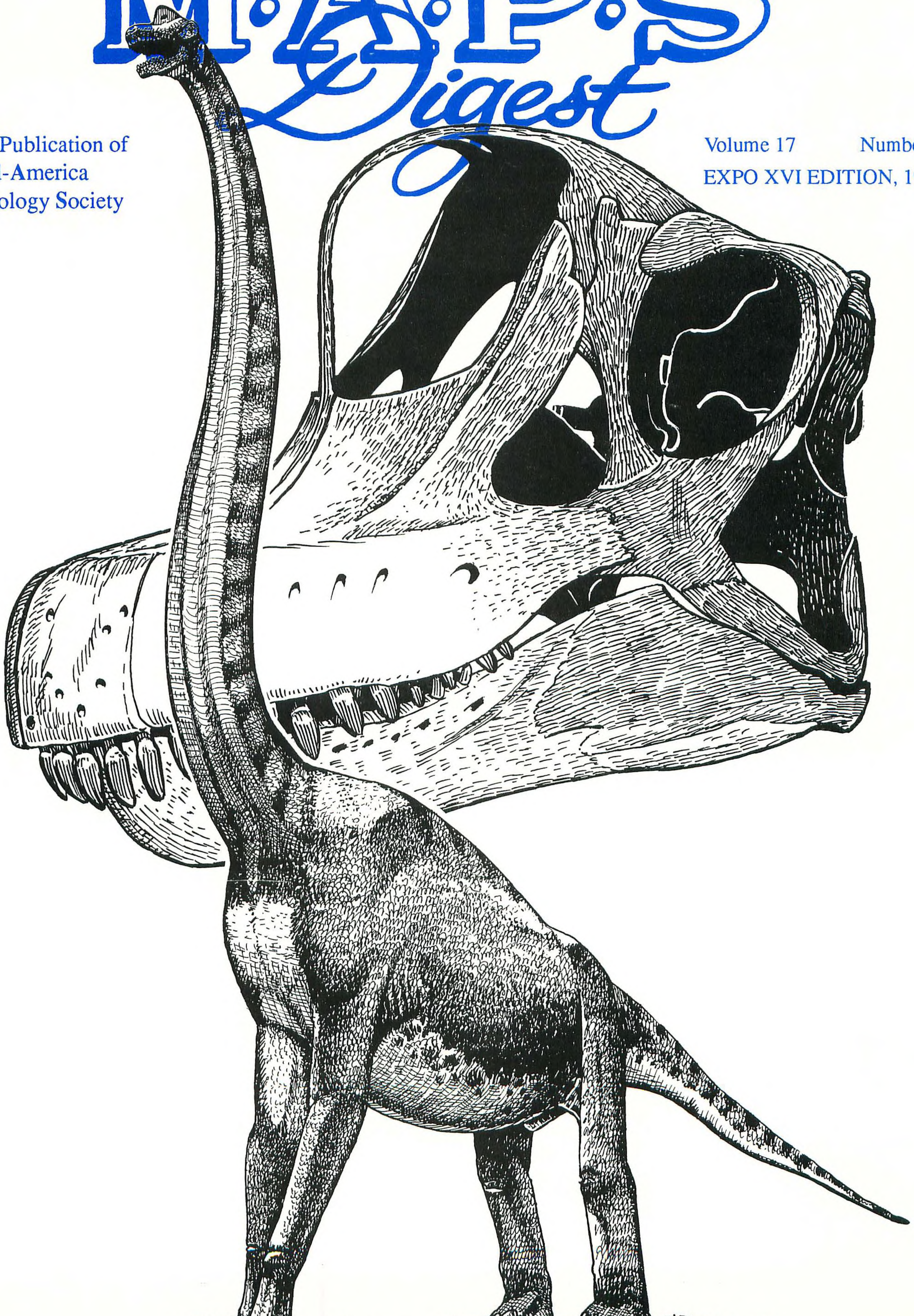

ABOUT THE COVER

The *Brachiosaurus* featured on the front cover_

ORDER - Saurischia
SUBORDER - Sauropodomorphia
FAMILY - Brachiosauridae

The largest dinosaur known from complete skeletons, with its giraffe-like neck up to 30 feet long, roamed the earth during the Late Jurassic Period searching for vegetation to feed upon. With its large size it needed to eat almost continually. It had the advantage of being able to eat from the tree tops, also to spot predators which might be lurking about.. The *Brachiosaurus* is found in North America and Africa, and has a *gentle - giant-like* appearance.

The back cover is the fierce carnivore *Tyrannosaurus* _

ORDER - Saurischia
SUBORDER - Theropod
FAMILY - Tyrannosauridae

The most popular dinosaur and easily recognized by its picture. The largest predator, with such powerful muscles, it could have run at speeds of over 30 MPH

It roamed North America and Asia during the Late Cretaceous period, and has the reputation of being the "ruler of the earth".

DINOSAURS

MAPS DIGEST

EXPO XVI EDITION

Mid - America Paleontology Society

A Love Of Fossils Brings Us Together

Western Illinois University
Union Ballroom
Macomb, Illinois 61465
April - 1994

ACKNOWLEDGEMENT

What an exciting time! Gathering information and data on **DINOSAURS** has been an experience I shall always look back on, and remember fondly. It has excited one of our most valuable resources, our children. When you mention dinosaurs they sit up and take notice; their eyes light up and an expression comes over their faces that should tell us, to get the word out to them about fossils.

I have seen this as I talked to children in the schools I've visited this year; they didn't mind if I had such few dinosaur bones and tracks to show them. I made up for that with posters and talk that was exciting to them.

If I had known as much about dinosaurs when I was visiting the schools, as I do now after reading all the interesting EXPO articles, I could have given the children a much better explanation of how they lived, raised their young and the environment in which they lived so long and ruled the world, as they did.

I thought of this great opportunity we have to open up to our young people the world of fossils and the facts (as we know them) rather than fiction.

But it also shows there is a higher power that rules the universe - or **Tyrannosaurus rex,** the **Allosaurus** and the **Supersaurus** might still be roaming the earth.

There are so many I want to acknowledge: Publishers - The Cambridge University Press, Qantas Airways Magazine and The Lapidary Journal for granting permission to reprint articles.

Artists, Authors and Contributors - David Peters; Thomas H. Rich and Patricia Vickers Rich; Kristin Donnan; Jim and Sylvia Konecny; Bruce Stinchcomb, David Parris, Barbara S. Grandstaff and Robert Denton, Jr.; Pamels Selbert; Allen Graffham; Anthony Verdi; Glen J. Kuban; Bill Morgan; Geoff Thomas; David Jones; Randy Faerber; Tim Stenerson, Cameron O'Conner; Dr. Donald L. Wolberg; and Larry D. Martin. A **Special Thanks** to the officers of **M.A.P.S.**

The Mid - America Paleontology Society was formed to promote popular interest in the subject of paleontology, to encourage the proper collecting, study, preparation and display of fossil material; and to assist other individuals, groups and institutions interested in the various aspects of paleontology. It is a non-profit society incorporated under the laws of the State of Iowa.

Margaret E. Kahrs, Editor
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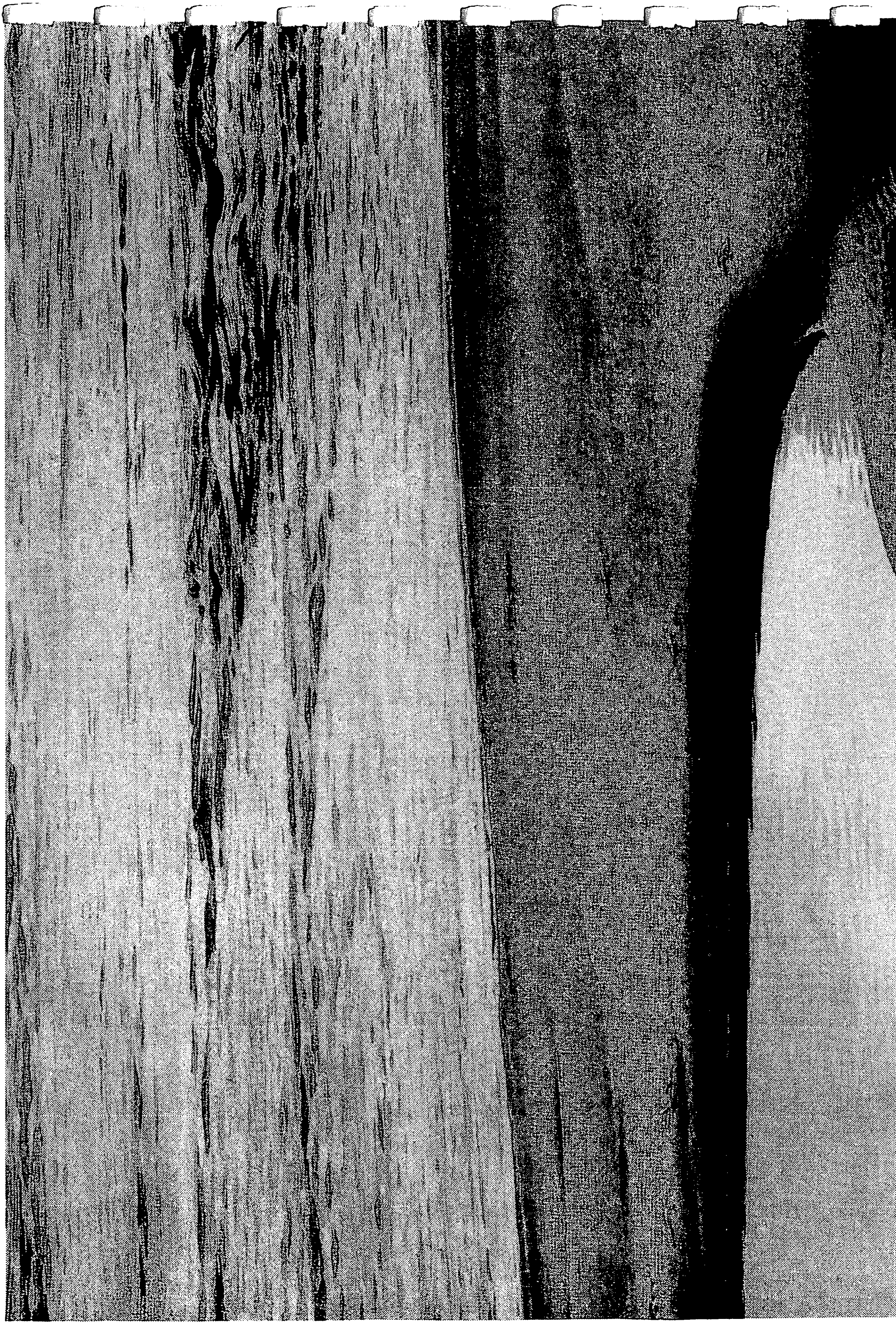
The following article "THE DINOSAURS WHO CAME IN FROM THE COLD", was contributed by Geoff Thomas and written by the Curator of Vertebrate Paleontology of the Museum of Victoria, Melbourne, Australia; Thomas H. Rich and Patricia Vickers Rich.

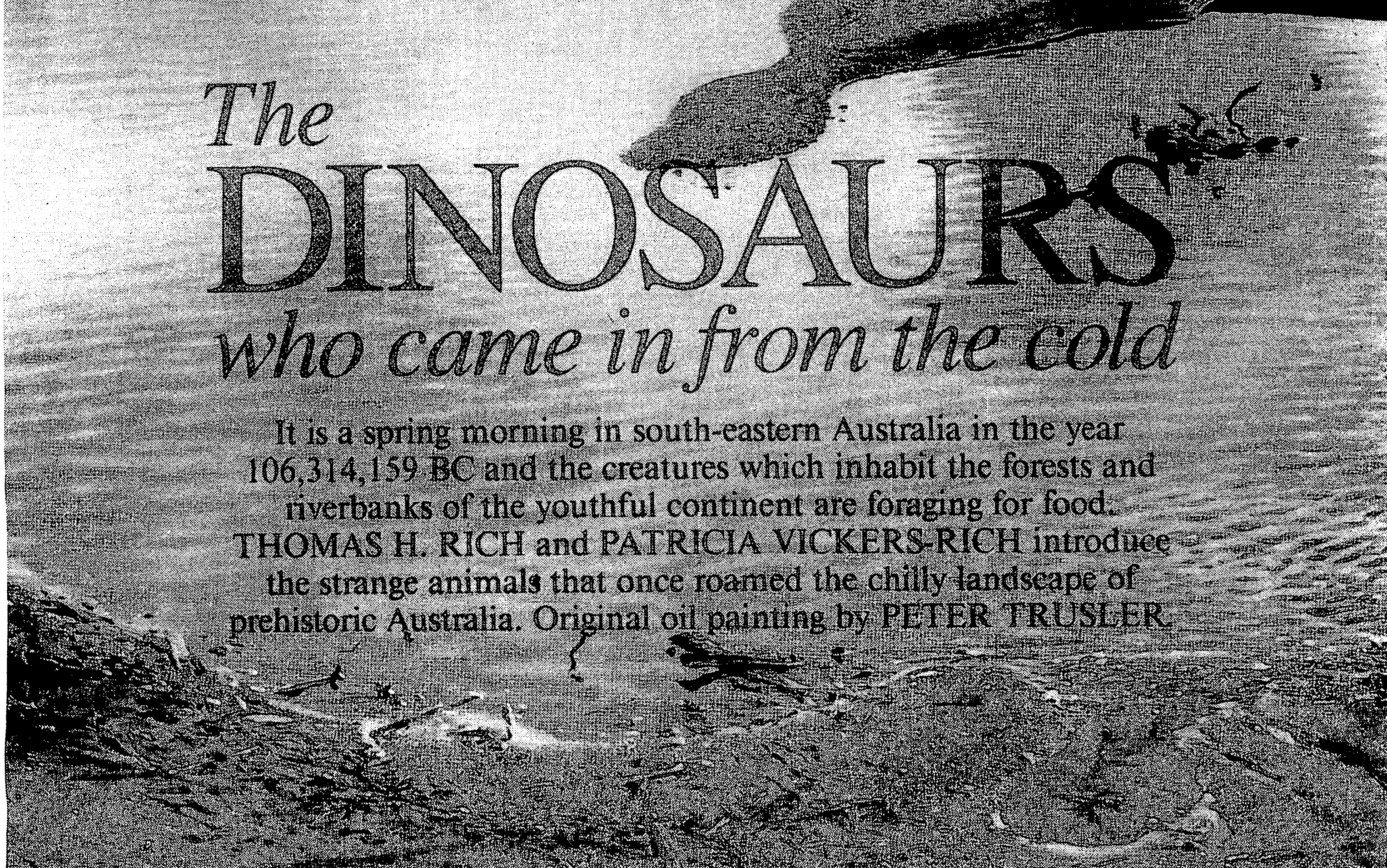
It appeared in the Qantas Airways Magazine January/February 1993.

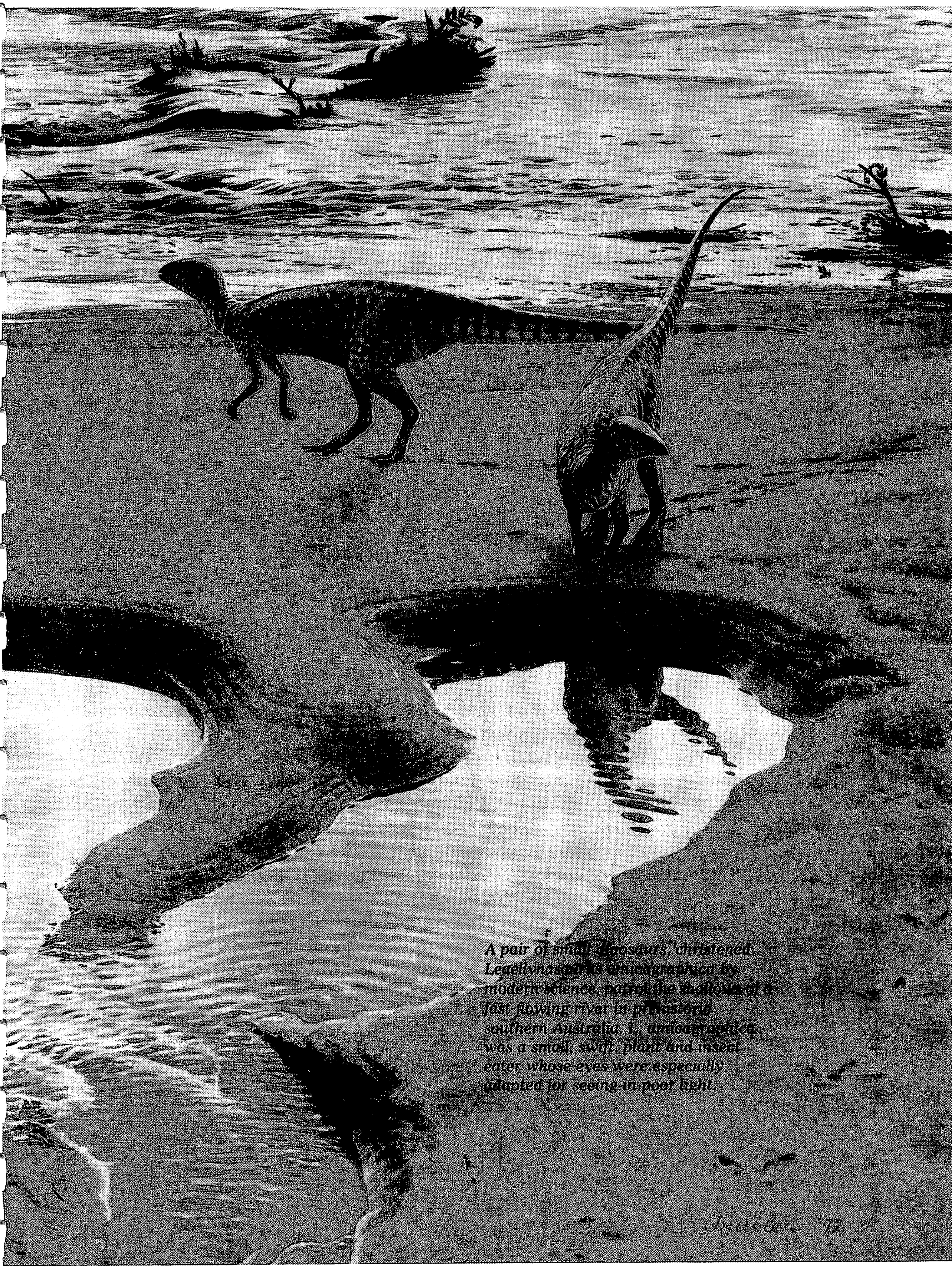
Permission granted to reprint by Mr. Brian Courtis, Editor of Qantas Airways Magazine Melbourne, Victoria, Australia. And the authors, Thomas H. Rich and Patricia Vickers Rich.



The DINOSAURS who came in from the cold

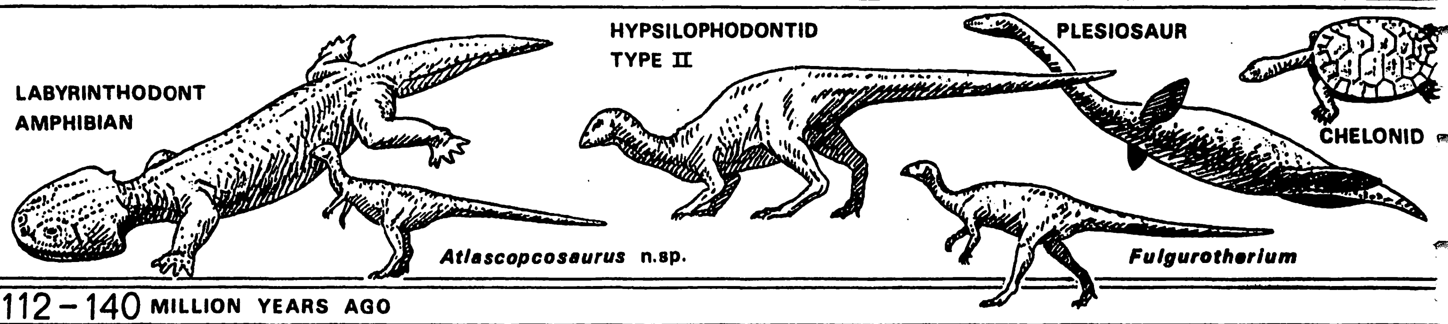
It is a spring morning in south-eastern Australia in the year 106,314,159 BC and the creatures which inhabit the forests and riverbanks of the youthful continent are foraging for food. THOMAS H. RICH and PATRICIA VICKERS-RICH introduce the strange animals that once roamed the chilly landscape of prehistoric Australia. Original oil painting by PETER TRUSLER.





A pair of small dinosaurs, christened Leaellynasaura amicagraphica by modern science, patrol the shallows of a fast-flowing river in prehistoric southern Australia. L. amicagraphica was a small, swift, plant and insect eater whose eyes were especially adapted for seeing in poor light.

STRZELECKI RANGES



112 – 140 MILLION YEARS AGO

THE DINOSAURS WHO CAME IN FROM THE COLD

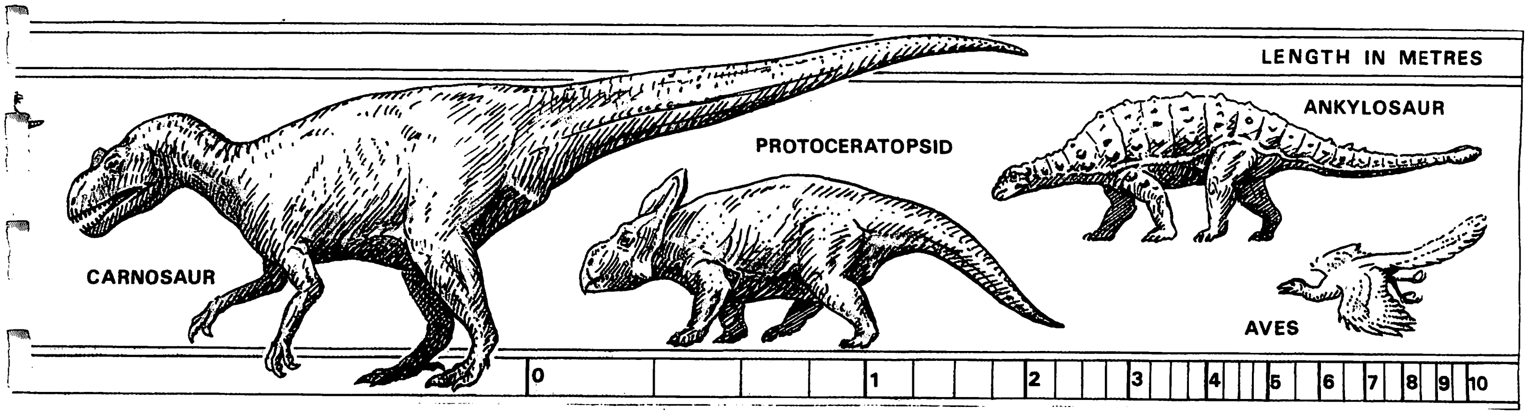
Thomas H. Rich and Patricia Vickers Rich
Museum of Victoria, 328 Swanston St.
Melbourne, Victoria 3000 Australia

Dawn, a polar dawn, came slowly during the early spring when dinosaurs lived in what is now the State of Victoria. Australia then lay close to Antarctica, more than 40 degrees closer to the South Pole than it does today. The south-eastern part of the continent was then well inside the Antarctic Circle.

In that long ago spring, a pair of small hypsilophodontid dinosaurs, *Leaellynasaura amicagraphica,* might have ventured down to the edge of a large, flood-swollen river to obtain a drink. These dinosaurs were herbivores standing perhaps 40 cm high and resembling modern-day potoroos in size and appearance although the two are only remotely related. The brains of these small dinosaurs show adaptation to the polar environment in which they lived; the optic lobes, where the nerve impulses from the eye are processed, were unusually large. Evidently this animal possessed enhanced visual acuity, suitable for seeing under low light conditions, such as prevailed for months at a time so close to the South Pole of the da

Caution was warrented for such small, inoffensive animals to venture out on to an open river flat; both large and small carnivorous dinosaurs lived in these cool climes as well. They left behind their footprints on the sandy river banks as well as their bony remains.

Debris floating by in the river, including logs of large , coniferous trees and pieces of charcoal, signalled another danger; the forest fires that occasionally swept across these massive conifer forest. The river also carried bits of the abundant and widespread ferns and palm-like cycads, all part of a varied flora like none known today. It was lush and diverse although living near the South Pole and occasionally it was unsettled by conflagration.



HOW ATLAS, ETC. GOT ITS NAME

How do dinosaurs come by their tongue-twisting names? When a dinosaur specimen is recognized to be distinct from all others, a species name can be proposed for it. For such a new name to be accepted as valid by the scientific community, a set of international rules and procedures must be followed. A complete name for a dinosaur comprises two words, not one; e.g. Tyrannosaurus (the genus) and rex (the species). A genus may have more than one species within it. The names often have Latin in or Greek roots.

Photo: Peter Menzel

In naming Atlascopcosaurus loadsi, recognition was given to a company (Atlas Copco Australia Pty.Ltd.) and a former Atlas Copco employee (Mr. William Loads) who provided mining equipment, without which the dinosaurs of southeastern Australia would be all but unknown. The root word *saurus* is Greek for "lizard", the closest word in that language to dinosaur as those animals were unknown in classic antiquity.

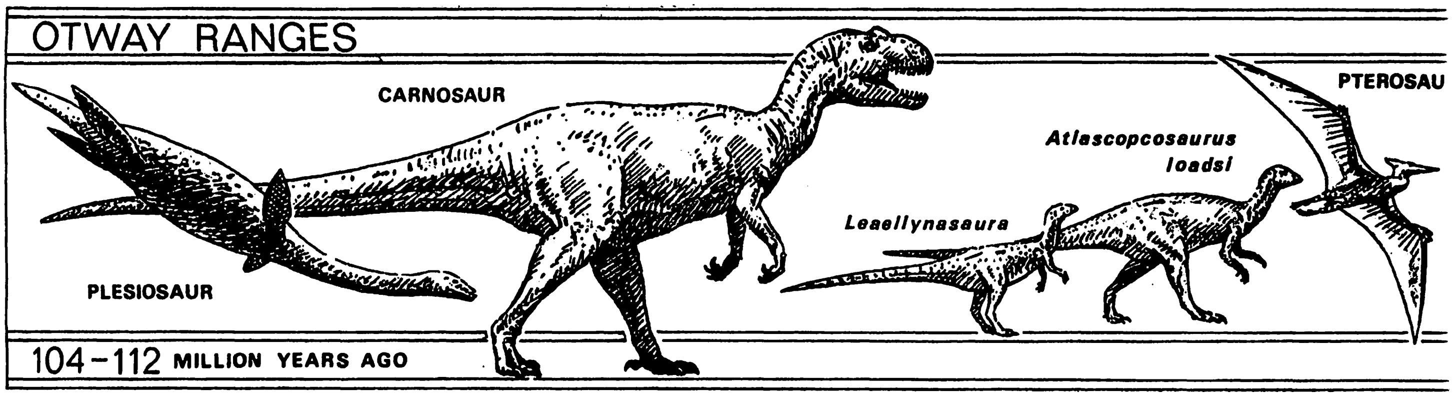
This picture of prehistoric life in south-eastern Australia is not a flight of fancy. Rather, it is the result of a careful synthesis of knowledge gained from fossils and the rocks in which they have been found at a number of localities scattered along the coast of Victoria. To gather this knowlegde, a joint program of Monash University and the Museum of Victoria has been underway for the past 15 years.

A major goal of the program has been simply to learn what vertebrates lived here so long ago and what the physical environment was like in this polar, yet not frigid, region of south-eastern Australia between 100 million and 125 million years ago.

The community of animals and plants experienced months of continuous darkness every year and the Southern Lights (Aurora Australis) may have been visible often. The area was not gripped year round in continuous, freezing conditions, however, unlike places of similar high latitude today. Because there is no modern counterpart to such an unusual biological community, the reconstruction of just how such an ecosystem functioned is the second principal goal of this project, one worth seeking even if it involves a monumental effort.

Finding and collecting fossils is the linchpin upon which this project relies. But obtaining such fossils is no simple task and numerous steps lie between the death of an organism and a museum drawer filled with fossil remains, begging a paleontologist to examine them.

When dinosaurs lived in southern Victoria, soft muds and sands were being constantly deposited in small streams, in large, rapidly flowing rivers and, during times of flood, on the floodplain that stretched across the rift valley floor between Australia and Antartica. Such sediments were transformed over millions of years into hard rock, the result of burial to depths as great as 3 kilometres below the Earth's surface as the



floor of the rift valley sank and it filled with volcanically-produced, air-fall debris. Only during the past 30 million years have these sediments been uplifted to form the Otway and Strzelecki Ranges.

From time-to time, the remains of animals and plants then living in the rift valley were buried in the sediments. As the mud and sands were compressed into mudstones and sandstones, these remains were fossilized. The study of both the fossils and the rocks in which they are buried allows us to reconstruct what polar southeastern Australia was like towards the end of the age of the dinosaurs.

These fossils have not been easily won and their collection has often required extraordinary measures. At the turn of the century, a single claw of a carnivorous dinosaur was found on a shore platform east of Melbourne. For the next 70 years this one specimen was virtually the only record of dinosaurs in south-eastern Australia. But from the late 1970's and beginning at the locality where the lone specimen had been found, systematic prospecting began to turn up additional dinosaur bones . At first they were found nearby and later, hundreds of kilometres to the west.

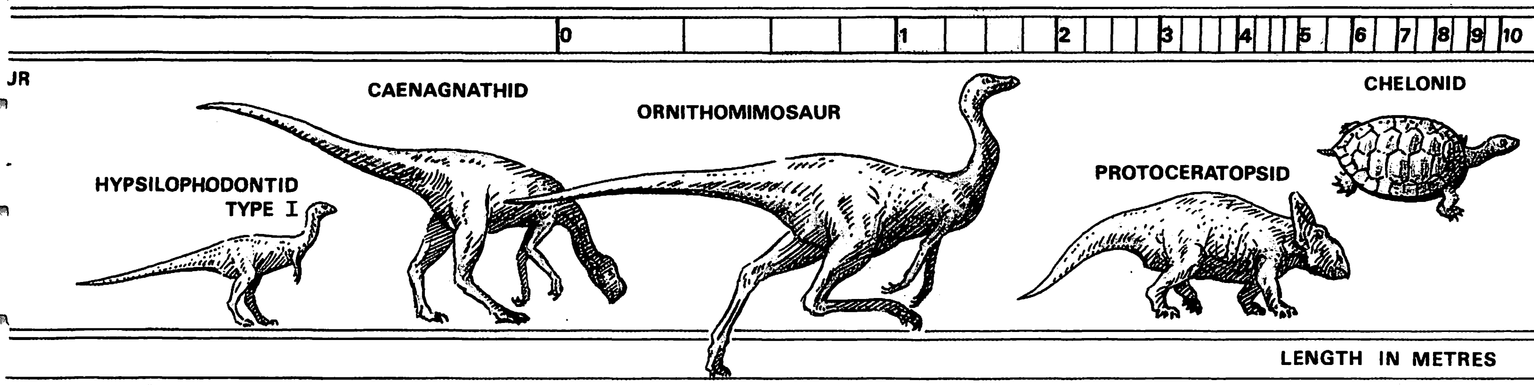
There was nothing magic about these discoveries. They occured because doggedly determined people who knew what they were looking for spent literally months closely examining every square metre of rock they could get to on shore platform along the Victorian coast. Paleontologists searched for any traces of fossil bones that might lead to significant discoveries once digging got underway. The chosen shore platforms were picked for a number of reasons.

First, because it is frequently swept by the pounding waves of the sea, fresh, bare rock is widely exposed there. Inland, the same kinds of rock are covered with vegetation, making it extremely diffficult to find any fossils. In addition, wave action means rock surfaces are fresh so that the chemical processes that normally convert rock into soil - and which frequently destroy fossils in the process - have not occured.

Second, the rock type on the shore platforms examined is sedimentary. Originally formed on the Earth's surface by accumulation of sand and clay particles, it has the potential to have buried within it bones, shells, and leaves preserved as fossils.

Finally these sedimentary rocks were deposited at the right time; when the dinosaurs lived and died. Although this was an interval that spanned more than 130 million years, it makes up only about 2 per cent of the total history of the Earth.

By the end of 1980, initial search for dinosaur localities on the shore platforms of Victoria was over. A site later to be named Dinosaur Cove, to the west of , Melbourne was deemed to have the greatest potential for dinosaur recovery. But underground tunnelling was necessary at Dinosaur Cove because the fossil-containing rocks went straight into a cliff.



So there the matter rested for more than 3 years because tunnelling is not something that paleontologists do lightly. Most have no experience with it at all.

But after much prodding by the newly formed Friends of the National Museum of Victoria, a 16 day excavation was carried out at Dinosaur Cove in 1984. The Friends provided funds to cover food and camping costs. Atlas Copco Australia, the heavy machinery engineering company, provided the mining equipment.

In the16 days, and despite knowing almost nothing about tunnelling techniques, the first crew managed to excavate an underground area in hard sandstone about equal in size to two telephone booths. From this small cavern 85 fossil bone fragments were recovered, including several that clearly belonged to dinosaurs.

That 1984 test excavation was a crossing of the Rubicon. With such favorable results, and growing confidence that the skills necessary to tunnel underground could be gained by a cadre of volunteers under professional supervision, the way was open to expand operations at Dinosaur Cove. In subsequent years, more sophisticated techniques were employed so that today there are 60 metres of tunnel, including two large underground rooms.

Outright cash support has been critical, for tunnelling is not cheap. The National Geographic Society together with Earthwatch, Coles and one private individual have made significant contribution. Corporate sponsors have provided most of the equipment and supplies. In addition to Atlas Copco which has supported the project from the beginning, principal amoung the corporate supporters have been Imperial Chemical Industries (explosives), Safeway, David Holdings and Coles (food), Shell and Mobil (diesel fiel), and Ingersoll Rand (mining equipment).

The work at Dinosaur Cove is scheduled to end in April this year. Although that phase of the program will become "extinct", sites newly recognized on the flanks of the Strzelecki Ranges promise to provide new insights into the polar dinosaur community of south-eastern Australia. Fortunately, these new sites will not require a logistical effort of similar magnitude to that at Dinosaur Cove because they are out in the open. Tunnelling for dinosaur bones in south-eastern Australia will, we hope, become a thing of the past.

Had the Strzelecki Ranges site been known a decade ago, Dinosaur Cove would never have been worked. It was because, Dinosaur Cove attracted enthusiastic volunteers when no other productive locality was in the offing, that additional sites were found. It was Dinosaur Cove volunteers who went off prospecting on their own who discovered the new site.

The new Strzelecki Ranges sites do not eclipse the significance of Dinosaur Cove but augment it because they are from 5 million to 20 million years older. They will provide paleontologists with glimpses of the polar dinosaur community through time, not restricted as hitherto to a single moment. Already, several insights have come from work in the Strzelecki Ranges. Animals that became extinct elsewhere in the world much earlier, survived later in the Strzelecki area. Principal among these "hangovers", or relicts, are the crocodilian- like labyrinthodont amphibians, animals that are more closely related to modern frogs and salamanders than to the reptiles they outwardly resemble.

Another late surviving group in the Strzeleckis were the carnivorous dinosaurs similar to the large bipedal Allosaurus, a relative of the well known Tyrannosaurus. Allosaurus became extinct in North America about 20 million years before they left their last known remains in Australia.

Because the record of dinosaurs in Australia is extremely meagre, it should not surprise us that strange and unexpected animals turn up. Yet it is still a surprise when a new beast is actually found, living well beyond its time. The horned dinosaurs or ceratopsians are such a surprise, a group which includes the well known Triceratops. Until 1992, the horned dinosaurs were thought to have evolved late in the history of dinosaurs, appearing about 95 million years ago. Until then they were believed to have lived only in Asia and North America, with questionable records in South America and Europe. It was not a group expected to turn up in the much older dinosaur- bearing rocks of coastal Victoria.

But in 1992 two bones found more than 200 kilometres apart, one in the Strzelecki Ranges and a second in the Otway Ranges, shattered this view. Both were ulnae (bone of the lower forelimb) and the Strzelecki specimen is strikingly similar to a small ceratopsian *Leptoceratops gracilis,* known from much younger rocks (about 65 million years old) from Alberta, Canada.

The two Victorian specimens are either ceratopsians or represent an unknown group that resembles ceratopsians in at least this one bone. Only further discoveries will decide the matter. The implication of these bones, if they are those of horned dinosaurs, is that the group may have originated in Gondwana, the great southern supercontinent, and only later spread northward to give rise to the impressive radiation of ceratopsians in North America.

So the picture that has emerged so far of life in polar Australia during the age of dinosaurs is only a partial one. Much more remains to be discovered. If what has been learned during the past 15 years is a guide, many intriguing surprises remain in store.

Volunteer workers remove overburden from fossil-bearing rock layers at Dinosaur Cove.

Volunteers sorting rock samples at Dinosaur Cove

The volunteer brigade

Without the contribution of volunteers, like those at right at Dinosaur Cove, little would be known about the dinosaurs of prehistoric south-eastern Australia. This is because the Dinosaur cove project is labor- intensive, even by the standards of dinosaur excavation which is nowhere an easy task.

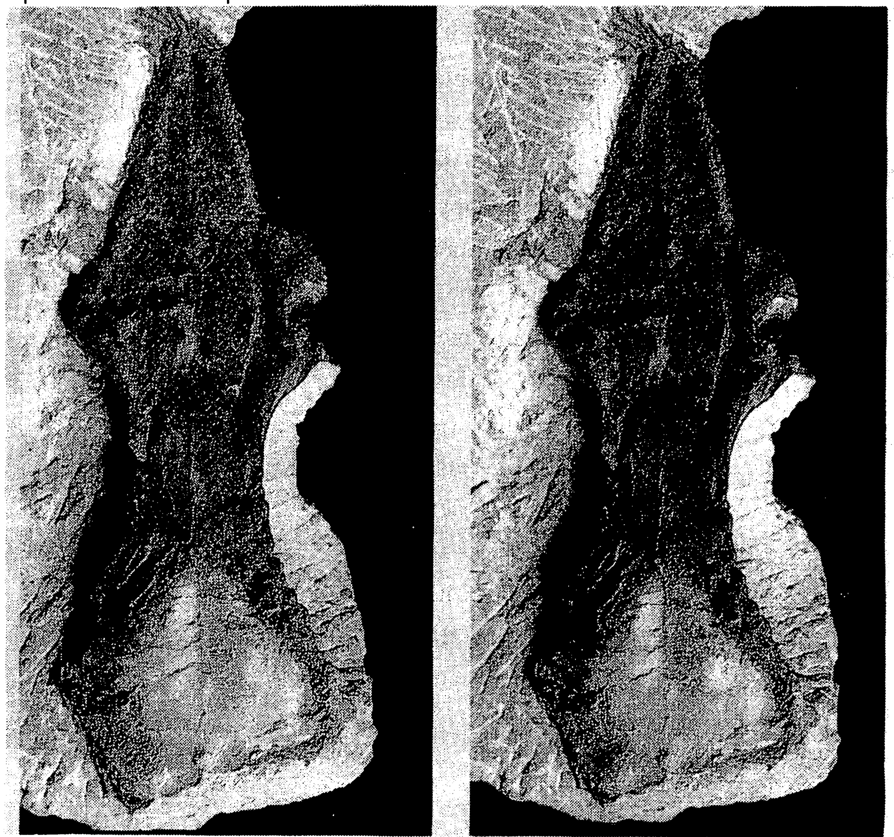
Estimated conservatively, at least 3,000 days of voluntary effort have gone into the work at Dinosaur Cove. One volunteer remarked, "you couldn't pay me to do this and yet here I am doing it for nothing!" The job could not have been done using paid labor because funding such a massive effort for the sole purpose of knowledge could never be economic. Many professionals, working as volunteers, donated time and skills to the project. They included mine managers, mine inspectors, explosives experts and mechanics. Without volunteers professionals and amateurs alike, the project would never have happened.

SEEING IS BELIEVING

These seemingly identical pictures, of top of a small dinosaur skull (length 52mm). are actually slightly different. The difference is about the same as your two eyes would see if you were looking at the actual object. Your left eye would see the left image and your right eye the right image. Because of the differences, your brain is able to form an image of the object in three dimesions, although each picture alone has only two dimentions.

In order to see this, separate the two photographs with a card or sheet of paper held vertical to the page. Similarly, separate your two eyes with the same card. Now look at the single picture visible to each eye. If you can manage to make the two images overlap to form one, the skull will appear to be three dimensional.

The left optic lobe which is so prominent on this specimen is seen on no other natural brain cast known in this family of dinosaurs.



Top of the skull of Leaellynasaura in three dimensions.

Fossilogue: *Ruth Mason Dinosaur Quarry, Faith, South Dakota, USA*
Rockdate: *65 million years before present*
Traveler: *Kristin Donnan*

Note: This "Fossilogue" is the first of an informal series of adventures into the past as experienced by the largest independent fossil preparatory in the world, the Black Hills Institute of Geological Research. Each trip will feature a specific event or locality that has revealed something new in the world of our ancient planet.

Keeping the Faith

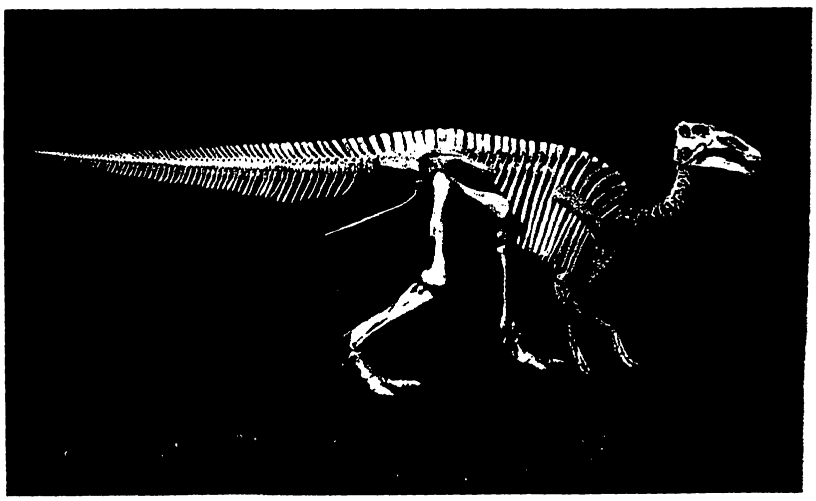
When I visited the quarry, it was mid-summer, 110 degrees, and dusty. The crew huddled beneath burlap sunshades and did what they do: they dug. They did not react to the several flies per minute that tickled their skin. They did, however, look at me through their sunglasses, beneath their visors, with one question: what did you bring to eat?

Their camp was a collection of tents perched on this hillside or that, a "kitchen" trailer, a shower with either frigid or scalding water, depending on your timing, and an outhouse. The river, a hike away through the prickles, was good for a splash, but there were virtually no trees for shade.

To the average vacationer, this is not the ideal setting for several weeks' respite from the daily grind. But for Peter Larson, "It's the most relaxing place to go. There is only one thing to think about, one thing to do, one thing to teach — fossils. There are no phones, faxes, or politics."

The children call it a "fun, usually never boring" place.

Due to the nature of the quarry, the approach to the work at the Ruth Mason dinosaur site is different than the approach taken in the excavation of a single animal's skeleton. Here, one is not confronted with a creature that may have politely lain down and died in a pleasant pose in the silt, and whose skeleton represents a virtual diagram of the beast. Mining this bone bed, where thousands of "duckbilled" skeletons are washed together, is a test of patience. It is also a cornucopia of information that necessitates many pairs of hands, many backs, and many minds.



"Dianasaur" poses for her "graduation" photo.
Photo: Ed Gerken.

After a few days, the flies faded from my consciousness, but it would be much longer before I realized that the quarry is both a product and an ingredient. It provides scientific information and a livelihood; it also contributes to the brains and lives of the people who dig there. It is the result of a commitment of time, money, and sweat, from its core group as well as myriad others individuals and entities who have shaped the experience over the years. I also began to appreciate more fully the positioning of my tent and the view of the shower door it provided.

ANCIENT FINGERS. It was near the turn of the century when Ruth was seven years old, riding horseback on her family's ranch in the prairie of northern South Dakota. That's when she saw them. Hundreds of them. She did not know what they were, but they looked like cow bones, except big and brown and broken. some of them were up to four feet long! Ruth hunkered down and looked at them, touched them. And Ruth imagined.

As she got older, Ruth stayed on the ranch, living the difficult life of the prairie. Through the range wars between sheep and cattle farmers, through her father's death and her own marriages, Ruth collected the bones, their ancient "fingers" reaching through her soil, and decorated her flower beds with them. She was unaware that her interest was in something called paleontology until one day she read about dinosaurs.

Ruth wrote to museums, none of which had money or personnel to come visit her desolate place in the Midwest. Still, Ruth kept faith in her pursuit, and finally, in 1979, when she was well into her 80s, Ruth was introduced to Peter Larson . At the time Larson and his brother Neal, along with friend Robert Farrar, had just incorporated an independent fossil collecting and preparatory business.
through their friend Kirby Siber, they were in the market for a dinosaur to sell to a museum in Europe. Pete came to visit Ruth's property and was astounded at the number of bones that lay within one knife-blade of the surface. "I didn't know where to start digging first," he exclaims. "They were literally everywhere!"

At long last, Ruth would witness what she had always dreamed. She watched the Black Hills Institute of Geological Research excavate the remains of what she had come to know as her extended family, officially members of the *Edmontosaurus annectens* species. She would live to see their skeletons reassembled, standing tall and glorious. And meanwhile, the Larsons inherited her love for dinosaurs.

With the support of Siber, the Larson brothers, Farrar, and their families started digging in 1979, but the Institute faltered for several years, close to bankruptcy - the European museum never raised the money for the specimen it had ordered, and no one bought a Larson dinosaur until 1983.

That year marked another turning point for the quarry, when the University of Wisconsin's Museum of Geology in Madison also wanted a specimen. However, instead of buying a dinosaur, Dr. Klaus Westphal brought students and museum volunteers who worked in exchange for some of the bones they unearthed. The University officially participated during the summer of 1983 to 1985 while diggers Jon Christians, Paul Ptacek, and Terry Wentz became talented paleontologists - and fixtures at the quarry for several years after that.

"Before coming to the quarry, I wasn't working in fossils at all," Wentz explains. "I'd been doing everything from advertising to taxi driving, and then someone said digging bones would be a neat thing to do. It changed my life!" Wentz became an official

Institute employee in 1987, and his enthusiasm for digging is still just as strong. During quarry season, he never leaves until the last vehicle pulls out.

University participation changed the face of the quarry by setting a new trend of volunteerism that maximizes bone production, along with increasing the Institute's exposure in the public and scientific communities. The volunteers bring fresh outlooks to the work and make valuable tangible contributions as well. Susan Hendrickson, an independent adventurer who volunteered for several years at the quarry, discovered "Sue," the worlds largest *Tyrannosaurus rex,* just two miles away.

Over the years, quarry diggers dodged floods, poisonous snakes, lightning strickes, fallen trees, fires, baseball-sized hailstones, propane leaks, injuries, and short tempers resulting from being "out there" too long. Bob Farrar achieved "veteran quarrier" status in 1980 after one stint of 62 days straight. "I was definitely supersaturated," he asserts. Since then I can only withstand a day or two at a time!"

However, the crew has also enjoyed awe-inspiring meteor showers and displays of the northern lights that "make you feel like you're being drawn right up into the heavens," according to another quarry vet, Denis Larson. Every person has a tale, whether it reveals the secrets of a Spam recipe gone wrong or a near miss with a rattlesnake. Each summer, the group becomes a family all over again, with a camaraderie that has spanned more than a decade already.

Countless employees, volunteers, scientists, and amateurs contributed time and energy to the site through 1991, by which time they had unearthed thousands of bones. The result to date is nine full skeletons, displayed in museums in Wales, Ireland, the Netherlands, Japan, and the United States.

The latest of the mounts, nicknamed "Dianasaur," is a juvenile composit *Edmontosaurus.* The Institute pioneered new techniques in mounting her, in that she is easily disassembled and portable. " Dianasaur" even became a teaching model, the centerpiece of "Dinosaurs on wheels," a mobil, educational outreach program for visiting schools.

With each summer comes more discoveries. Since the Institute is a business as well as a scientific entity, its owners strive for a combination of maximum efficiency and maximum quality. Their efforts have produced state-of-the-art methods of bone collecting and preparation, methods that have allowed superfragil dinosaur skeletons from the Hell Creek formation (where Ruth's ranch is located) to be successfully preserved for the first time.

"It seems doubtful that early collectors would have given serious thought to collecting bones from here," Pete muses. "Each bone is broken into hundreds, even thousands, of pieces." To be able to pick up the bones that usually fall apart, the Larson group began adding special glues and hardeners to the fossils while the fragments were still in the ground.

Pete explains: "Shellacs, Glyptal, and other hardeners have been used for years, but the Institute really pioneered the use of cyanocrylate (super glues) for field work. Now, many collectors have adopted this practice." These glues, plus the Institute's modified bone-jacketing process, allows these highly experienced excavators to work quickly, while protecting the fossil better than ever before.

Also with each summer arrive new faces. In 1991, two of them belonging to Barry Brown and David Burnham, added another note to the ever-changing science of paleontology. Brown and Burnham sifted the quarry dirt in an effort to catch small fragments of coelurosaur specimens (vulture-size carnivorous dinosaurs) that got lost in the big-dinosaur shuffle. Until their efforts, coelursaurs were thought to be very rare, but these two Institute employees found so many teeth in one spot that they changed that common perception.

And speaking of teeth, Matt Larson, Pete's Number One son, may have accumulated the worlds largest private collection of *Tyrannosaurus rex* teeth ever. He has the "gift" of finding things, a gift that apparently runs in the family. (At the age of 13, he asserts that he, too, wants to be a paleontologist.)

The bulk of the information learned from the Ruth Mason quarry, however, focuses on the huge herd of *Edmontosaurus annectens,* the duckbill dinosaurs, that died there. Nearly 10,000 bones from at least 100 individual animals have been unearthed and catalogued since 1979 - and only a portion of the quarry has been mined. Extrapolating from the quantities found, the Larson group estimates that the entire deposit contains several thousand duchbill skeletons. The presence of so many creatures in one spot allows for new knowledge about group dynamics, which can be tossed into the river of data on dinosaurs collected since the mid-1700s.

PIECES OF THE STORY. Larson tell a story about "Dianasaur" during his school assemblies that chronicles the life and death of the duckbill herd from Ruth Mason's quarry (see "Ruth Catches a Dinosaur"). The tail was compiled from facts and speculations drawn from this year there, along with research from other scientists' sites. The children hear the end result, imaginings that include life and death struggles and visions of vast numbers of huge beasts roaming the planet. These imaginings were drawn from the story told in the ground:

Ruth Catches a Dinosaur: How It Might Have Been

In his talks to school children, Pete Larson of the Black Hills Institute of Geological Research prepares stories portraying ancient life that are based on the facts he has gleaned from the Institute's field work and the work of other paleontologists at other sites.

It seems that you can hop from one to another, because as far as you can see, the earth is covered with them. The heads and backs of the huge dinosaur herd move back and forth like an ocean, for miles. Each 35-foot-long adult stands up on its two back birdlike feet to forage among the leaves and branches of the sequoia trees. Their necks are long enough for them to poke their flat bill-like noses among the higher limbs.

This year, a group of females is leaving the ever-migrating herd to lay eggs in the same spot the herd has used for generations. Each mother dinosaur digs a pit about six feet in diameter and deposits several eggs. She then covers her nest with twigs and leaves, which when they decay, provide warmth for the incubation of the young. Several weeks later, she scoops away the covering to reveal hatchlings unable to walk efficiently because their joints are so soft. The mothers fetch food for their hungry babies, perhaps for a few months. Finally, the mothers and young return to the herd

Ruth Mason (right) with Karen Alf, now of the Denver Museum of Natural History in a photo taken near Ruth's home in 1981. Photo courtesy Karen Alf.

When the alarm is sounded by the scouts on the outskirts of the herd, it is time to move. A predator is lurking, often one of those tall, huge things with small front arms and deadly teeth. Their jaws work like giant shears, and they can gobble a young duckbill in two bites. No chewing required.
But today, it is not a Tyrannosaurus rex at all. It is something mysterious that causes panic in the forward ranks. By the end, it will kill every last beast in this

gigantic herd. Whatever it is, it is deadly. Perhaps a disease, perhaps a huge storm, but something leaves a vast graveyard spanning one-half mile. Only bodies lie there.

First, the scavengers come, and then the rains. the carcasses of the families wash together, one atop the other, perhaps catching on their way to the near by inland seaway, only nine miles distant. Years and eons pile sediment, then more and more sediment, atop the site. Eventually, more than 100 feet of earth mask the remains.

The planet changes during this time, also. Heat and cold, ice and rain, and hugh upheavals plunder and rock the land. The topsoil above the duckbills no longer supports tall redwood trees. Now, there are rolling hills and prairie grasses. Slowly, the Moreau River begins cleansing the earth away. Layer after layer of time pulls off and rushes downstream, until in the early 1900s, little Ruth discovered the bones of a majestic group poking out of the soil on her ranch. She sees what we all can see, If we only take the time to look.- KD

* **Paleoecology.** The fossil record of 65 million years ago shows that today's prairies were not the same flat stretches of grasses, whose only protection from the sun is the visor on your hat. Then, the predominant plant was the sequoia tree, although deciduous trees and palms also lived in the warm, moist climate that supported crocodiles, salamanders, lizards, turtles, birds, small mammals, and dinosaurs. The duckbills shared the place with ceratopsians, tyrannosaurs, ankylosaurs, coelurosaurs, dromaeosaurs, and bird-mimic dinosaurs, among others.

* **Sociology**. In studying "Dianasaur's" huge herd, Larson uses the behavior of contemporary herding animals, like bison or wildebeests, as a model. "Herbivores travel together for safety," he explains. "A group consists of many females and few 'bull' males. Ruth's duckbill population seems to consist of a similar grouping of individuals, so we can postulate that they probably traveled and protected themselves in a similar fashion."

The lack of skeletal remains of babies supports research done by Jack Horner in Montana, where he discovered a duckbill nesting site. Apparently, the beasts bore their young away from the herd, and reintroduced them to the herd after they had matured in the "nursery." Very preliminary information at the Ruth Mason quarry invites speculation that the duckbills may have in "babysitting" behaviors similar to those exhibited by present-day cattle.

* **Taphonomy.** How the animals were buried (*taphos* is the greek for burial) and hence preserved is another piece of the story. In an effort to determine what led to the bone deposit, the Institute personnel look to the geologic record for clues. "Surprisingly, even after more than a decade of study, it is still impossible to confirm what caused the deaths of so many animals in one place," says David Burnham. "There is no sedimentary evidence of a volcanic eruption, for example. Most likely, some other catastrophic event, perhaps involving weather, took their lives."

The geologic record does say, however, that after the herd died, their bones were subjected to one or more episodes of flooding in what is now the quarry. The condition of the bones tells Larson *et al,* that the duckbills were covered by mud within a few weeks of their deaths.

* **Ontogeny** In studying individual development, comparison of specific bone lengths indicates that, similar to puppies or foals, young duckbills had large feet, long legs, and short noses for their bodies. By the time they reached full size, their proportions evened out.

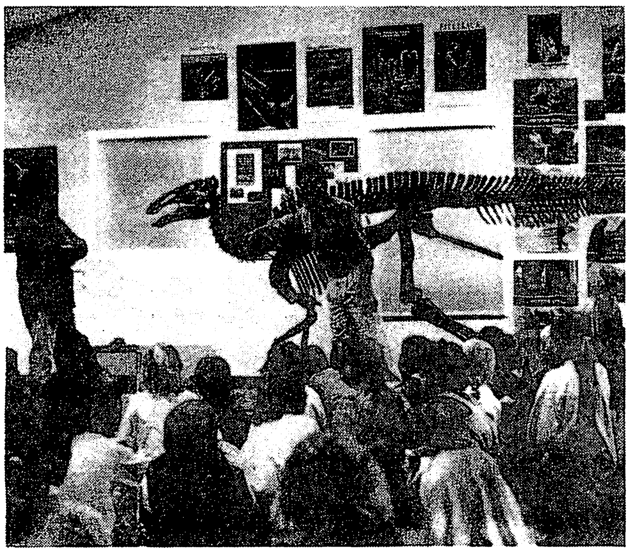
After graphing the bones collected from the quarry, Larson has identified what he believes to be four or five size plateaus within the herd, the smallest one representing each year's new youngsters. Much like annual pencil marks in our own doorways, these sizes might mark how much a young dinosaur grew in the few years it took to reach adulthood (a size they then retained for the rest of their presumed 15 to 20-year life spans). The largest size probably represents the "bull" males.

* **Osteology.** Believing that the group represents one herd, and therefore just one species, scientists can more accurately chart individual variations (similar to human comparisons of eye color or hand size) among the group. In minutely studying the bones, Gayle Nelms, from the University of California at Berkeley, is discovering just how many differences existed among Ruth's herd of duckbills. In the past, an isolated unusually shaped skull, for example, may have been thought to have come from a member of a different species.

Other bone information, including internal structural similarities with birds, supports Dr. Robert Bakker's theory that dinosaurs were warm-blooded. In addition, Peter Larson's current research into determining the sex of dinosaur skeletons of various species and groups finds preliminary correlation in this duckbill population. "I suspect that in this group, the larger, more robust bones represent the males, as occurs in other herding animals," he explains.

Ruth Mason died in 1991, at the age of 92, and the ranch and quarry are now owned by her nephew, Mel Spencer. Unfortunately, due to legal difficulties surrounding the *rex* named "Sue," the Black Hills Institute has temporarily suspended work at the Ruth Mason quarry, and workers have not dug there since 1991. "Dianasaur" is being sold to help defray legal costs (But the Institute hopes to build a sibling soon, to accompany "Dinosaurs on Wheels"). Even so, the company maintains its quarry camp, and everyone is anxious to resume work. I learned my lesson and stocked up for the next adventure: pie, ice cream, an inflatable swimming pool, and some lounge umbrellas.

This Article "Keeping The Faith", appeared in Lapidary Journal September 1993. Written by Kristin Donnan. Permission granted to reprint by Greg Landry , with the Lapidary Journal. ____Contributed by MAPS member Randy Faerber.



Peter Larson, David Burnham, and "Dianasaur" teach schoolchildren about ancient life. Photo: Kristin Donnan.

Barry Brown and Tim Larson plaster themselves and a bone in preparation for the bone's removal. Photo: Matt Larson.

Susan Hendrickson, Terry Wentz, Neal and John Larson, and Robert Tate pose with "Sue's" skull, found just two miles from the Ruth Mason dinosaur quarry. Photo: Ed Gerken.

DINOSAURS OF ARIZONA

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Arizona is noted for the Grand Canyon, giant saguaro cactus, romantic sounding place names (Hangman's Gulch, Skull Valley, Deadman Wash & Bloody Basin) but, dinosaurs in Arizona? Several western states are better known for their dinosaur finds but, yes, dinosaurs have been found in Arizona. In fact Arizona can boast that it is one of few states that has dinosaur remains from all three Mesozoic Eras - Triassic, Jurassic & Cretaceous.

Let us begin with Arizona's Triassic Park. No, I don't mean Jurassic Park. Arizona's Triassic Park is the world famous Petrified Forest National Park known for its beautifully colored petrified logs of _Araucarioxylon arizonicum_. The park sits upon the Colorado Plateau. This region is comprised of most of northern Arizona and parts of the adjoining states of the four corners area. (See Fig. 1). The deposits in the Petrified Forest National Park are of upper Triassic Age - Chinle Formation, Petrified Forest Member. This correlates with the Dockum Formation of Texas and the Newark Group of the east coast.

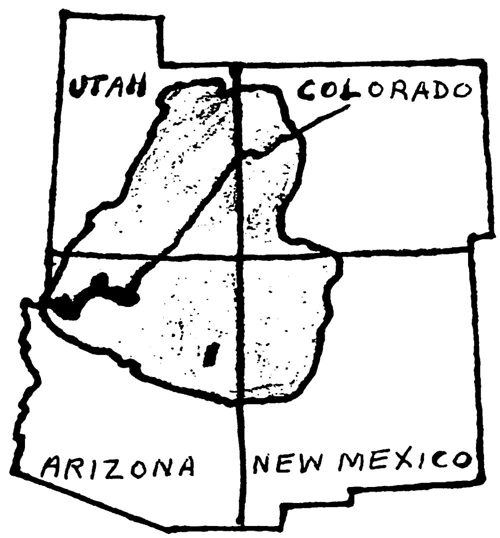


Fig. 1 Colorado Plateau

During the Permian this region was covered by a shallow sea. Following the withdrawal of the sea in late Permian the area was in a time of emergance in the Triassic. The climate was tropical/ sub tropical with seasonal rains much like the present day tropics. The region was a forest dominated by the conifer _Araucarioxylon arizonicum_. Other trees present were _Woodworthia arizonica_ and _Schilderia adamanica_. The understory consisted of several species of horsetails, numerous ferns, cycadoids and cordaites. The meandering stream running through this forest was inhabited by nine kinds of fish. The fish were preyed upon by the large amphibian Metoposaurus formerly known as Buettneria. Excluding the dinosaurs, the reptiles were represented by six genera.

Coelophysis leads the list of dinosaurs that inhabited this region. Although remains of Coelophysis have been found in the park it is best known from its discoveries by Dr. Edwin H. Colbert at the Ghost Ranch in Rio Arriba County, New Mexico. This spectacular find preserved many complete and nearly complete skeletons which appear to have been victims of a mass catastrophe. Coelophysis was a small carnivore, 5 to 6' in length, which probably fed on smaller reptiles. (See Fig. 2). Aside from remains having been found in Arizona, New Mexico and Utah bones have also been found in Connecticut which would indicate that Coelophysis was wide spread across North America during this time period. Prior to 1984 Coelophysis was the only dinosaur to have been found within the park boundries. In August 1984 while working in the Painted Desert portion of the park a team from the University of California - Berkeley discovered the remains of a great dane size dinosaur dubbed Gertie. (See Fig. 3). Prior to the recent discoveries in Argentina "Gertie" was the oldest dinosaur known.

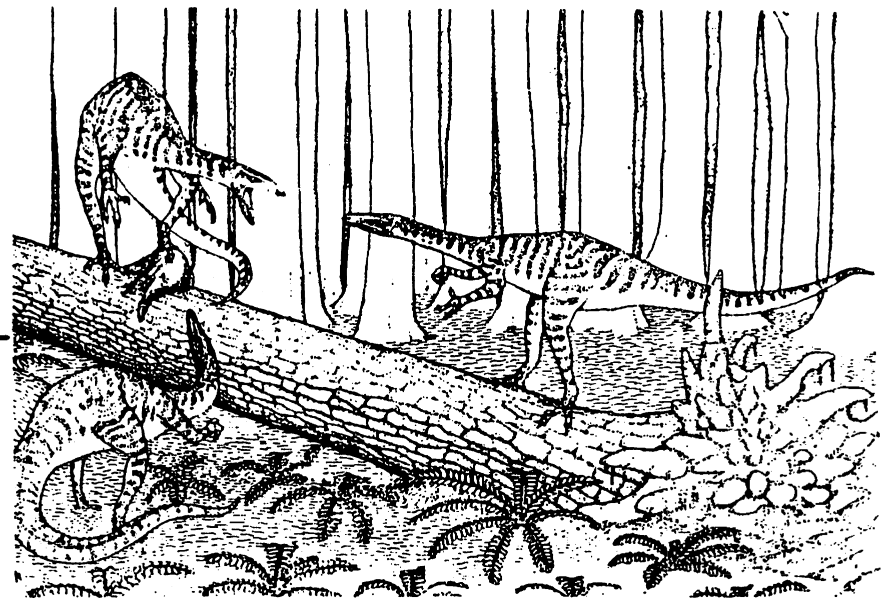


Fig. 2 Reconstruction of Coelophysis (from Ratkevich 1986).

Now let us move on to the Jurassic. Since the rocks of southern Arizona are mostly volcanic and clastic units the

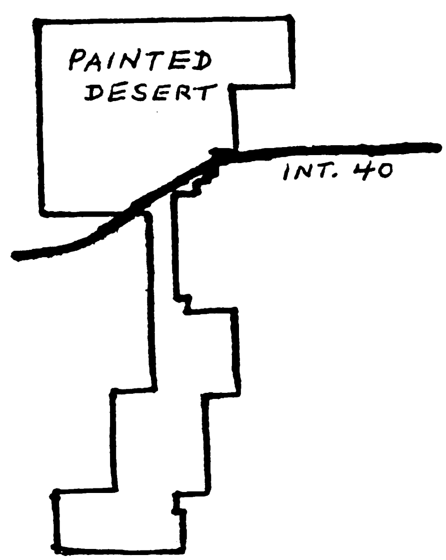


Fig. 3
Petrified Forest National Park

scope of this report will be confined to the Colorado Plateau. The rock units consist of the Glen Canyon Group which is comprised of four formations. This group extends from the Triassic into the Jurassic. The Triassic/Jurassic Boundary lies within this group. However, its exact position is still under debate. The Glen Canyon Group is overlain by the San Raphael Group which consists of six formations. This group is in turn overlain by the Morrison Formation. Depending on where the exact position of the Triassic/ Jurassic Boundary is determined it is possible that the time span of Coelophysis would extend into the Jurassic.

Aside from scattered bones the best dinosaur skeletal remains are those of a virtually complete skeleton of Dilophosaurus. Dilophosaurus remains have been found nowhere else in the world except northern Arizona. Like Coelophysis, this 20' long carnivore was bipedal. The head was topped with two plate like, parallel crests. (See Fig. 4).

Fig. 4 Reconstruction of Dilophosaurus (from Sadler 1993).

Also from the Glen Canyon Group a small ornithischian dinosaur has been identified as Scutellosaurus. Also bipedal, this 5' long critter was covered with bony plates, or scutes, similar to our modern crocodilians.

The most abundant Jurassic dinosaur remains are in the form of trackways. Museum of Northern Arizona, Flagstaff, files document six early Jurassic tracksites. Three other tracksites have been recorded, however, only limited information on these has been recorded. All of the sites occur in the various formations of the Glen Canyon Group. Seven different tracks have been reported from these sites. (See Fig. 5). Tracks or footprints are also known as ichnites, therefore the genera that these tracks are described from are known as ichnogenera. Based on the bones that have been recovered from this region it has been suggested that the possible trackmakers are Coelophysis, Dilophosaurus, Syntarsus, Segisaurus, Ammosaurus and Scutellosaurus. (See Fig. 6). Note that all of the trackmakers are bipedal. Makes one wonder if there is any significance to this.

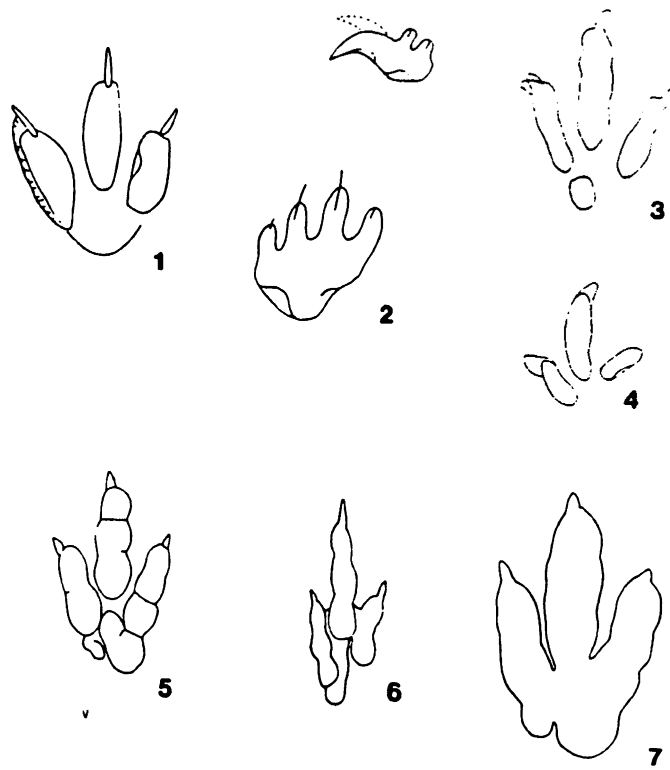
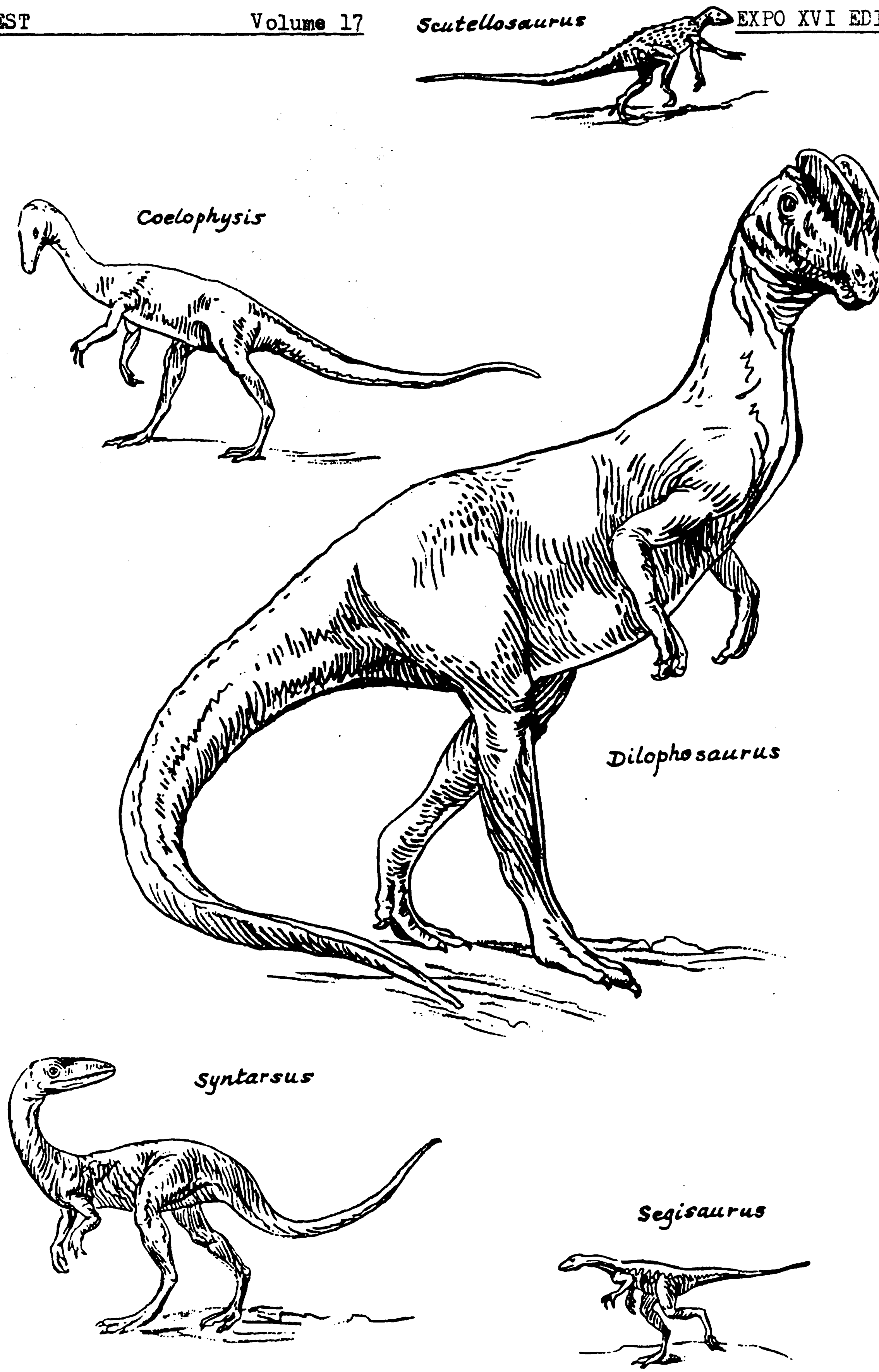


FIGURE 5--Ichnogenera reported from Early Jurassic sites in MNA paleontology files. Not drawn to scale. 1, *Dilophosauripus* Welles 1971, Sites 333, 389, 789, 1153; 2, *Navahopus* Baird 1980, Site 226; 3, *Kayentapus* Welles 1971, Sites 197, 789; 4, *Hopuchnus* Welles 1971, Site 197; 5, *Anchisauripus* Lull 1904, Sites 560, 789; 6, *Grallator* Hitchcock 1858, Sites 560, 789; 7, *Eubrontes* Hitchcock 1845, Site 789.

(from Irby 1993).

Though not as dramatic as skeletons, trackways, or rather the study of trackways, increases our knowledge of dinosaurs' social behavior and mobility. Keep in mind that the trackways are preserved exactly where the dinosaurs trod, wheras, skeletal remains in many instances have been transported after the individual's demise.

Recently near the town of Cameron a trackway of nearly 300 tracks was rediscovered. (See Fig. 7). Sometime in the 1930's R.T. Bird of the American Museum of Natural History in New York discovered and recorded this large trackway. Subsequently the trackway was covered with wind blown sediment. Although the site was recorded it's exact location was poorly described. In 1986 a fossil preparator at the Museum of Northern Arizona found a book which contained some poorly described photographs of the site.



(from Irby 1993)

Figure 6 - The trackmakers. Drawing by Margaret Colbert. Scale 1/32 natural size.

Using these photographs, by geographic orientation (matching the photos with the terrain) he was able to 'rediscover' this site.

Locality information to the aforementioned sites is unavailable, not only to protect them from vandalism, but because they are located on the Navajo and Hopi Indian Reservations. Only with written permission from tribal offices can these areas be visited. There is however a tracksite open to the public near Tuba City.

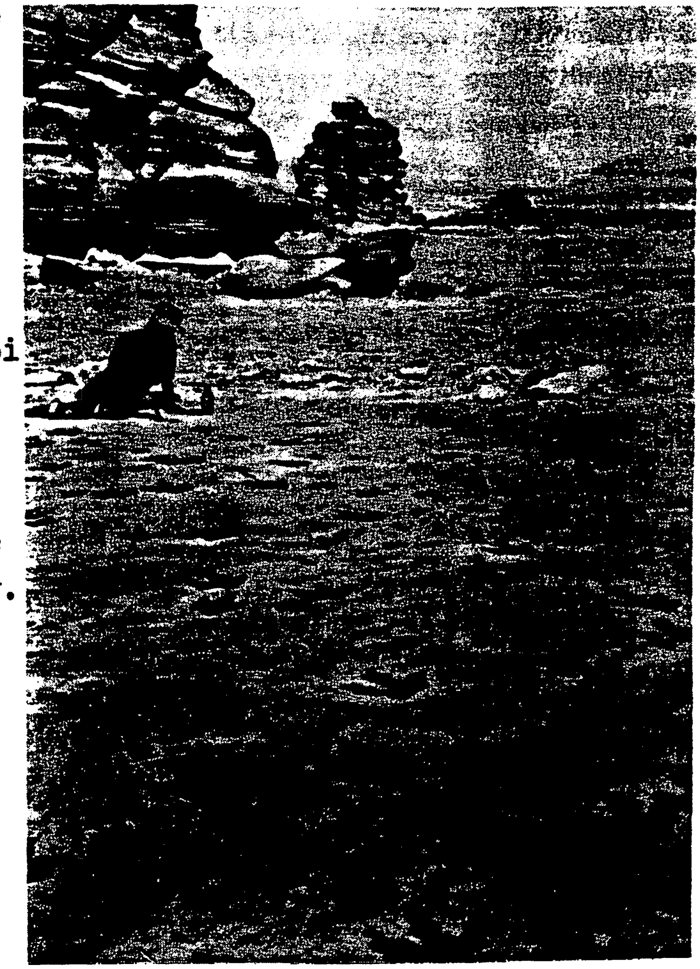


FIGURE 7--Self-portrait of R. T. Bird at Cameron Dinosaur Tracksite (from Colbert, 1983).

The Morrison Formation outcrops in northeastern Arizona mainly in the north and eastern edges of an area known as Black Mesa. This area is actually better known for its Cretaceous coal deposits. The Morrison Formation is known for its abundant and diverse dinosaur fauna in Utah and Colorado but it has received little exploration in Arizona. Some large dinosaur bones have been found in this formation, however, due to its extremely inaccessible terrain they have not been collected.

The last leg of our journey through the Mesozoic of Arizona takes us to the Cretaceous. Still on the Colorado Plateau we find that all the Cretaceous rocks are sedimentary. Two of the six formations are fossiliferous with impressions of flowering plants found in one and a varied assemblage of invertebrates along with shark and plesiosaur remains found in the other. But, alas, no dinosaur remains. The best Cretaceous dinosaur remains on the Colorado Plateau are found in New Mexico where a wealth of remains has been found.

We now move to the southeast corner of the state where a very limited amount of both lower and upper Cretaceous dinosaur remains have been found. Four formations comprise the Bisbee Group of lower Cretaceous Age. A nearly complete femer of an iguanodontid has been recovered from the Empire Mountains about 40 miles southeast of Tucson. Bones of a stegosaurian have been reported from the Papago Reservation near the town of Sells. The upper Cretaceous has given better results. Exposures of the Fort Crittenden Formation are found in Adobe Canyon in the Santa Rita Mountains. The abundant aquatic invertebrates along with fish and turtle remains point to this as a fresh water environment. Jaw fragments of a hadrosaur along with teeth of a carnivorous dinosaur have been identified from this locality. The teeth have been tentatively identified as *Gorgosaurus*. (See Fig. 8).

In conclusion, it is easy to see that there are no dinosaur quarries located in Arizona such as are found in Utah, Colorado, Wyoming, Montana and New Mexico. At the present time there is no indication that such an area exists. Aside from the Jurassic tracksites, dinosaur remains in Arizona are sparse. Never the less it is evident that dinosaurs inhabited this area for many millions of years.

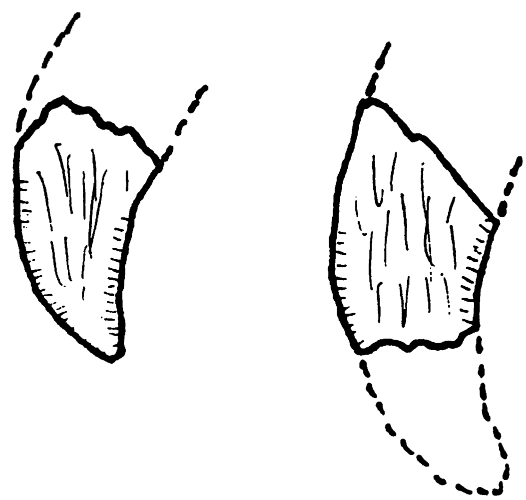


Fig. 8

Gorgosaurus tooth fragments (natural size) collected by the author's wife, Sylvia.

"Gertie" update:

It has been established that "Gertie" is a staurikosaur. Reconstructions of staurikosaurs can be found in the New Dinosaur Dictionary. Plans are underway to put "Gertie" on display at the Petrified Forest National Park late in 1994.

REFERENCES:

Colbert, Edwin H. 1972. Vertebrates from the Chinle Formation. Investigations in the Triassic Chinle Formation. Carol S. Breed and William J. Breed, Eds. Museum of Northern Arizona, Flagstaff.

Glut, Donald F. 1982. The New Dinosaur Dictionary, Citadel Press Secaucur, New Jersey.

Irby, Grace V. 1993. Early Jurassic Tracksites, Northeastern Arizona. Proceedings of the First Annual Symposium, Fossils of Arizona. Eds. Debra Boaz and Michael Doran. Mesa Southwest Museum, Mesa, Arizona.

Meyer, Larry L. 1986. D-Day on the Painted Desert. Arizona Highways, July.

Miller, Halsey W., Jr. 1964. Cretaceous Dinosaurian Remains from Southern Arizona. Journal of Paleontology, Vol. 38, No. 2.

Nations, Dale and Edmund Stump. 1981. Geology of Arizona. Kendall/ Hunt Publishing Company, Dubuque, Iowa.

Ratkevich, Ron. 1986. Meet New Mexico's State Dinosaur. Dinograph Southwest, Alamogordo, New Mexico.

Sadler, Christa. 1993. Life in Stone, Plateau, Vol. 64, No. 3, Museum of Northern Arizona, Flagstaff, Arizona.

EARLY BIRDS

A Short Survey of Jurassic and Cretaceous Birds

David Peters April 1994

In 1964 paleontologist John Ostrom unearthed the fossilized remains of an 8-foot-long, super-clawed, theropod with long slender fingers and a bird-like pubic bone. He named this killing machine *Deinonychus antirrhopus.* He and others soon began to realize that this rapacious dinosaur shared a suite of characters with a tiny archosaur which had been known for over a century – but not as a dinosaur.

Archaeopteryx, the earliest known bird, was not a dinosaur, according to most scientists, because, as Gerhard Heilmann convincingly stated in 1926, *Archaeopteryx* had a substantial furcula (fused clavicles), a feature known in no other dinosaur (at the time) yet traceable to more primitive archosaurs. Heilmann reasoned that *Archaeopteryx* must have been related to some, as yet undiscovered, Triassic archosaur. This theory is still held today by a few scientists.

Since 1926 a variety of dinosaur furcula have been recognized, most recently in an undisturbed allosaur specimen. Previously many were mistaken for gastralia (abdominal ribs) which they closely resemble.

Ostrom's discovery, however, convinced most paleontologists that birds are indeed maniraptoran theropod dinosaurs. In fact, as recent finds of the Argentinian protodinosaur *Eoraptor* have shown, *Archaeopteryx* has more in common with the very earliest dinosaurs than do virtually all others now known.

Mesozoic birds had been extremely rare in the fossil record until recently. Previous to 1974, only two well-preserved Cretaceous birds, *Hesperornis* and *Ichthyornis*, and six others fragmentary specimens were all that was known. And most of these were discovered before William McKinley took office. In the twenty years since 1974, nearly two dozen more Cretaceous birds have been discovered in Russia, China, Argentina, Spain, Canada and Australia, Brazil, Mexico, Chile, Antarctica, England, France, Romania, Korea, and Mongolia. Many are known from complete skeletons, sometimes including feathers. Footprints are also known. Each discovery is answering old questions and raising new ones.

The early radiation of birds is turning out to be more complex than anyone expected. Many of the early discoverers considered their find to be an important "missing link" between *Archaeopteryx* and living birds, and, to a certain extent, they were correct. Ironically, however, most are not related to living birds, but are members of a previously unrecognized order that did not survive the K/T extinction event. Chiappe (1991b) reconstructed the most recent and accurate family tree.

This report will summarize some of the most important and complete finds. A quick look at dinosaurs as a group, and *Archaeopteryx* in particular, will set the basic framework for an understanding of bird morphology.

Dinosaurs ruled the Mesozoic. The back of a dinosaur is short and stiff. The legs are long and erect. Together these features enable dinosaurs to run without wriggling from side to side, the way most sprawling reptiles do.

When lizards crawl in a sinuous fashion, they alternately contract their left and right ribs. This, of course, interferes with their breathing. In contrast, dinosaurs move without involving their ribs. They can run and breathe at the same time, enabling them to both outrun pursuers and prey. This was probably the number one reason why dinosaurs became so successful. A warm-blooded metabolism probably evolved at the time of their origin.

DINOSAUR

Among archosaurs,
dinosaurs share the following derived characteristics.

1. Some ankle bones integrated with the tibia.
2. Metatarsals (foot bones) elongated.
3. Digitigrade (typically walks with ankles off ground).
4. Fifth digit reduced or absent
5. Legs elongated.
6. Backbone short and stiff (13-14 dorsal vertebrae).
7. Neck S-curved.
8. Hind limbs erect, head of femur turned in toward acetabulum (hip socket).
9. Acetabulum completely perforated.
10. Five or more vertebrae attach to pelvis.

Meat-eating theropods were the most conservative dinosaurs, departing least from the original body plan. They retained a bipedal stance and meat-eating habits. With arms freed from the restraints of locomotion, most theropods reduced the size of their forelimbs. The earliest dinosaurs were about the size of *Archaeopteryx.*

THEROPOD

Among dinosaurs,
theropods share the following derived characteristics.

1. The second finger, rather than the third, is the longest.
2. Tibia with large knee crest
3. Tibia longer than femur.
4. Limb bones hollow
5. Hallux (1st toe) reversed, its base does not reach the tarsus (ankle).
6 Toes symmetrially centered on third toe.
7. 10 neck vertebrae
8. Furcula (fused clavicles) rarely present.

In direct contrast to most theropods, maniraptorans had longer arms and grappling hook fingers. In smaller arboreal forms these fingers were useful in grabbing tree trunks. Others leaped on prey larger than themselves. Maniraptorans include velociraptors, made famous in **Jurassic Park**. *Utahraptor* is the largest at 20 feet. The strangely crested plant-eating *Oviraptor* from Mongolia stood about 3-1/2 feet tall. *Troodon* was a slender speedster typically portrayed as the brainiest of the dinosaurs. Birds are the smallest maniraptors.

MANIRAPTORAN

Among theropods,
manirapotorans share the following
derived characteristics.

1. Shoulder blade very narrow
2. Clavicles fused (furcula present)
3. Arm elongated
4. Hand elongated and three-fingered, 3rd is bowed
5. Wrist bone semi-circle shaped for lateral hand folding
7. Pubic bones point toward rear
8. Tailbones stiffened

Aves are true birds because they are known to have feathers. Had feathers not fossilized, the most primitive avian, *Archaeopteryx,* would have been classified as a dinosaur. They were neither strictly arboreal nor terrestrial but lived both in trees and on the ground as do many birds today. As arboreal forms, they may have developed feathers to reduce the impact of a leap from a tree, to impress enemies and potential mates, and also as the insulation smaller endotherms need.

The first undisputed bird, and one of the earliest ever discovered, remains Archaeopteryx of the latest Jurassic. *Protoavis,* a Late Triassic contender for the title of earliest bird, is difficult to deal with due to the range of interpretations given to the specimen. The fact that all dinosaurs descended from a Triassic ancestor that was already very bird-like means that we will undoubtedly continue to discover crow-sized bipeds capable of leaping into and out of trees.

AVES

Among maniraptorans,
aves share the following derived characteristics.

1. Braincase enlarged,
2. Neck ribs shortened
3. Shoulder blades horizontal
4. Feathers
5. Calcaneum and astragulus (large ankle/heel bones) fused
6. Postorbital bone reduced or lost
7. Fewer than 25 tail vertebrae
8. Reversed hallux in contact with the ground.

ARCHAEOPTERYX LITHOGRAPHICA

(Meyer, 1861)
"Ancient wing of the printing stone"
Solnhofen Formation, Tithonian age
145-152 million years ago
Late Jurassic, Bavaria, Germany

Feathers make the dinosaur, *Archaeopteryx*, a bird. It has no other unique skeletal features not found in other maniraptoran theropods other than a reversed hallux (first toe) which reaches the ground and provides some measure of support. Other maniraptorans, such as the velociraptorids, troodontids, oviraptorids, and avimimids, may also have been feathered, but so far the evidence is lacking. *Compsognathus*, often cited as a "close cousin" to *Archaeopteryx* and found in the same sediments, had no feathers.

Details: The quadrato-jugal-squasmosal (cheek bone) articulation is absent. The teeth are small, sharp and conical.

The furcula angle is broader than in any other bird, and the furcula has no hypocleidium (medial strut). No calcified sternum (breast bone) is present. Gastralia (abdominal ribs) are present. The vertebral centra are amphicoelus (concave at both ends). Six vertebrae attach to the pelvis. The three paired elements of the pelvis remain unfused. The pubis is directed vertically downward. The tail is long and unmodified from that of a typical theropod.

The limb bones are hollow, but not pneumatic (filled with air). No pneumatic fossa (air hole) pierces the humerus. The three fingers are long and sharply clawed. Flight feathers emerge from the trailing edge of the forelimbs, but no papillae (pimples) are present on the trailing edge of the ulna.

The calcaneum and astragulus (largest ankle bones) are fused together, but not to the tibia where a suture line remains visible. The metatarsals (foot bones) are partly fused. The claws of the foot are not sharply curved.

Comments: According to many scientists, *Archaeopteryx* is too specialized to be the ancestor of all later birds because it has a large deltoid crest on its humerus, a strong furcula, and partly fused metatarsi, items not found in early Cretaceous birds (except *Concornis).* Larry Martin considers *Archaeopteryx* an enantiornithe bird. Luis Chiappe disagrees. Nevertheless, *Archaeopteryx* remains an excellent example of the mother of all birds. It is the sole known member of the order Archaeornithes ("ancient birds.") The Eichstätt specimen illustrated here is 1/3 smaller than other *Archaeopteryx* specimens.

Following *Archaeopteryx*, Early Cretaceous birds radiated widely both in geographical dispersal and in body shape. Over 30 genera of Cretaceous birds are now known. All belong to a group known as **Metornithes** ("Among the birds").

Mononykosaurs are the most primitive known metornithes. They are known from only one species at present, the recently discovered *Mononkyus* from Mongolia. The mononykosaurs are the sister group to all other Cretaceous birds. Their ossified and keeled sternum is evidence they were flyers at one time, but all known specimens were clearly flightless. They are the only Cretaceous birds known to have retained a long dinosaurian tail. The degree to which mononykosaurs were feathered is not known, but in living flightless birds, the feathers typically degenerate into a long hair-like structures.

Mononykosaurs

Among aves, mononykosaurs share the following derived characteristics.

1. Large rectangular keeled sternum
2. Fibula does not reach tarsus (ankle)
3. Gracile body proportions and long legs
4. Robust yet reduced forelimbs.
5. Manal digits II and III very small or minute
6. Manal digit I enlarged
7. Olecranon process (elbow) enlarged.

MONONYKUS OLECRANUS

(Altangerel, Norell, Chiappe, and Clark 1993)
"one claw, elbow head"
Nemegt Formation and Djadokhta Formation,
Maastrichtian age, 66 - 74 million years ago
Late Cretaceous, Mongolia

Mononykus recently made the cover of Time Magazine when scientists announced the discovery of this Late Cretaceous, stump-winged running bird. Primitive in most respects, it looked like a long legged, long necked version of *Archaeopteryx* with abbreviated wings tipped with a single stout claw. Claws like this are usually found on digging animals, so this combination of burrowing and running traits has caused quite a bit of head scratching.

Two skeletons were originally described, one twice the size of the other. One was collected in 1987 during the Soviet-Mongolian Paleontological Expedition. The other during the 1992 Mongolian-American Museum of Natural History Expedition. Between the two, nearly every skeletal element was found. A furcula (wishbone) was not found. Another specimen recently turned up in a museum drawer. It was collected during the Andrews Expeditions of the 1930s and labeled "bird-like dinosaur." Today seven specimens are known. The largest of these belonged to an animal 2-1/2 to 3 feet long.

Details: The skull does not have an accessory fenestra (a hole in front of the archosaur opening), unlike *Archaeopteryx* and other non-avian theropods. The ventral margin of the apparently toothless maxilla (upper jaw) lacks alveoli (nerve and vein perforations). A tiny sharp tooth, probably from the premaxilla, was found out of place inside the skull. The tooth is carinate (keeled) unlike the conical tooth of *Archaeopteryx*, but like those of *Ichthyornis*.

The small sternum has a keel and is longer than wide, unlike that of dromaeosaurids. Seven vertebrae fuse to form a synsacrum. The pubis lacks a boot. The pubis and ischium are not fused but are closely aligned along their entire length.

The coracoids are crescent-shaped and smaller than those of velociraptors. The unique little arms are robust and feature a huge elbow and a single large first digit tipped by a stout claw. Metacarpals II and III have virtually disappeared and digits II and III are absent.

In velociraptors femora, the two cylindrical articulating facets of the distal end are widely separated. In modern birds they grow together forming a pulley-like structure with a medial groove. In *Mononykus* the facets are wide with only a narrow space separating them. The tibia and tarsus are only partly fused. As in *Archaeopteryx*, the calcaneum is fused to the astragulus. The metatarsals remain unfused, as in most non-avian theropods.

Comments: Due to its ossified, keeled sternum and other features, *Mononykus* seems to be closer to living birds than is *Archaeopteryx*, despite its bizarre adaptations. Its presence indicates that an early, and previously unknown, branch of the avian family tree was present throughout the Cretaceous.

Except for *Archaeopteryx* and *Mononykus* all known birds fall into the group **Ornithothoraces** ("Bird breast"). For the small flying birds of the early Cretaceous, evolution seems to have favored a size decrease due to the fact that active flight is easier for a smaller tetrapod. Later some birds increased their size again as the flight apparatus became more refined. During the earliest Cretaceous, the bones concerned with flying were rapidly modified while those of the hind quarters remained essentially unchanged. In other words, the wings and tail quickly took on a modern appearance, but the legs and hips remained similar to those of their dinosaur ancestors. The reduction of the tail along with the enlargement of the head and sternum produced a forward shift in the center of gravity, toward the chest.

Ornithothoraces

Among metornithes, ornithothoraces share the following derived characteristics.

1. Dorsal vertebrae reduced to 11
2. Tail reduced to large pygostyle (10-15 caudals fused) plus 8 free caudals
3. Coracoids strut-like
4. Furcula with hypocleidium
5. Sternum with keel
6. Thumb very short
7. Foot claws enlarged

Two independent groups comprise the ornithothoraces: **Ornithurae** ("Birds") - modern birds plus their ancestors, and **Enantiornithes** ("Opposite birds") - Cretaceous birds with skeletal details not like those of ornithes.

Both groups produced similar-looking genera, yet details of their anatomy betray their separate evolution. Enantiornithes became extinct at the Cretaceous/Tertiary boundary. Ornithurae also suffered from extinction, but some members survived to repopulate today's world with flying dinosaurs.

SINORNIS SANTENSIS

(Sereno and Rao, 1992)
"China bird, place of three temples"
Valanginian age, 140 million years ago
Early Cretaceous, northeastern China

Known from one very fragmentary skeleton, *Sinornis* gives us a glimpse at the evolution of birds just 15 million years after *Archaeopteryx*. Since *Sinornis* was preserved in freshwater inland lake sediments, it was probably capable of flight, which occurs in most living birds only after they have grown to adult size. Other features of the sparrow-sized skeleton also indicate that it was an adult.

Details: The skull and cervical vertebrae are unknown.

The body and tail are both shortened. Gastralia (abdominal ribs) are present. A broad sternum and pygostyle (fused tail bones) are present. Only eight free caudals (tail bones) remain. 11 dorsal vertebrae are present, rather than 14 as in *Archaeopteryx* and most other theropods. The glenoid (arm socket) faces laterally, permitting the humerus to rise above the back during the flight stroke.

The humerus is not preserved. The ulna and second digit are twice the diameter of the radius and first digit, rather than subequal as in *Archaeopteryx. Sinornis* has small hands, greatly reduced claws, and a sturdy middle finger. Hence, the forelimb plays no role in securing prey, but is used only for flight. The carpus (wrist) and manus (hand) are separate and the metacarpals (hand bones) remain unfused. The wrist bones are modified like those of modern birds enabling the wing to fold in an acute angle of 70 degrees, in contrast to a maximum of 90 degrees for *Archaeopteryx.*

Sinornis is diagnosed on its saber-shaped ischium and its highly recurved foot claws. The pubic bone retains a foot. The metatarsals are fused only at their proximal ends as in *Archaeopteryx*. The 5th metatarsal, which was vestigial in *Archaeopteryx*, is absent here and in later birds.

Comments: *Sinornis* is commonly placed next to *Archaeopteryx* in cladograms because it is considered the most primitive of all known Cretaceous ornithurae due to the continuing presence of abdominal ribs and other features.

IBEROMESORNIS ROMERALI

(Sanz and Bonaparte 1992)
"Iberian intermediate bird"
species named for its discoverer, Armando Romeral
Las Hoyas formation, Barremian Age
124-119 million years ago
Early Cretaceous, Cuenca Province, Spain

Sparrow-sized *Iberomesornis* is known from a small articulated fossil. Only the skull and first few cervical vertebrae, manus (hand), carpus (wrist), and pubic bone are not preserved. It is found in the Las Hoyas bed (Early Cretaceous), in the Cuenca Province of Spain. This formation represents a lake deposit environment.

Details: The cervical neurapophysis (dorsal spines on the neck vertebrae) are absent. The cervical ribs are fused to the centra. *Iberomesornis* has eleven dorsal vertebrae as compared to 13-14 in *Archaeopteryx* and four to six in living birds. Eight of the caudal (tail) vertebrae remain free, but the last dozen or so are fused to form a pygostyle. Gastralia (stomach ribs) are absent. The coracoid is strut-like, as in modern birds, not crescent shaped. The furcula (wishbone) has a hypocleidium (midline projection) and an angle of only 60 degrees between the major prongs. Primitively *Iberomesornis* retains only 5 sacral (hip connecting) vertebrae.

The hind limbs are essentially unchanged from those of *Archaeopteryx*, except for size. The femur is only 15 mm long. The metatarsals are completely unfused. The unguals (claws) of the foot are highly curved, probably an adaption for a firm perching grasp.

Comments: Considering that *Iberomesornis* is intermediate between *Archaeopteryx* and later birds, the authors erected a new order for this specimen, the Iberomesornithiformes. They also erected the clade Euornithes for this bird and *Concornis. Iberomesornis* has no abdominal ribs, but is otherwise similar in many respects to *Sinornis*.

In the 1970s, paleontologist José Bonaparte discovered 60 presumed avian bones, including all of the major postcranial elements from at least 5 individuals. The fore- and hindlimb elements could be associated only tentatively. This find occurred in the uppermost (probably Maastrichtian) Cretaceous formations of Salta Province, Argentina. The habitat was probably a fluvial plain.

In 1981, Cyril A. Walker briefly described these specimens and named them Enantiornithes or "opposite birds" because of the unusual details of their skeletal anatomy. They remained unstudied until Chiappe named them in 1993.

LECTAVIS BRETINCOLA

(Walker 1981)
(Chiappe, 1993)
"Lecho formation bird, inhabitant)

YUNGAVOLUCRIS BREVIPEDALIS

"Yunga region bird, short foot"

SORAVISAURUS AUSTRALIS

"Sister of *Avisaurus*, southern hemisphere"
Lecho Formation, Maastrichtian Age
66-74 million years ago
Late Cretaceous, northwestern Argentina

The Bonaparte specimens represent three types of birds whose bones vary considerably in size and shape but with a shared basic structure. One type, *Lectavis bretincola*, had a long tarsometatarsus and tibiotarsus and was probably a wader or a runner. Another, *Yungavolucris brevipedalis*, had a very broad tarsometatarsus that fanned out distally, characteristics of a diving bird. The third, *Soravisaurus australis*, is related to the North American enantiornithine *Avisaurus*. In all three, the tarsometatarsi (foot/ankle bones) are only partly fused, indicating that this branch in the avian family tree probably split from other birds in the earliest Cretaceous.

Some of these birds were large. The largest forelimb probably came from an individual with a wingspan of at least 1 meter. In this specimen, however, a large sternal notch and a weak humeral articulation suggest that this particular bird may not have been a flyer, according to one scientist. Others disagree.

The earliest known form is *Concornis* from Spain, followed by *Nanantius* from Australia. At one time the enantiornithes were thought to have become isolated in the southern Gondwana continents, but recent finds in North America, Russia and China have extended the range of these birds worldwide. They became extinct, along with the other dinosaurs, at the K/T boundary.

Enantiornithes

Among ornithothoraces,
enantiornithes share the following derived characteristics.

1. Fourth metatarsal splintlike or more slender than second or third
2. Tubercle on front of metatarsal II (except Concornis)
3. Trochlea (pulley-like distal end) of metatarsal II broader than that of metatarsal III
4. Tarsometatarsus ossifies from proximal to distal, sutures remain visible (opposite living birds)
5. Tibiotarsus medial distal condyle bulbous, lateral distal condyle narrow
6. Tibiotarsus cnemial area without flanges
7. Nine sarcrals and a pygostyle often with a dorsal shelf.
8. Rear of sternum deeply notched with distal expansions on lateral processes
9. Sternum keel ossified from rear forward (opposite living birds)
10. Pubis sub-circular in cross-section (not flattened as in living birds)
11. Prominent bicipital crest on humerus
12. Head of humerus flat or concave
13. Convex posterior margin on coracoid (straight on living birds)
14. A facet on the scapula and a boss on the coracoid (opposite living birds)
15. Furcula articulates with scapula
16. Glenoid faces posteriorly

ENANTIORNIS LEALI

(Walker 1981)
"Opposite bird"
Maastrichtian age, 66 - 74 million years ago
Late Cretaceous, Salta Province, Argentina

This name appears only in the legend of a table and has become the basis for the entire group.

NANANTIUS EOS

(Molnar 1986)
"dwarf opposite, dawn"
Toolebuc Formation, Albian age
112-97 million years ago
Early Cretaceous, Queensland, Australia

Known from a single left tibiotarsus (shin/ankle), this small enantiornithe was the size of *Alexornis*, but distinctly different in detail.

Details: A single tarsometatarsus with a fibula flange extending to the proximal head. The distal condyles are distinctly unequal. The medial one is bulbous and the lateral one is quite narrow.

Comments: Small (2cm) feathers have been recovered in nearby rocks of a similar age.

GANSUS YUMENENSIS

(Hou and Liu, 1984)
Named for the Gansu Province
Xiaou Formation, 130 million years ago
Early Cretaceous, Gansu Province, China

Discovered in 1981 and known from only a single complete foot, Gansus was seen by Hou and Liu as the ancestor of shore birds and water birds and possibly an ancestor to Ichthyornis. A new order of birds was erected for this bird, the Gansuiformes. The foot and toes together measured about 7 cm. in length.

Details: Known only from an articulated left foot including a distal fragment of the tibiotarsus, a tarsometatarsus, and a complete set of toes. The longest toes (III and IV) are longer than the metatarsals. Toe IV is the longest, as in Hesperornithiformes and other swimming birds. The claws are slightly curved and without flexor tubercles (tendon attachments) which means it was probably not a tree-dweller.

Comments: The incomplete fusion of the metatarsals, their relative length and number, and the shape of the distal end of the tibiotarsus indicate that *Gansus* may be an enantiornithine, but Chiappe doubts it. Other enantiornithes were not compared in the paper.

CATHAYORNIS YANDICA

(Zhou Zong-he, Jin Fan, and Zhang Jian g-yong 1992)
"Cathay [old poetic name for China] bird"
Jiufotang Formation, 136 million years ago
Earliest Cretaceous, Liaoning Province, China

Discovered in 1990, *Cathayornis* is known from part and counterpart of a slab. It is virtually the only Early Cretaceous bird for which a complete skull is known.

Details: The skull bones remain primitively unfused. The occipital foramen (spinal cord opening) is somewhat ventral in position. The premaxilla (upper jaw tip) contains four teeth. They are conical with slightly constricted bases. Two teeth are found on each dentary (lower jaw).

The furcula is acutely angled. The coracoids are strutlike. The round sternum has a low keel at the rear and two posterior processes. The pelvic bones remain unfused. Eight sacral vertebrae are fused into a synsacrum. A pygostyle is present.

The humerus contains a pneumatic fossa (hole), as in most living birds. The bicipital crest is not strongly developed. The head of the humerus is low and flat. The ulna is twice the width of the radius. Carpi (wrist bones) and metacarpi (hand bones) are fused to form carpometacarpi, as in modern birds. The hand retains small claws and three distinct fingers.

No cnemial (knee) crest or supratendinal bridge is found on the tibiotarsus bone. The fibula is reduced but not fused to the tibiotarsus. The metatarsals are unfused. Digit III of the foot is the longest. The foot claws are strongly curved and pointed.

Comments: *Cathayornis* was probably arboreal and a better flyer than *Archaeopteryx.* A new order of birds was erected for this genus, the Cathayornithiformes. *Sinornis* is more primitive than *Cathayornis*, but a direct comparison has not yet been documented. *Cathayornis* is probably an enantiornithine due to the shape of its humeral head, the unfused metatarsals, and other features.

CONCORNIS LACUSTRIS

(J. L. Sanz and A. D. Buscalioni, 1992)
"Cuenca Province bird with a lacustrine habitat"
Las Hoyas formation, Barremian age
124 - 119 million years ago
Early Cretaceous, Cuenca Province, Spain

A contemporary of *Iberomesornis, Concornis* was twice its size and, therefore, 3 to 4 times as heavy.

Details: The specimen comprises most of the skeleton, excluding the skull. The sternum has a conspicuous posterior keel. The furcula (wishbone) is very large, flat and angled at 60 degrees. A long hypocleidium is present but is unfused to the furcula. The coronoids have a convex posterior edge. The pubis is equal in size and overall shape to the furcula and is fused at the distal end.

The limb bones are pneumatic (hollow and air-filled) as in modern birds. The humerus has a prominent bicipital crest. The ulna is broader than the radius but without scars for feather attachment. In ultraviolet light, however, feathers can be seen connected to the skeleton as in *Archaeopteryx.* The hand/wing is like that of some living birds. Claws are present on digits II and III of the hand.

The tibia and tarsus are fused to form a tibiotarsus. The cnemial (knee) crest is smooth. The three distal (far) ends of the metatarsus fan out as in modern birds and are tipped with distinct trochlear (pulley-like) structures. The trochlea of metatarsal II is the broadest. The proximal (near) ends are fused. Metatarsal IV is very slender.

Comments: The most striking difference between *Concornis* and *Iberomesornis*, is the large size of the hallux ungual (reversed toe claw) on the former. The other foot claws are only slightly recurved, as in *Archaeopteryx. Concornis* has recently been assigned to the enantiornithes due to a number of features. However, metatarsal II lacks a tubercle usually found on other enantiornithes.

ALEXORNIS ANTECEDENS

(Brodkorb 1976)
named for Alexander Wetmore, paleornithologist
Bocana Roja Formation, Campanian age
74 - 84 million years ago
Late Cretaceous, Baja California, Mexico

About the size of a sparrow, *Alexornis* is known only from fragments (nothing larger than a centimeter) of the humerus, ulna, scapula, coracoid, femur and tibiotarsus. Originally it was thought to have been ancestral to Coraciiformes (kingfishers, etc.) and Piciformes (woodpeckers, etc.), despite what the author recognized as a large number of unique features. In 1976 Brodkorb considered it the only certain land bird known from the Cretaceous. Today, after many subsequent discoveries in other parts of the world, *Alexornis* is considered an enantiornithe.

AVISAURUS ARCHIBALDI

(Brett-Surman and Paul 1985)
(Chiappe 1992)
(Hutchinson 1993)
"bird lizard"
Campanian age, 74 - 84 million years ago
Late Cretaceous, Utah

Avisaurus was originally described as a bird-like dinosaur. The discovery of enantiornithes shed light on its avian affinity. More complete remains of a second individual confirmed that it was indeed a bird very much like *Neuquenornis.* The disarticulated remains include most of the skeleton except for the skull.

Details: The posterior portion of the sternum is known, as is the rear of the pelvis, including a pubis with a prominent rear-facing boot. The furcula is long and slender and articulates with the scapula, not the coracoid, as in modern birds. The pygostyle (fused caudal vertebrae) has a dorsal shelf.

The ulna is in fragments, but feather papillae (attachment points) are present. The hand may have retained more mobility than modern birds possess. At least one large claw was present.

Comments: *Avisaurus* gives us more details on the anatomy of the enantiornithes and extends their range beyond the southern hemisphere.

NEUQUENORNIS VOLANS

(Chiappe 1991b)
"Neuquén Province Bird"
Rio Colorado Formation, Coniacian age
87 - 88 million years ago
Late Cretaceous, Neuquén Province, Argentina

This enantiornithine was the size of a falcon and is known from an articulated partial skeleton including all of the major elements except the front of the skull. It is the first articulated specimen of an enantiornithe bird known.

Details: *Neuquenornis* has not been completely described yet (see Chiappe and Calvo, in press), but observations of the specimen indicate it had a small keeled sternum. The sternum has lateral processes with expanded tips. The furcula (wishbone) has a hypocleideum . The scapula and coracoid are set at an acute angle.

The humerus shorter than the radius and ulna. The head of the humerus is slightly concave.

The legs are proportionately similar to other Cretaceous birds. The claw on the reversed first toe is very robust.

Comments: Previous discoveries had suggested that the enantiornithes had only limited flight capabilities. This bird, however, was clearly made to fly. It is is illustrated here with the name "Neuquén City Bird." *Neuquenornis* is related to *Avisaurus* under the family name Avisauridae.

UNNAMED ENANTIORNITHES

(Lamb, Chiappe and Ericson, 1993)
Late Cretaceous, Alabama

Two ichthyornithiformes and one enantiornithe bird were recently described from minute disarticulated elements discovered by screen-washing sediments. The enantiornithe is known from a pygostyle, a humerus fragment, a femur fragment and two vertebrae.

Details: The caudal vertebrae lack haemal (ventral) arches. On the dorsal vertebra, the tubercle for the attachment of the lower head of the rib is in the middle of the bone rather than at the anterior end, as in living birds. The pygostyle, as in Avisaurus, has a dorsal shelf.

The humeral head is concave in the middle.

The femur lacks a groove for the patella.

Comments: The presence of this enantiornithine in Canada confirms the worldwide dispersal of this group.

GOBIPTERYX MINUTA

(Elzanowki 1974, 1977, 1981)
"Gobi [Desert] wing, tiny"
Barum Goya Formation, Middle Campanian age
74 - 84 million years ago
Late Cretaceous, Mongolia

Gobipteryx is known from two incomplete skulls, each 45mm long, 2 incomplete embryonic skeletons and fragments of 5 others. They were discovered during the Polish-Mongolian Palaeontological Expedition to the Gobi desert in the 1970s. Adults were probably the size of a partridge.

Bird fossils are rare. Embryos are rarer still. Bird embryo fossils are almost unheard of. Those of *Gobipteryx* are extremely precocial (well-developed). The shoulder/wing areas are completely ossified and suggest that the chicks were able to leave the nest shortly after hatching. The beak is tucked under one wing, as in a chicken embryo.

Details: The incomplete skulls include a strong toothless beak pierced by 4 rows of nutrient foramina (vein passageways). The mandible was fused at the midline as in living birds. The quadrate (jaw hinge) was primitive, similar to that of *Archaeopteryx*. The length of each embryo was probably 4 cm. The eggs themselves were 4cm x 2cm in diameter. One dorsal vertebrae was enlarged and would have formed a hard ridge in the chick's back. Perhaps it was used to help break open the shell.

Comments: Elzanowski suggests that *Gobipteryx* is the oldest known palaeognathous (ancient mouth) bird. This group includes the ostrich, rhea, and kiwi, and is otherwise known only from Eocene to the present. Olson and Brodkorb do not place *Gobipteryx* with the birds. Cracraft suggests otherwise and places it as the sister group of the paleognaths. None of these writers made comparisons to the enantiornithes, but L. Martin, allies *Gobipteryx* with the enantiornithes.

PATAGOPTERYX DEFERRARIISI

(Chiappe and Calvo, 1989)
(Alvarenga, H.M.F. and Bonaparte, J., 1991)
"Patagonia [big foot] wing"
species named for Professor Oscar de Ferrariis

Rio Colorado formation, Coniacian age
87 - 88 million years ago
Late Cretaceous, Neuquén Province, Argentina

This strange flightless bird is known from 2 articulated specimens encased in sandstone plus other disarticulated parts. It once lived on a fluvial (flood) plain. The size of a chicken, *Patagopteryx* has wings only half as large as its robust running legs.

Details: Only the back of the skull has been preserved along with a portion of a toothless mandible.

Heterocoelus (both sides saddle-shaped) vertebrae, are restricted to the neck. 11 dorsal vertebrae are present. A synsacrum (fused sacrum) is present containing 9 vertebrae, although the last two do not articulate with the ilium. The synsacrum is much wider at the rear, as in modern birds. The end of the tail is missing. *Patagopteryx* has a sternum without a keel. The pubis is slender and does not end in a boot.

The wing is very small, but all the elements are present. Digit I is absent.

The femur is very robust. The tibiotarsus is longer than the femur and has a large cnemial crest. The tarsometatarsus is very short and the phalanges are long and stout. The foot claws are long and sharp.

Comments: A new family of birds was erected for this genus, Patagopterygidae, as well as a new order: Patagopterygiformes. A long coracoid indicates that *Patagopteryx* is derived from a flying ancestor.

Ornithurae

Among euornithes,
ornithes share the following primitive characteristics.

1. Beak, with subsequent loss of teeth in laterforms.
2. Dorsal vertebrae reduced to 6, 5 or 4
3. Pygostyle reduced
4. Pelvic bones fused
5. Carpals and metacarpals (hand bones) often fused, manal digits often reduced
6. Development of the joint surfaces to facilitate the folding of the wing
7. Humerus head round
8. Humeral articulation for radius and ulna well-formed
9. Sternum and keel enlarged (sometimes reversed)
10. Groove on coracoid for the passage of the tendon of the supracoracoideus muscle (wing lifters)
11. Facet on coracoid, boss on scapula
12. Glenoid faces laterally
13. Furcula articulates with procoracoid process of coracoid
14. Metatarsals fused from distal to proximal
15. Cnemial crest on tibiotarsus with flanges

All living birds plus Hesperornithiformes, Ichthyornithiformes and *Ambiortus* are ornithurae. Two of the latter three are known to be toothed. It is likely that *Ambiortus* also had teeth. This feature separates these extinct forms from all living birds.

Hesperornithiformes - diving birds, wings reduced
Ichthyornithiformes - gull-like seabirds

AMBIORTUS DEMENTJEVI

(Kurochkin 1985)
"ambiguous beginning"
Species named for Prof. G. P. Dement'yev
Khurilit-Ulan-Balak locality,
Neocomian/Aptian age, 113 - 124 million years ago
Early Cretaceous, Mongolia

Ambiortus was among the first Early Cretaceous birds found. The only known specimen, discovered in 1977, comes from a shallow lake deposit in Mongolia. *Ambiortus* is known from a typically avian scapula and coracoid, a keeled sternum, a humerus fragment, a partial carpometacarpus (wrist/hand), a finger, and a string of 11 cervical vertebrae and 3 dorsals, plus feather impressions. About the size of a small crow, *Ambiortus* was an advanced bird and a good flyer. Its skeleton shows similarities to *Ichthyornis* and certain palaeognathus (primitive palate) flying birds.

Details: The middle cervical vertebrae are amphicoelous (biconcave), as in Archaeopteryx and Ichthyornis, but unlike all modern birds. The furcula has no articular facets, a primitive trait. It is also equally thick along its length, unlike modern birds in which the furcula either narrows or widens at the tips.

On the humerus, no bicipital crest appears. A procoracoid process is present on the coracoid.

Comments: *Ambiortus* is known from deposits only 25 million years younger than those in Solnhofen where *Archaeopteryx* was found. It is an ornithuran due to the presence of the procoracoid process.

Known since before the turn of the century, the large flightless diving birds known as hesperornithiformes have intrigued avian paleontologists who have tried unsuccessfully to ally them with modern loons and grebes. Despite having many primitive features, it is clear that these diving birds descended from flying relatives. They are a sister group to living birds.

ENALIORNIS

(Seeley 1876)
"living in the sea bird"
Cambridge Upper Greensand Formation, Albian age
97 - 113 million years ago
Early Cretaceous, England

First discovered in 1858 and described as being "rather larger than the common Pigeon," *Enaliornis* has always been an enigma. Seeley described a number of pieces, each less than an inch long, that taken together give a pretty good idea of the bird's characteristics. But each piece was discovered individually, in different places and times. Therefore they probably represent as many individuals as there are bone fragments. Scaling is also a problem.

Taken altogether, the bones seem to represent a rather small hesperornithiforme, yet surprisingly specialized nearly to the degree seen in Late Cretaceous forms.

Details: Seeley described a 1-inch wide braincase, a cervical, dorsal, sacral and caudal vertebrae. a 1.5-inch long femur, both ends of a tibio-tarsus, and both ends of an unfused metatarsal. No wing material is known. A 2-1/2-inch premaxilla has also been tentatively ascribed to *Enaliornis*, but its size puts it well out of the range of the other specimens.

Comments: It is surprising to see a bird as specialized as *Enaliornis* is so early in the Cretaceous. In all regards it looks like a likely ancestor of *Baptornis* and *Hesperornis*.

BAPTORNIS ADVENUS

(Marsh 1977)
(Martin and Tate 1976)
"Dipping bird"
Niobrara Formation, Coniacian age
87 - 88 million years ago
Late Cretaceous, Kansas

In 1877 Marsh described a tarsometatarsus sufficiently different from the better known *Hesperornis* to erect a new genus based on the specimen. He named it *Baptornis*. In 1964 Martin and Tate discovered a well-preserved partial skeleton in the University of Nebraska museum. It was re-examined in a 1976 paper along with numerous other examples found in other institutions. Now it is known from a composite skeleton, lacking only most of the head. *Baptornis* was slightly larger than a loon, but had a much longer neck.

Found in marine deposits, some specimens of *Baptornis* are immature, suggesting that nesting sites were nearby, despite the absence of evidence for a nearby shoreline.

Details: The mandible symphysis (tip of the lower jaw) is not fused. The clavicles remain unfused, which seems to be a reversion to a pre-avian condition. The sternum is flat, which is also a reversion.

The wings are vestigial yet a humerus, radius, ulna, and tiny wing bones are present.

The ends of the pubic bone are separate. A patella (knee bone) is present but not large. It takes the shape of a pyramid in *Baptornis* and is compressed in *Hesperornis*. The third and fourth trochlea (pulley like joint) of the tarsometatarsus (shin/ankle) are about equal in size. The tibiotarsus lacks a bridge. The tarsometatarsus is compressed in the baptornithidae and not in the hesperornithidae.

Comments: *Baptornis* is not often described without inviting comparison to its larger, more derived and more famous relative, *Hesperornis*.

HESPERORNIS REGALIS

(Marsh 1880)
"Royal western bird"
Niobrara Formation, Coniacian age
87 - 88 million years ago
Late Cretaceous, Kansas to Alaska

This toothed diver had powerful legs built for swimming. Its wings had virtually disappeared.

Details: The teeth of *Hesperornis* are restricted to the rear portion of the maxilla (upper jaw) but run the length of the lower jaw. The teeth are set in grooves, derived from tooth sockets. The premaxilla (tip of the upper jaw) forms a beak. The palate was paleog-nathus. The maxilla slid back and forth a few millimeters enabling the sharp edge of the beak to slice through prey and the sharp recurved teeth to disengage from prey.

The vertebrae are amphicoelus, as in most Cretaceous birds. The neck is long and very flexible. The tail vertebrae has broad lateral flanges.

The vestigial humeri are mere splints. The rest of the arm/wing has completely disappeared

A huge patella forms a strong base for the swimming muscles. The 4th toe phalanges (toe bones) has a unique ball and flange articulation enabling extended toe rotation, a feature not found to the same extent in *Baptornis*.

Comments: This 1 meter long bird was among the largest of the Mesozoic Some authors have suggested that *Hesperornis* could not have stood or walked on its hind legs, due to the lateral positioning of its femur (unlike that of any other dinosaur or bird). However, a conservatively positioned museum mount indicates that this bird could probably get along on land bipedally at least as well as a penguin.

NEOGAERONIS WETZELI

(Lambrecht 1929)
Maastrichtian age, 66 - 74 million years ago
Late Cretaceous, Chile

Neogaeornis was the first South American bird discovered and was the only one known for the next 45 years. It lived during the last of the Cretaceous and has been described as the youngest known hesperornithiforme. It is known by only a single tarsometatarsus.

Ichthyornithiformes are the Cretaceous birds most like modern ones, except that no modern bird has teeth. It is a small group comprising *Ichthyornis* and one other dubious relative. The exact relation between this gull-like bird and modern birds remains difficult to ascertain. Marsh united the ichthyornithiformes and the hesperornithiformes in the order Odontornithes (toothed birds).

ICHTHYORNIS

(Marsh 1880)
"fish bird"
Niobrara Formation, Coniacian age
87 - 88 million years ago
Late Cretaceous, Kansas, Manitoba, New Mexico

The size and shape of a sea gull, *Ichthyornis* was a genus of about 6 species of toothed seabird from the great inland sea of North America. For awhile the toothed jaws of *Ichthyornis* were thought to have been from a small mosasaur, but it would have been the smallest mosasaur known and its jaws were always associated with an *Ichthyornis* skeleton. Later a more complete toothed skull was discovered proving beyond a doubt that this bird has teeth. No complete skeletons are known.

Details: As in *Hesperornis*, only the maxilla has teeth. The premaxilla does not. Teeth line the entire dentary (mandible). The palate of *Ichthyornis* is unknown.

The vertebrae are amphicoelus (both ends hollow), like those of *Archaeopteryx*. The necks is long and very flexible. Among all the Cretaceous birds, *Ichthyornis* had the largest sternal keel. It was probably the best flyer of the bunch. The furcula articulated with a procoracoid process of the coracoid. The ribs, like those of modern birds, were provided with uncinate processes, helping to bind them together. The tail was tipped with a small modern-style pyogstyle.

The enormous deltoid crest on each humerus is unique among birds. The carpometacarpus is completely fused and the digits are vestigial.

The hindlimbs were proportionately smaller than in any other Cretaceous bird, but similar to those in living gulls.

Comments: *Ichthyornis* must have been a powerful flyer with its deep sternal keel and modern wings.

APATORNIS

(Marsh 1873)
"deceitful bird"
Niobrara Formation, Coniacian age
87 - 88 million years ago
Late Cretaceous, Kansas

Apatornis is known only from a sacrum and other scraps. Some authors suggest that it must have been related to *Ichthyornis*. Others say it was like more like the Eocene flamingo/duck, *Presbyornis*.

Mesozoic birds and the year of their description.

1861	Archaeopteryx
1876	Enaliornis
1880	Hesperornis
	Ichythyornis
	Apatornis
1929	Neogaeronis
1974	Gobipteryx
1976	Alexornis
	Baptornis
1981	Enantiornis
1982	Ambiortus
1984	Gansus
1985	Avisaurus
1986	Nanantius
1989	Patagopteryx
1990	Sinornis
1991	Cathayornis
	Neuquenornis
1992	Iberomesornis
	Concornis
1993	Mononykus

A number of other Cretaceous birds are also known, but chiefly from scraps. They are all from New Jersey and were described before the turn of the century by Marsh. Some are dubious, in other words, they may turn out to be dinosaurs or enantiornithes. The others, listed here, are undoubtedly ornithurae.

GRACULAVUS VELOX

(Marsh 1872)
Maastrichtian age, 66 - 74 million years ago
Late Cretaceous, New Jersey

Known only from the proximal (near) end of a humerus, it is similar to that of *Presbyornis*, a gregarious long-necked, long-legged, duck-like wading bird otherwise known from the Eocene epoch.

TELMATORNIS PRISCUS

(Marsh 1870)
Maastrichtian age, 66 - 74 million years ago
Late Cretaceous, New Jersey

Known from a humerus and other fragments, this bird was a smaller than, but otherwise similar to *Graculavus*.

LAORNIS EDVARDSIANUS

(Marsh 1880)
Maastrichtian age, 66 - 74 million years ago
Late Cretaceous, New Jersey

Known from only a fragment of tibiotarsus, this bird was as large as a crane.

OTHER GONDWANA BIRDS –

In 1985 S. Chatterjee (unreferenced) found loon-like bird fossils in Late Cretaceous Antarctic sediments. He suggests that perhaps these were the ancestors of penguins.

The earliest evidence of South American birds seems to be isolated feather fossils from the Santana formation, Early Cretaceous, Brazil.

An avian carpometacarpus fragment was found in the Late Cretaceous Baurú formation of Brazil (unpublished).

Living birds differ from Mesozoic forms chiefly in lacking teeth. The escape of some birds and not others at the K/T extinction event is a new mystery we will have to consider in the future. A number of very satisfactory intermediates are now known linking *Archaeopteryx* with modern genera. Also some interesting convergences in avian evolution have been reported. The field of avian evolution has expanded exponentially in the past few decades., and I look forward to many new discoveries to come.

I wish to thank Luis M Chiappe of the American Museum of Natural History for reviewing this manuscript and for providing much valuable information and guidance. However, any errors or omissions are my own.

Bibliography

Altangerel, P., Norell, M.A., Chiappe, L.M., Clark, J. M., 1993. Flightless bird from the Cretaceous of Mongolia. Nature, 362, pp. 623-626.

Alvarenga, H. M. F., & Bonaparte, J. F., 1991. A New Flightless Landbird from the Cretaceous of Patagonia. Proceedings of the 2nd International Symposium on Avian Paleontology and Evolution (SAPE) Los Angeles

Brett-Surman, M. K. and Paul, G. S., 1985. A new family of bird-like dinosaurs linking Laurasia and Gondwanaland. Journal of Vertebrate Paleontology, 5, pp. 133-138.

Brodkorb, P., 1976. Discovery of a Cretaceous Bird, Apparently Ancestral to the Orders Coraciiformes and Piciformes (Aves: Carinatae). Smithsonian Contributions of Paleobiology, Number 27, pp. 67-73

Chiappe, L. M., 1991a. Cretaceous birds of Latin America. Cretaceous Research 12, pp. 55-63

Chiappe, L. M., 1991b. Cretaceous Avian Remains from Patagonia Shed New Light on the Early Radiation of Birds. Alcheringa, 15, pp. 333-338.

Chiappe, L. M., 1992. Enantiornithine tarsometatarsi and the avian affinity of the Late Cretaceous Avisauridae. J. Vertebrate Paleontology 12(3): 344-350.

Chiappe, L. 1993. Enantiornithine (Aves) Tarsometatarsi from the Cretaceous Lecho Formation of Northwestern Argentina. American Museum Novitates 3083. 27pp.

Chiappe, L. M. and Calvo, J. O. *Nequenornis volans*, a new Upper Cretaceous bird (Enantiornithes: Avisauridae) from Patagonia, Argentina. J. Vertebrate Paleontology (in press)

Cracraft. J., 1986. Origin of Birds. Paleobiology, 12, pp. 383-396

DeBeer, G.R., 1954. *Archaeopteryx lithographica*. A Study Based upon the British Museum Specimen. Brit. Mus. (Nat. Hist.) London

Elzanowski, A., 1974. Palaeognathous bird from the Cretaceous of Central Asia. Nature, Vol. 264, pp. 51-53.

Elzanowski, A. 1977, Skulls of *Gobipteryx* (Aves) from the Upper Cretaceous of Mongolia, Results of the Polish-Mongolian Palaeontological Expeditions - Part VII. Palaeontologia Polonica, No. 57, pp. 154-167

Elzanowski, A., 1981. Embryonic bird skeletons form the late Cretaceous of Mongolia. Palaeontologia Polonica 42, pp. 147-179

Gingerich, P.D., 1970. Skull of *Hesperornis* and Early Evolution of Birds. Nature 243, PP. 70-73

Hecht, M.K., Ostrom, J. H., Viohl, G. and Wellnhofer, P., editors, 1985. The Beginnings of Birds, Proceedings of the International Archaeopteryx Conference, Eichstätt.

Heilmann, G., 1927. The Origin of Birds. Appleton, New York

Hou, L. and Liu, Z., 1984. A New Fossil Bird from Lower Cretaceous of Gansu and Early Evolution of Birds. Scientia Sinica (Series B) Vol. 27, No. 12

Hutchison, J. H. *Avisaurus*: A Dinosaur Grows Wings. Society of Vertebrate Paleontology Abstracts of Papers 1993. Vol. 13, Supplement to No. 3.

Kurochkin, E., 1985. A True Carinate Bird from Lower Cretaceous Deposits in Mongolia and Other Evidence of Early Cretaceous Birds in Asia. Cretaceous Research 6, pp. 271-278

Lamb, J.P. Jr., Chiappe, L. M., Ericson, P.G.P. A Marine Enantiornithine form the Cretaceous of Alabama. Society of Vertebrate Paleontology Abstracts of Papers 1993. Vol. 13, Supplement to No. 3.

Lambrecht, K., 1929. *Neogaeornis wetzeli* n.g., n. sp., der erste Kreidevögelder südlichen Hemisphaere. Palaeontologische Zeitschrift 11, pp. 121-128.

Marsh, O. C., 1880. Odontornithes: A Monograph of the Extinct Toothed Birds of North America (U.S. Geological Exploration of the 40th Parallel, Washington, DC.), publ. 7

Martin, Larry D. and James Tate Jr., 1976. The Skeleton of *Baptornis advenus* (Aves: Hesperornithiformes). Smithsonian Contributions of Paleobiology Number 27, pp. 35-42

Molnar, R.E., 1986. An enantiornithe bird from the Lower Cretaceous of Queensland, Australia. Nature Vol. 322, 21, pp. 736-738

Sanz, J. L., Bonaparte, J. F., & Lacasa, A., 1988. Unusual Early Cretaceous Birds from Spain. Nature Vol. 331, No. 4, pp. 433-435.

Sanz, J. L. and A.D. Buscalioni, 1992. A New Bird from the Early Cretaceous of Las Hoyas, Spain, and the Early Radiation of Birds. Paleontology 35, Part 4, pp. 829-845

Seeley, H. G., 1876. On the British Fossil Cretaceous Birds. Quart. Journ. Geol. Soc. Vol. 32, pp. 496-512, plus plates.

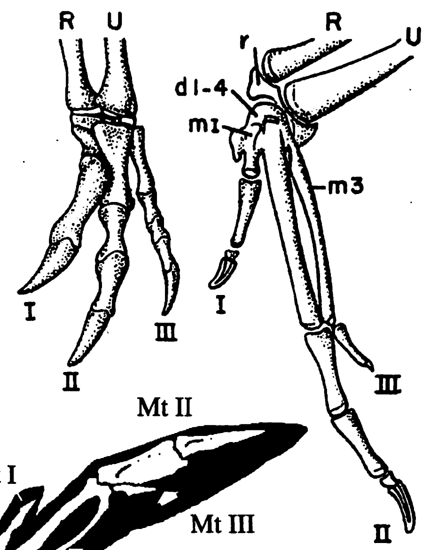
Sereno, P. and Rao, C., 1992. Early Evolution of Avian Flight and Perching: New Evidence from the Lower Cretaceous of China. Science, Vol. 255, pp. 796 and 845-848

Walker, C.A., 1981. New subclass of birds from the Cretaceous of South America. Nature Vol. 292, pp. 51-53

Zhou, Z., Jin, F. and Zhang J., 1992. Preliminary Report on a Mesozoic Bird from Liaoning, China. Chinese Science Bulletin,Vol. 37, No. 16, pp. 1365-1368

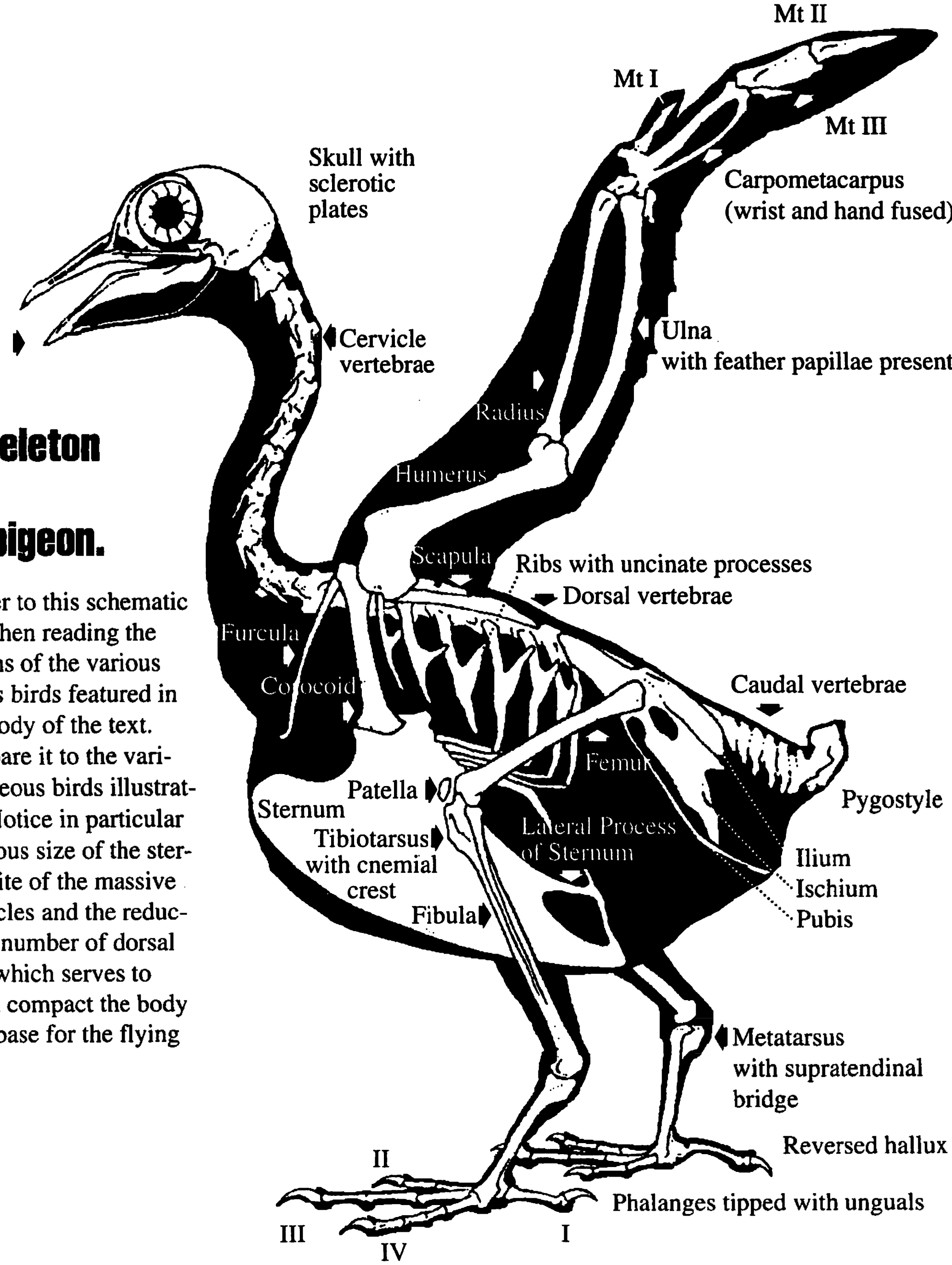
Theropod Manus

Right manus, dorsal view of *Allosaurus* (left) and *Anser*, the goose (right). Both of these theropods have three fingers tipped with claws. Digit I is the shortest and twists forward. Digit II is the longest while digit II is the most slender. Metatarsal III is separated in *Allosaurus*, bowed in *Anser and* all other birds. In *Anser* the distal carpals are fused, either with one another or with the metatarsals forming a carpometacarpus. In enantiornithes claws are usually retained. In ornithurae, the claws are usually absent and the fusion of the carpometacarpus and phalanges is much more complete.

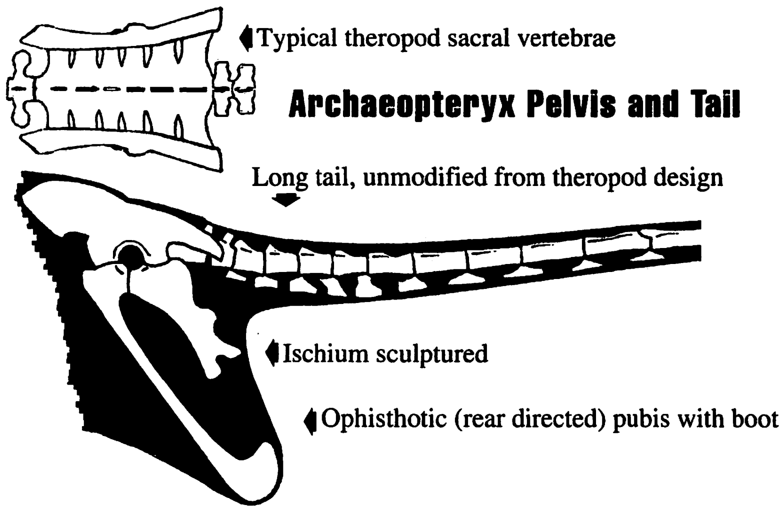


The skeleton of the living pigeon.

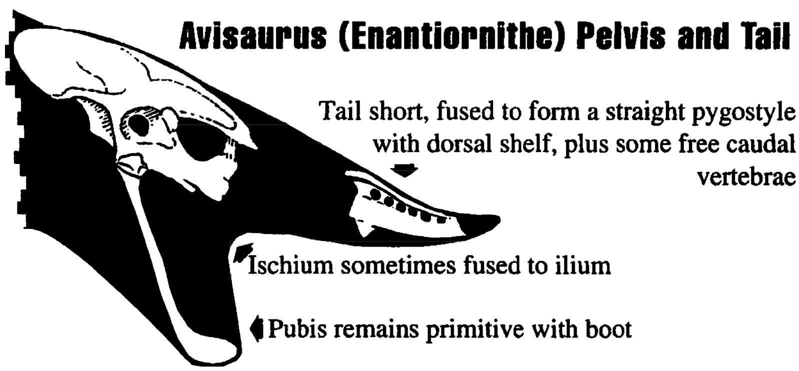
Please refer to this schematic drawing when reading the descriptions of the various Cretaceous birds featured in the main body of the text. Also compare it to the various Cretaceous birds illustrated here. Notice in particular the enormous size of the sternum, the site of the massive flight muscles and the reduction in the number of dorsal vertebrae which serves to stiffen and compact the body as a solid base for the flying muscles.



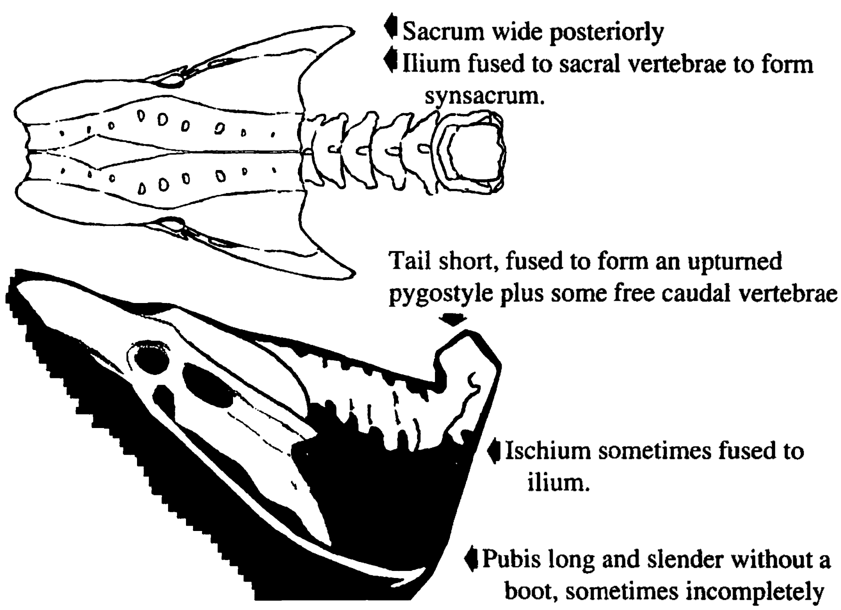
Archaeopteryx Pelvis and Tail



Avisaurus (Enantiornithe) Pelvis and Tail



Pigeon (Ornithe) Pelvis and Tail



Bird Hips

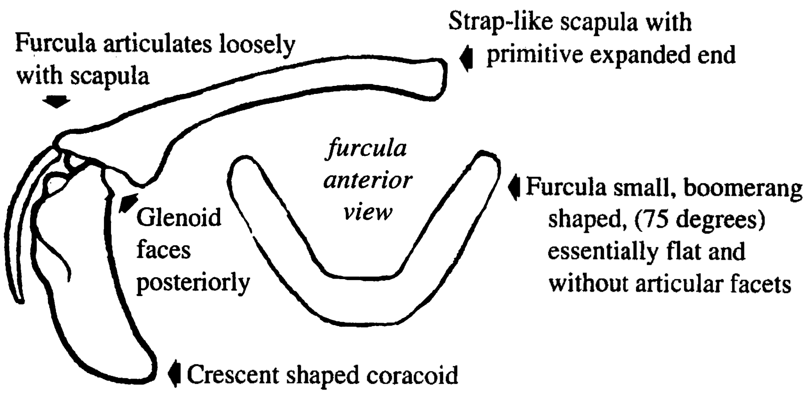
In birds, the tail was among the first things to change and the hips were among the last. In non-avian dinosaurs and in *Archaeopteryx*, a number of caudal vertebrae serve as the base for the caudofemoralis muscle, the major muscle for retracting the femur during terrestrial locomotion. However, in birds the functions of the tail and hind limbs are separated, and so is the connection between the two. In birds, the tail and forelimbs work in concert with one another.

In enantiornithes the pelvis remained essentially primitive. In some cases the ischium fused with the ilium, but usually the two remained separate. The distal caudal vertebrae fused to form a pygostyle with a dorsal shelf, while the proximal caudals remained free as in ornithes.

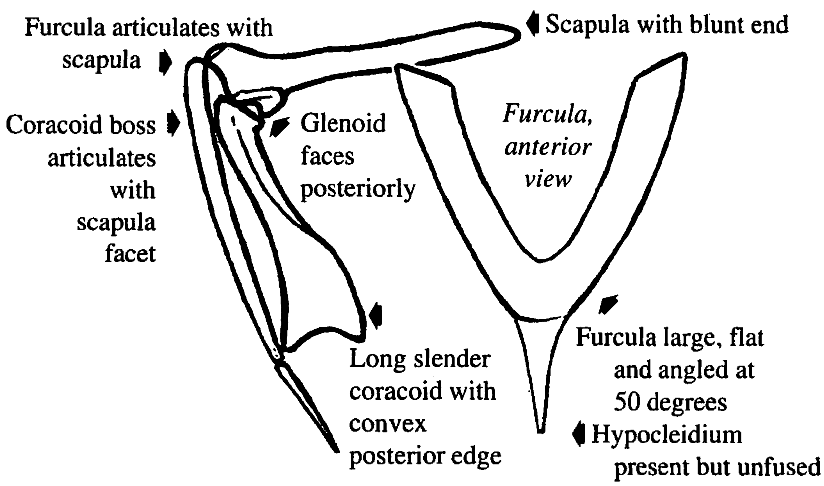
In ornithes the sacrum and ilium fuse to become one bone, the synsacrum. Often the ischium is also fused to it ventrally. The pubic bones do not form a symphysis, but instead their tips remain separate. The same is true of the ischia. Perhaps this facilitates egg-laying in these, the smallest dinosaurs. The pygostyle in ornithes is upturned and of a different design than that of enantiornithes.

Bird Shoulder Girdles

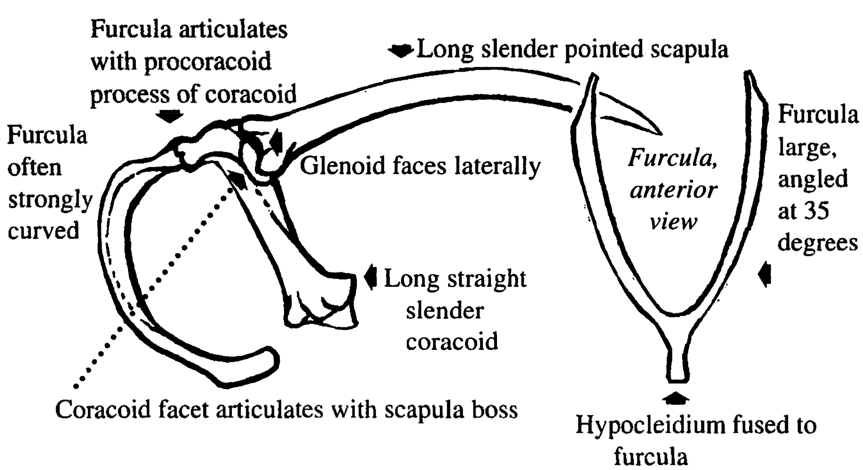
Archaeopteryx Shoulder Girdle Lateral View



Enantiornithe Shoulder Girdle Lateral View



Ornithe Shoulder Girdle Lateral View



The *Archaeopteryx* the shoulder girdle resembles that of velociraptors and other maniraptoran dinosaurs. An ossified sternum is present in *Deinonychus*, but lacking in *Archaeopteryx*. The corocoid is short and broad and the furcula bears only a loose articulation to the other elements.

In enantiornithes the furcula is larger but remains essentially primitive. In some forms an articular facet is present, but it articulates with the scapula. The corocoid is long and narrow forming a brace against the ossified sternum, always present in enantiornithes. The sternum is usually small but it is provided with a keel and lateral projections increasing its surface area.

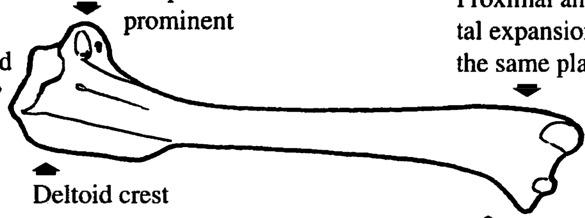
In ornithes, the furcula is a large complex bone that articulates with the procorocoid process of the corocoid. The glenoid, or shoulder socket, faces laterally, enabling the wing to swing in a wider arc. The sternum is usually large, strongly keeled and provided with lateral processes, except in secondarily flightless forms.

Bird Humeri

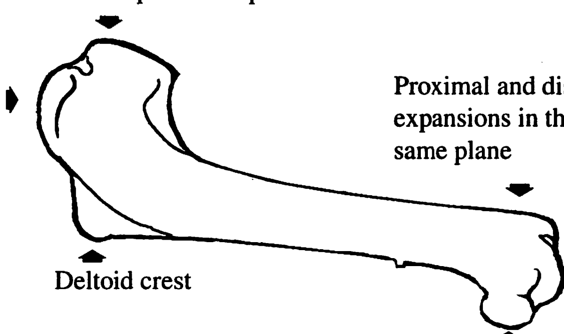
The humerus, forming the upper wing of the bird, is rather like that of other theropods in *Archaeopteryx*, growing increasingly complex in other birds. In enantiornithes, the head is flat or concave, and the articulations for the radius and ulna are not well-formed. In ornithes, the head is rounded, as in *Archaeopteryx*, and ulna/radius articulations are well-formed.

Archaeopteryx humerus

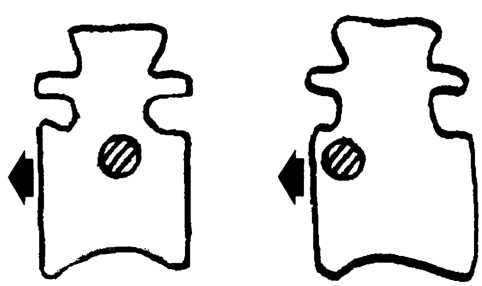
Enantiornithe humerus



Ornithe humerus

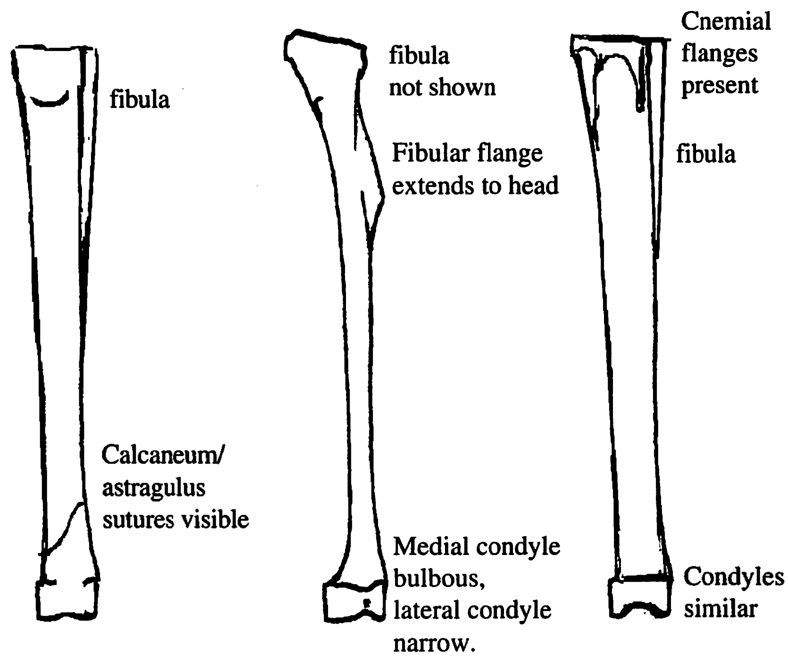


Bird Dorsal Vertebrae



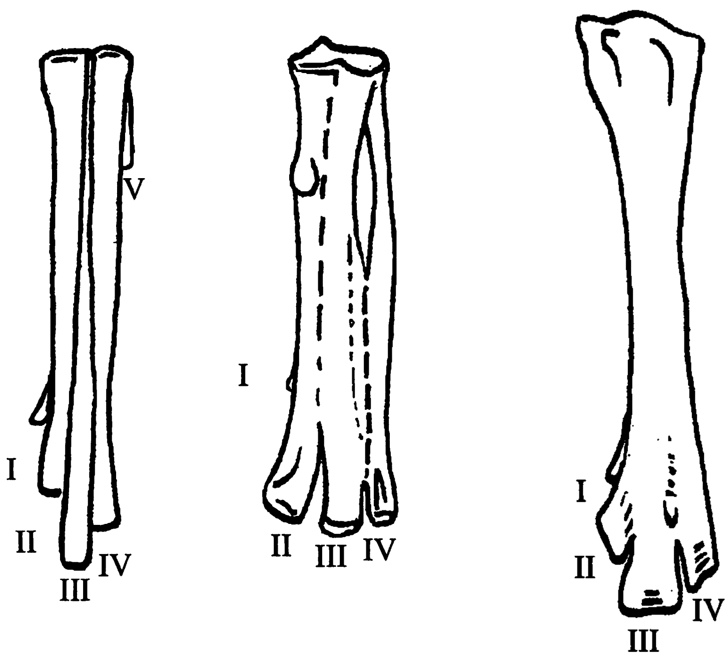
Dot represents tubercle of rib articulation. Arrow points anteriorly. In enantiornithes, the articulation for the ribs is in the middle of each vertebrae. In ornithes it is set anteriorly.

Bird Legs



Left Tibiotarsus
Anterior View

The tibia and the proximal tarsals fuse in birds to form a tibiotarsus.



Left Tarsometatarsus
Anterior View

The distal tarsals and metatarsals in birds are more or less fused to form a tarsometatarsus. Sutures remain visible in *Archaeopteryx* and enantiornithes. Fusion is complete in ornithes. Other details, listed here, are highly characteristic of each of the major groupings, despite differences in proportion which occur between genera.

Archaeopteryx

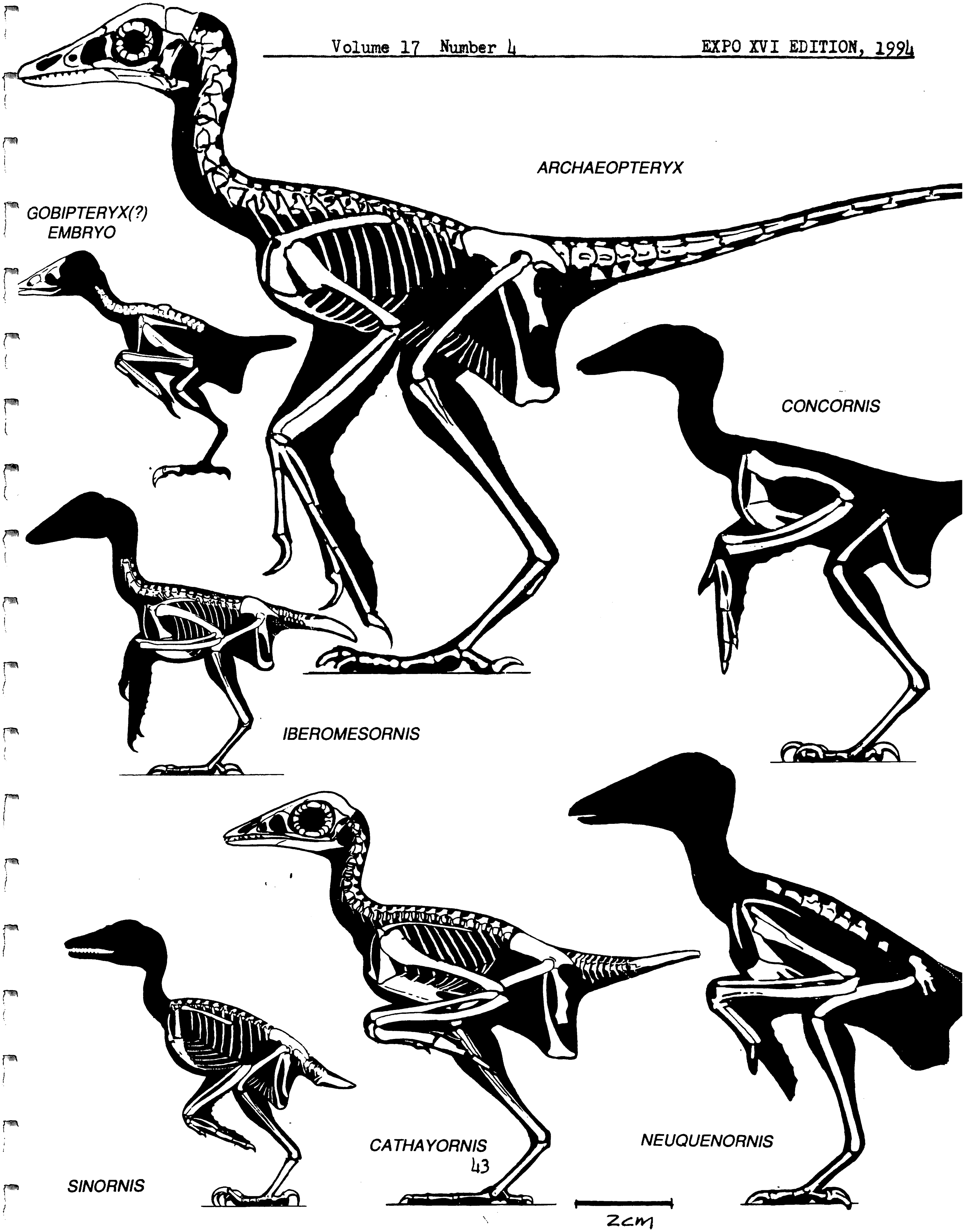
- Metatarsals I-V unfused, sutures visible
- Central portion of Mt I unossified
- Proximal end of Mt III pinched between II and IV in anterior view

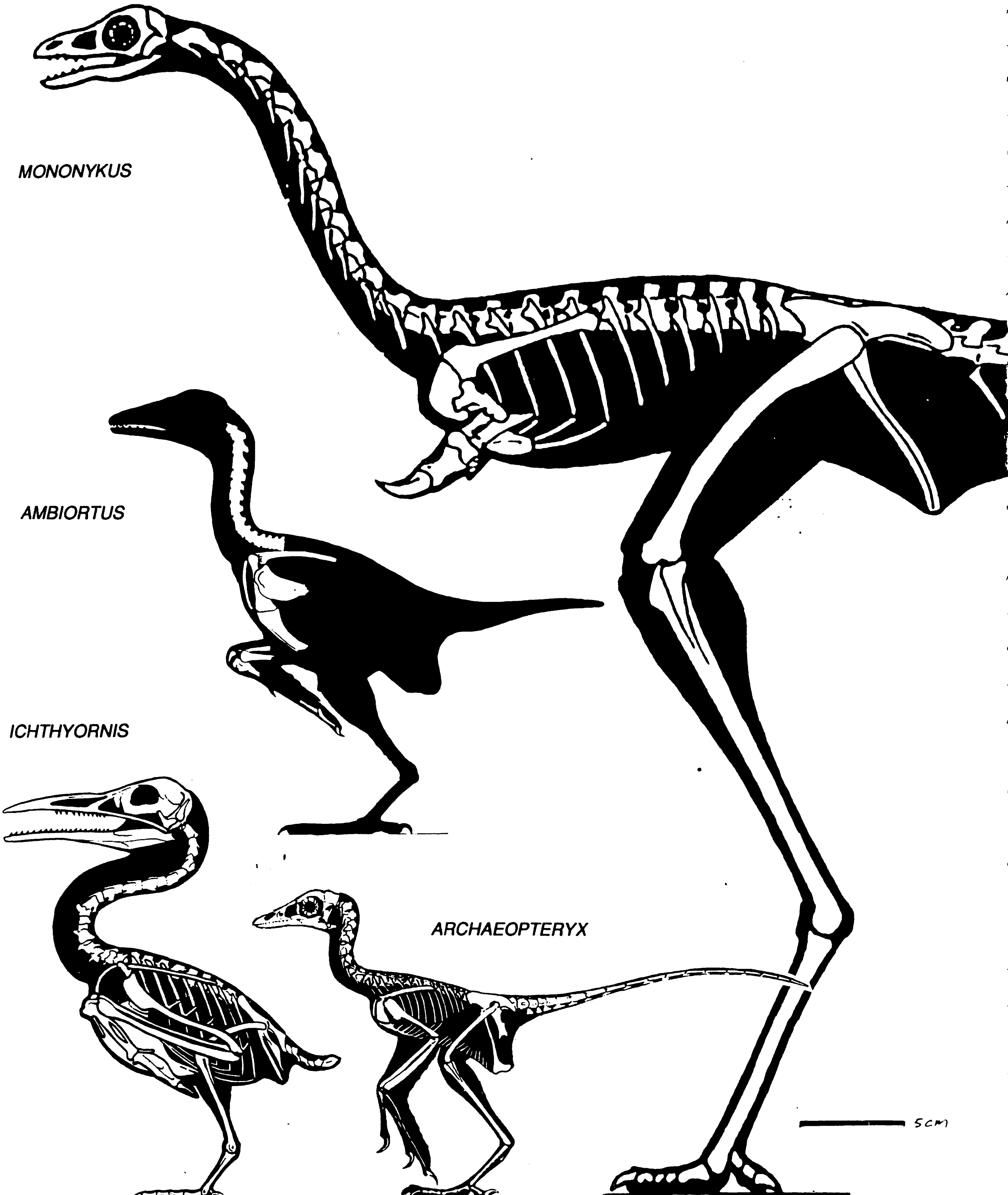
Enantiornithe

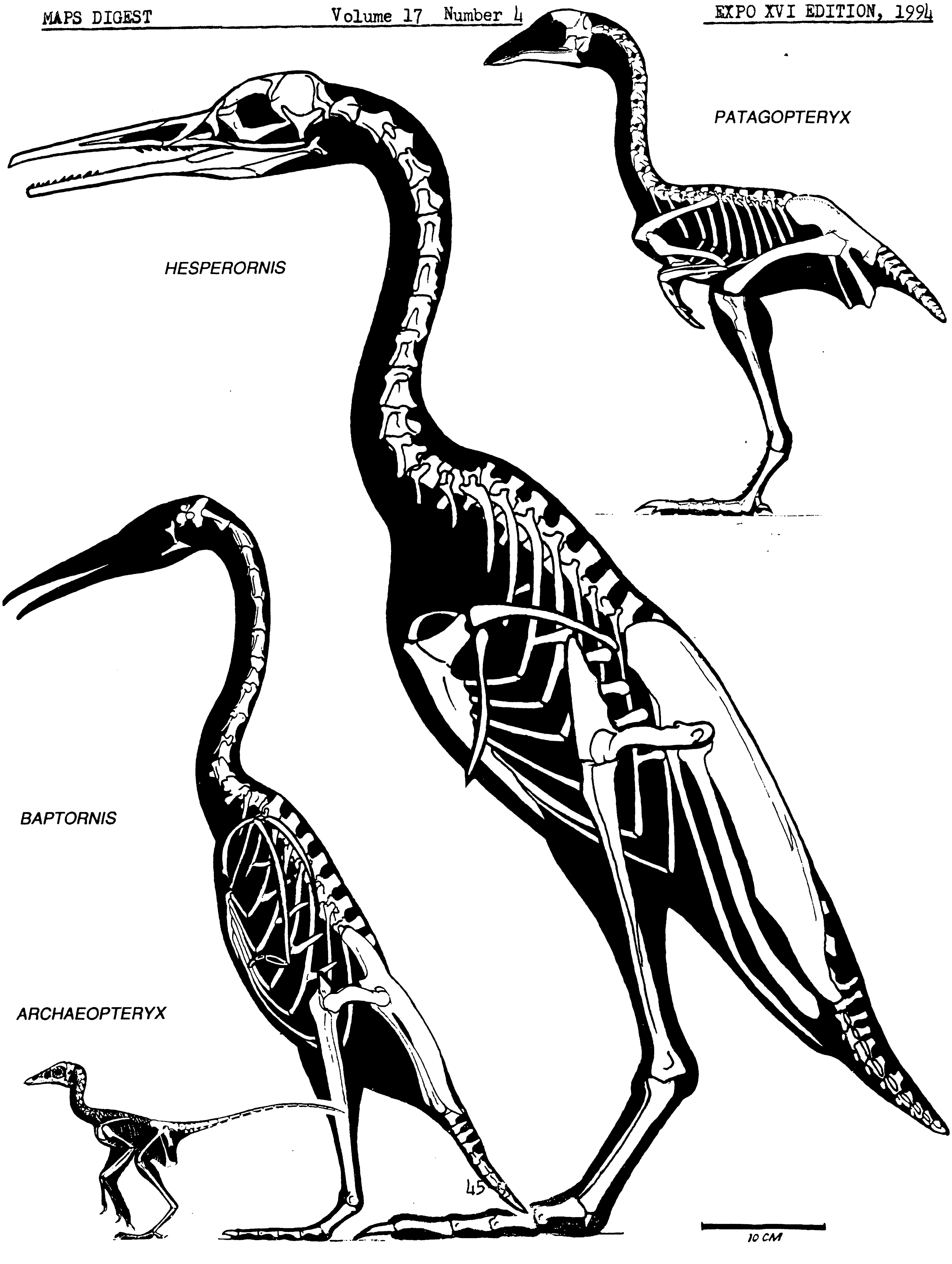
- Mt I absent
- Distal end of Mt II larger than Mt III
- Mt IV reduced
- Tubercle on anterior shaft of Mt II
- All sutures visible, partial fusion

Ornithe

- All metatarsals fused in adults
- Distal end of Mt III larger than II or IV


ARCHAEOPTERYX
GOBIPTERYX(?)
EMBRYO
CONCORNIS
IBEROMESORNIS
NEUQUENORNIS
CATHAYORNIS
SINORNIS
2cm


MONONYKUS
AMBIORTUS
ICHTHYORNIS
ARCHAEOPTERYX
5cm


PATAGOPTERYX
HESPERORNIS
BAPTORNIS
ARCHAEOPTERYX
10 CM

THE CHRONISTER SITE

(CRETACEOUS OF MISSOURI) AND ITS VERTEBRATE FAUNA

by

Bruce L. Stinchcomb, David C. Parris,
Barbara S. Grandstaff and Robert Denton, Jr.

Introduction

Surely one of the most interesting pieces of unfinished paleontological business is the investigation of the Chronister Site. Long known as the locality of "The Missouri Dinosaur", it was serendipitously discovered and modestly studied. While occasional flurries of interest have been expressed, it has remained a subject of speculation (rather than rigorous investigation) since 1945. This report of renewed work there may provide some answers to four decades of questions about the site.

History of the Site

As reported by Gilmore and Stewart (1945) and Heller (1943) the Chronister family of Bollinger County, Missouri discovered fossil bones at several levels during excavation of a well on their property (Center of section 26, Township 31 North, Range 9 East), in Crooked Creek Township, Glen Allen Quadrangle (Figure 1). The bones, primarily caudal vertebrae, were assembled as a sequence and made the type of a new genus and species, Neosaurus missouriensis. The taxon was attributed to the Sauropoda for want of any substantial idea to the contrary. Later that same year the generic name Parrosaurus was proposed, due to preoccupation of Neosaurus (Gilmore, 1945). Tentatively correlated to the McNairy Sand, the site was added to the lists of localities for dinosaurs from marine sediments, (see Horner, 1979).

Because only one specimen came from the locality, the attention given to this find was minimal. Occasional inquiries were made to the Chronister family, but no substantial investigations took place until the last decade. With the acquisition of the property by Bruce Stinchcomb, new excavations were begun and the known fauna increased.

Meanwhile Baird and Horner (1979) completed a review of North Carolina dinosaur sites. They reviewed the species Hypsibema crassicauda Cope and determined that Parrosaurus was a junior synonym of Hypsibema. This added little to a determination of its affinities; indeed it made it more of a mystery. They suggested (Baird and Horner, 1979) that the answer to the affinities of Hypsibema was in Missouri in the Chronister well.

This present work is the result of combined efforts by several of the workers above and others who were working on the Ellisdale Local Fauna (New Jersey), the other site where Hypsibema has been found. Together, we have reopened the well, collected extensively at the site, and studied the entire fauna.

Abbreviations for institutions cited in this report are AMNH - American Museum of Natural History, KUVP - University of Kansas Natural History Museum, NJSM - New Jersey State Museum, USNM - Natioanl Museum of Natural History (Smithsonian Institution).

Geologic Setting

The southeastern Ozarks of Missouri are different from the rest of the uplift. Underfit stream valleys, excessively thick clay-chert regolith and " fragmentary remains of a former sedimentary layer cover the Paleozoic rocks" (Bretz, 1956), are unique to this part of the Ozarks. These phenomena suggest that the southeastern Ozarks and adjacent embayment have had a rather complex late Mesozoic and early Cenozoic history which is imperfectly known and understood.

The reopening of the Chronister site has exposed a sequence of clays, sand and residual material which constitute this remarkable deposit. The bones were found in a series of gray and bluish clays of a possible composite graben-paleokarst. Associated with the bone-bearing clays and embedded in them are a variety of limestones representative of different parts of the Paleozoic. Boulders of Middle Ordovician Plattin and late Ordovician Kimmswick limestones; late Ordovician phosphatic pebbles of the Maquoketa Formation, early Silurian Bainbridge red limestones and early Devonian Bailey Formation all have been recognized. These boulders are similar to the type and age range of boulders found in the Marble Hill and Glen Allen structures, (McCracken, 1971) which are probably structurally and tectonically related. The Marble Hill structure yielded gray and red laminated Cretaceous clays bearing a small late Cretaceous (McNairy sand ?) leaf compression angiosperm flora, but no vertebrate material.

The Chronister site, Glen Allen and Marble Hill paleokarst/grabens are surrounded by topographically higher areas of Lower Ordovician dolomites, cherts and sandstones. Cherts within the Cretaceous clays are derived primarily from Lower Ordovician strata, also suggesting that these rocks were widespread surface rocks during late Mesozoic depression filling. Peculiar manganese-oxide-stained chert pebbles occur in the clays and frequently exhibit a high polish. Their origin and provenience remains unknown. They appear to be derived from the hard cherts of ancient Cambro-ordovician rocks of nearby non-graben/karst areas.

The bone-bearing horizon at the Chronister site overlies a paleorogolith of pre-late Mesozoic age. This regolith consists of gray or white clay containing porcellanous chert anf/or flint chunks. This regolith differs from typical Ozark chert regolith in its lack of iron oxidization (red-orange color) and in the bleached or weathered appearance of the enclosing chert masses.

In the deepest part of the excavations (around the Chronister cistern which was the source of the original dinosaur material), approximately one meter of dark gray clay overlies the residual gravels. This in turn is overlain by approximately two meters of gray/bone-bearing clays. The upper horizons of this gray clay contain areas of oxidation. Yellow oxidized clay in turn overlies this, which contains large amounts of Lower Ordovician chert and sandstone clasts, some of considerable size (1-2 cubic meters). Highly deteriorated large bones, including many turtle fragments occur locally at the contact between the gray and yellow clays. The clays throughout most of the site show evidence of a mixing or churning action, a phenomenon which impedes bone collecting and preparation. This mixing which sometimes shows itself in slickensides surfaces, may be related to extensive seismic activity in the region, as recorded in the 1811-12 New Madrid earthquake.

Current Excavations

Reopening of the Chronister well was accomplished with heavy equipment (bachhoe and bulldozer) while observers carefully monitored the site for fossils. A few fragments were found in the upper levels of the clay, some of which were identifiable. Bulk samples were taken for microfaunal testing. Spoils were spread out by separate scoop loads and mapped for later prospecting after weathering had exposed more material.

The Chronister well, fully described by Gilmore and Stewart (1945), had been lined with rocks for use as a cistern. This cistern was later backfilled. It was completely re-excavated as part of the three-day operation, and its southwest wall was exposed.

Collecting from the spoil piles continued onto the 1988 field season. The sediment samples and bulk matrix samples were processed for mineral and fossil content.

Excavation continued during 1988, using a backhoe, over an area about 100 m long extending east and south of the cistern. The Cretaceous clays were found to extend throughout this area and produced fossils throughout their extent. Additional bulk samples were taken both from the 1987 spoil piles and from the 1988 excavations.

Results

Geometry of deposits: The excavations revealed a cross-section more typical of a pond or bog deposit than of marine sediments (Figure 2). The exposed strata and nearby test holes showed that the well was dug in a lenticular blue-gray clay deposit directly overlying a regolith of dolomite clasts, the latter presumable derived from the Ordovician Plattin Formation. The tentative correlation to the McNairy Sand Member of the Ripley Formation can no longer be accepted, as the clay bears no resemblance to any stratum described for the McNairy Member (or Formation) in Missouri outcrops and wells (Crone, 1981; Fredericksen et al., 1982; Grohskopf and Howe, 1961; Matthes, 1933; Mesko, 1988; Stepheson, 1955. Heller (1943) was alone in considering some blue-gray clays of the area to be attributable to the Ripley Formation.

The clay deposit at the Chronister site is apparently confined to a small area of no more than a few hundred square meters. Test holes show it to be confined to the valley of this ephemeral tributary of Crooked Creek, in the vicinity of the old Chronister house. It is no more than a few meters in thickness.

Sediment Analysis

The main fossiliferous deposit at the Chronister site is a massive blue-black plastic clay. Also occuring peripherally to as well as interbedded with the blue-black clay are lenses and beds of chromatic green, red and yellow clays. The yellow clay generally overlies the main deposit and grades upwards into a weathered, sand/chert soil.

The clays at the site were segregated by color and removed for laboratory analysis of mineral content and morphology. The were analyzed by x-ray diffraction (ZRD), differential thermal analysis (DTA), hydration (swelling clay ID), and SEM. Results of testing can be summarized as follows:

Blue- Black Clay -XRD and DTA indicated the presence of illite or illite-smecite mixed layer lattice silicate as the predominant clay mineral. There was a significant., well ordered quartz phase present at a level of approximately 30-35 wt. % Microscopic examination of the sample showed the quartz phase exists as a well sorted, fine dispersion. A minor well ordered mineral phase present was identified as calcite. Also large (4-8 cm), rotted calcareous (geodes?) lined with drusy quartz crystals were found in the clay samples studied.

Green Clay - XRD and DTA showed the presence of a distinct major phase consisting of a mixed layer illite-smectite. A minor, well ordered quartz phase was present at a level of approximately 15 wt. %. No calcareous phase was noted in the samples studied.

Red-Yellow clay - XRD and DTA confirmed the presence of illite smectite mixed layer lattice silicate as the predominant mineral phase. A second, minor phase, was identified as well ordered quartz phase was identified at a level of approximately 15-20 wt.%. A third minor phase was identified as kaolinite. The presence of kaolinite was verified by microscopy. No calcareous phase was noted in the samples examined.

The Fauna

The Chronister local Fauna is as yet rather limited in numbers and diversity. Approximately 30 fossil bones have been recovered and only the reptilian fauna is fairly well represented.

Class Chondrichthyes; Order Batoidea

Class Osteichthyes; Order Semionotoidea
Family Lepisosteidae, indeterminate

Class Reptilia;
Order Chelonia

Adocus sp.
Naomichelys speciosa Hay

Trionux sp.

Order Crocodilia
cf. Leidyosuchus sp.

Order Ornithischia

Family Hadrosauridae

Hypsibema missouriensis, Gilmore

Discussion and Conclusions

The original lithostratigraphic correlation with the marine McNairy Sand (Maastrichtian) was based no doubt on the presumed Cretaceous age, the presence of bedded clay, and proximity to marine deposits of Cretaceous age in the Mississippi embayment (Gilmore and Stewart, 1945).

The clay layer at the Chronister site rest on a base of Plattin limestone (Middle Ordovician) and is accompained by fossils from the Upper Ordovician (Maquoketa) and Silurian (Bainbridge). The surrounding rocks have been identified and mapped as Lower Ordovician Jefferson City Formation. This suggests a down-dropped block (graben?) or other fault structure as the depositional basin. Studies of the kaolinite deposits of the Glen-Allen and Marble Hill region have suggested a similar mode of occurence for these clays (Tennison, 1960). Most likely, this faulting occured during the downwarping of the Mississippi embayment in the early Cretaceous. Karst processes may have enlarged fissures formed during faulting at the site, and full scale sinkhole or cavern development was followed by rapid accumulation of solutional residues of the Ordovician carbonates. Smectite may have been produced diagenetically from volcanic ash, which is ubiquitous in the Cretaceous system of North America or may be argillaceous residue from Ordovician carbonates. Illite is most likely a weathering product of the smectite in either case. The occurence of kaolin in the red clay can be attributed to leaching of calcareous componets by weathering (kaolin formation is inhibited by alkalies) and is most certainly of diagenetic nature.

We reinterpret the deposit as a lenticular clay of freshwater orgin in a paleokarst terrain. The geometry of the deposit, the mineralogy, and the paleontology are all consistent with such an interpretation.

Such deposits are known eisewhere in the region. The formations of the Mississippi embayment (Crone, 1981); Fredericksen etal., 1982; Oman, 1986) have no true lithic similarity to the Chronister site. As yet no definitely marine taxa have been found at the site.

The age correlation, previously based in part on the lithostratigraphic interpretation, must also be reexamined. Naomichelys is known from the Aptian to the Campanian. Hypsibema is known from only two other formations, the Marshalltown Formation of New Jersey and the Black Creek formation of North Carolina. Both are of Campanian age. The Chronister deposit should be regarded as Campanian, the only age consistent with the known fauna.

The Problematic Genus Hypsibema

We hope to determine the phylogenetic position of Hypsibema Cope, a genus which was "born in confusion and has persisted in the same state for more than a century", (Baird and Horner, 1979). We contend that Hypsibema is a hadrosaurine dinosaur for the following reasons:

Anatomical features: as noted by Baird and Horner (1979), Caudal vertebrae of Hypsibema have the slightly amphicoelus centra, "amidships" position of the neural arch, and short anterior zygapophyses of the Hadrosauridae. While these three aspects may seem insufficient for a reference to that family, nonetheless they exceed all resemblances of Hypsibema to any other group. Indeed, the caudal vertebrae of the type specimen of Hadrosaurus foulkii (Leidy, 1865) resemble Hypsibema more than any others known to us.

Caudal centra of the same general shape are known only for some Jurassic sauropods and a few early Cretaceous nodosaurines (e.g. Nodosaurus). Comparisons with these taxa show no significant similarities to Hypsibema, however.

The features in which Hypsibema differs from typical hadrosaurid caudals, such as lack of lateral compression (Baird and Horner, 1979) and lack of anterior chevron facets (Gilmore and Stewart, 1945) seem relatively minor compared to differences from typical Jurassic sauropods, especially in lateral view.

Gilmore (in Gilmore and Stewart, 1945) noted the existence of hadrosaurids of sufficient size to compare to the Missouri specimen. However, he made comparison with the mid-caudal region, probably because the size of the centra made it seem unlikely that they were posterior caudals. Such large hadrosaurids are now know (Morris,1972) that comparison to posterior caudals seem reasonable and Hypsibema compare very well to those of hadrosaurines.

Additional vertebrae found during the 1988 field season resemble hadrosaur midcaudals in their short length and lateral compression, but resemble Hypsibema in having a pattern of concentric ridges on their ends.

The type specimen of Hypsibema missouriense includes two fragments in addition to the caudal centra. These were mentioned, but not described, by Gilmore and

Stewart, (1945). One is a fragment of left maxilla of an ornithischian dinosaur, the other a fragment of left predentary of an ornithopod dinosaur. There is no reason to doubt the association of these fragments with the type.

Faunal Associations: Hypsibema is known from only four sites, all coastal or nearly so at the time of deposition. Now that all four sites have yielded substantial numbers of specimens, the faunal associations are better known.

Although scattered at the site, in part due to excavation method, most of the dinosaur bones from the Chronister site could belong to a single individual, a large hadrosaur. This is true even if the bones of the type specimen of Hypsibema *missouriense* are included. At Ellisdale, New Jersey and at the two North Carolina sites for Hypsibema, hadrosaurines are the only common dinosaurs. At these sites various theropods and the giant crocodile Deinosuchus are found, but none of these reptiles are likely to have had caudal vertebrae like those of Hypsibema. Furthermore, none of these sites has yielded anything attributed to a sauropod dinosaur other than Hypsibema caudals. In view of the sample size now available and the size and durability of many sauropod bones, it seems incredible that no other sauropod bones have been found, if Hypsibema were indeed a sauropod. We believe that the answer is that the genus is hadrosaurine, perhaps some species of Hadrosaurus itself. It appears that Cope (1869) was accidentally correct in his reference of his mixed and confusing type material to the Hadrosauridae.

The Perry County "Dinosaur"

Comments on another specimen may appropriately be added here. A supposed dinosaur specimen from Missouri was recently described by Galbreath (1987). We have examined this specimen (KUVP8547 1) and are skeptical about its identification.
the specimen is badly abraded and encrusted with iron and manganese oxides and shows little original bone surface.

The specimen comes from Mystery Cave in Perry County, Missouri. A typical fossil from a Missouri cave is a Pleistocene mammal rather than a Cretaceous reptile (Saunders, 1977). Our Comparison suggest that KUVP8547 1 is indeed a Pleistocene mammal, a femoral fragment of a proboscidean. The anatomical features that may be seen are summarized as follows:

1. The elongate trabeculae in the tapering end of KUVP8547 1 suggest the presence of a long axis, and the interior bone texture within the concavity resembles that of the interior of a long bone.

2. Comparisons to the right distal femur of a mastodon (Mammut americanum, Kerr) show not only a similar size but similar narrowness along the shaft. The femoral shaft could correspond to the tapered projection of KUVP8547 1, which has the only obvious natural bone surface. That surface is texturally similar to that of the anterior side of the mastodon femur. There is also a groove in the shaft of a mastodon femur along that same surface, just as there is in KUVP8547 1.

3. The posterior surface of the distal femur of a mastodon has a number of small nutrient foramina just above the femoral condyles. Remants of similar foramina are present in the corresponding position of KUVP8547 1 (although the surface is somewhat abraded).

4. On NJSM11267, commonly called the Bojak Mastodon, a natural crack has formed in the medial shaft, reflecting a common trend of breakage in an untreated bone. If unimpeded this crack would yield a specimen very similar to KUVP8547 1, splitting away the medial condyle and exposing cancellous bone surface and a concavity in the same position as seen on the Perry County specimen.

The weight of anatomical evidence indicates that KUVP8547 1 is a proboscidean . (right distal femur). We have seen one mammoth molar from this cave, and other Pleistocene mammalian fossils are known from the lacality. The mammoth molar is heavily encrusted with oxides, as is KUVP8547 1.

Our field inspection of the cave itself, confirmed by conversation and correspondence with others familiar with it, found no evidence of pre-Pleistocene cavern development. On the contrary, it appears to be a typical Pleistocene cave, albeit a very large one. It bears no resemblance to the Bollinger County Cretaceous sites.

Acknowledgements

We thank the St. Louis Academy of Science for a grant in support of our field excavations, without which this study would not have been possible. The friends of the New Jersey State Museum provided funds in support of field work by David Parris.

We also gratefully acknowledge the field assistance of Guy Darrough, Robert O"Neill, Ronald Crews and Scott Cronce and the cooperation of Michael Brett-Surman and Greg E. Ostrander provided access to specimens in their care. Drs. Donald Baird and John R. Horner assisted us with identification of some specimens and discussed the manuscript. Frank and Becky Hyne donated comparative specimens of Hypsibema from North Carolina. Dr. Dewey H. Amos, Jerry D. Vineyard and Kent M. Bratton provided valuable information from field notes and extensive experience in the region.

Sediment analysis was performed with facilities provided by Johnson and Johnson Dental products Company. Jean A. Williams and Linda Hill executed the manuscript through numerous revisions and reorganizations

Appendix I
Specimens from the Chronister Site

Field #	Identification	Portion	Remarks
1	Hadrosauridae, indeterminate	Metatarsal fragment	
2	Hadrosauridae, indeterminate	Left metacarpal IV or distal fibula	
3	Hadrosauridae, indeterminate	Right metatarsal III	
4	Hadrosauridae, indeterminate	Metatarsal or phalanx (pes) fragment	
5	cf. Hadrosauridae	Possible femoral fragment	
6	Hadrosauridae, indeterminate	Fragment of cervical vertebra	
7	cf. Hadrosauridae	Possible zygopophysis	
8	cf. Hadrosauridae	Possible ulnar or radial shaft, or scapula	
9	Hadrosauridae, indeterminate	Hypocentrum	Cast: NJSM
10	Hadrosauridae, indeterminate	Fibular shaft fragment	
11	Crocodilidae, cf. *Leidyosuchus*	Right coracoid articulation	Cast: NJSM
12	*Hypsibema missouriense*	Caudal centrum	USNM 16735, Cast NJSM
13	Hadrosauridae, indeterminate	Fragment of caudal vertebra	
14	Hadrosauridae, indeterminate	Ulnar fragment	

CHRONISTER SITE

15 Hypsibema missouriense Caudal centrum USNM 16735, Cast NJSM

16 cf. Leidyosuchus Armor scutes (3) Cast: NJSM

17 Chelonia, Right ilium fragment Cast: NJSM

18 Crocodilidae Phalanx

19 Chelonia, Distal tibia

20 Chelonia, cf. Adocus Carapace fragments

21 Hadrosauridae, indeterminate Cervical zygopophysis

22

23 Hadrosauridae, cf. Tooth Cast: NJSM

24 Hadrosauridae, cf. Tooth Cast: NJSM

25 cf. Adocus carapace fragment

26 Hadrosauridae, indeterminate Fragmentary phalanx

27 Lepisosteidae Bone fragments

28 Hypsibema missouriense caudal centrum USNM 16735 Cast: NJSM

29 Hypsibema missouriense caudal centrum USNM 16735 Cast: NJSM

30 Naomichelys sp. Left xiphiplastron Cast: NJSM

31 Naomichelys sp. ? Dermal ossification Cast: NJSM

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Bibliography

Allen, Victor T.
1935 Mineral Composition and origin of Missouri Flint and Diaspore Clays: Appendix IV in 58th Brennial Report, Missouri Geological Survey and Water resources. pages 1-24

Amos, D.H.
1987a Geologic Map of the Friedheim Quadrangle, Cape Girardeau, Bollinger, and Perry counties, Missouri: United States Geological Survey Miscellaneous Field Studies MF-1905.

1987b Geologic Map of the Scopus Quadrangle, Bollinger County, Missouri: United States Geological Survey Miscellaneous Field Studies MF-1910.

1987c Geologic Map of the Marble Hill Quadrangle, Bollinger County, Missouri: United States Geological Survey Miscellaneous Field Studies MF-1900.

Baird, Donald and John R. Horner
1979 Cretaceous Dinosaurs of North Carolina: Brimleyana Number 2:1-28.

Bretz, J.H.
1956 Caves of Missouri: Division of Geological Survey and Water Resources Bulletin 39 (second series), 490 pages.

Cope, Edward D.
1869 [Remarks on Eschrichtius polyporus, Hypsibema crassicauda, Hadrosaurus tripos, and Polydectes biturgidus]: Proceedings of the Academy of Natural Sciences of Philadelphia 1869:192.

Crone, A.J.
1981 Sample Description and Stratigraphic Correlation of the New Madrid test well-1-X, New Madrid County, Missouri: United States Geological Survey Open-File Report 81-426: 26 pages.

Frederiksen, N.O.; Bybell, L.J.; Christopher, R.A.; Crone, A.J. Edwards, L.E.; Gibson, T.G.; Hazel, J.E.; Repetski, J.E.; Russ, D.P.; Smith, C.C. and Ward, L.W.
1982 Biostratigraphy and paleoecology of lower Paleozoic, Upper Cretaceous, and lower Tertiary rocks in U.S. Geological Survey New Madrid test wells, southeastern Missouri: Tulane Studies in Geology and Paleontology, Volume 17, No. 2. pages 23-45.

CHRONISTER SITE

Bibliography

Galbreath, Edwin C.
1987 A Ceratosauroid Tarsus (Theropod Dinosaur) from Southeastern Missouri: Papers in Vertebrate Paleontology in Honor of Morton Green: Dakoterra volume 3, pages 14-15.

Gilmore, Charles W.
1945 Parrosaurus, new name, replacing Neosaurus Gilmore: Journal of Paleontology 19:540.

__________ and D. R. Stewart
1945 A new Sauropod dinosaur from the Upper Cretaceous of Missouri: Journal of Paleontology 19:23-29.

Grim, R.E.
1968 Clay Mineralogy (second edition): McGraw-Hill, Inc.

Grim, R.E; Lamar, J.E.: and Bradley, W.F.
1937 The Clay Minerals in Illinois Limestones and Dolomites Journal of Geology Volume 45, pages 829-843

Grohskopf, John G. and Wallace B. Howe
1961 Cretaceous System in John W. Koenig (editor) The Stratigraphic Succession in Missouri: Missouri Division of Geological Survey and Water Resources Reports, Second Series, Volume 40, pages 123-124.

Hay, O.P.
1908 The Fossil Turtles of North America. Carnegie Institute of Washington Publication Number 75.

Heller, Robert L.
1943 Geology of the Marble Hill Area, Bollinger County, Missouri: Unpublished Master of Arts Thesis, Graduate School of the University of Missouri, Columbia, 109 pages, map.

Horner, John R.
1979 Upper Cretaceous dinosaurs from the Bearpaw Shale (marine) of south-central Montana with a checklist of Upper Cretaceous dinosaur remains from marine sediments in North America: Journal of Paleontology 53(3):566-577.

Hurlbut, Cornelius S. Jr. and Klein, Cornelis
1985 Manual of Mineralogy, 20th edition, New York, Wiley, 596 pages.

Johnson, Hope and Storer, John E.
1974 A Guide to Alberta Vertebrate Fossils from the Age of Dinosaurs: Provincial Museum of Alberta Publication Number 4.

CHRONISTER SITE

Bibliography

Langston, Wann, Jr.
1974 Nonmammalian Comanachean Tetrapods: Geoscience and Man Volume VIII: Pages 77-102.

Leidy, J.
1965 Memoir on the extinct reptiles of the Cretaceous Formations of the United States: Smithsonian Contributions to Knowledge 14(6): 1-135.

McCracken, Mary H.
1971 Structural features of missouri: Mo., Geol. Survey. Water Resour., Rep. Invest. No. 49.00 p., illus (incl. map).

McCracken, Mary H.
1971 Ozark and Lincoln Fold Areas of Missouri: In Future Petroleum Provinces of the United States; their Geology and Potential. Vol. 2, Am. Assoc. Pet. Geol., Mem., No. 15, p. 1082-1088, illus (incl. sketch maps).

McCracken, Mary H.
1971 Structural features map of Missouri scale 1/500,000: Mo. Geol. Surv. Water Res. (Rolla)

Mackenzie, R.C., Editor
1970 Differential Thermal Analysis, Academic Press

McQueen, H.S.
1929 Geologic Relations of the Diaspore and Flint Fire Clays of Missouri: Journal of the American Ceramic Society 12, pages 687-697

Matthes, F.E.
1933 Cretaceous sediments in Crowley's Ridge, Southeastern Missouri: Bulletin of the American Association of Petroleum Geologists, Volume 17, pages 1003-1009.

Mesko, T.O.
1988 Subsurface Geology of Paleozoic, Mesozoic, and Cenozoic Units in Southeast Missouri; United States Geological Survey Miscellaneous Investigation Map I-1875

Morris, William J.
1972 A giant hadrosaurian dinosaur from Beja California Journal of Paleontology: Volum 46, number 5, pages 777-779

Oman, Joanne K.
1986 Stratigraphic framework and correlation of the Tertiary Lignite-Bearing Formations from Southeast Missouri to the Fort Pillow Test Well of West Tennessee: United States Geological Survey Bulletin 1644: 7 pages.

Bibliography

Ostrom, John H.
1970 Stratigraphy and Paleontology of the Cloverly Formation (Lower Cretaceous) of the Bighorn Basin Area, Wyoming and Montana: Peabody Museum of Natural History, Yale University; Bulletin 35, 234 pages.

Parris, David C.; Grandstaff, Barbara S.; Stinchcomb, Bruce L., and Denton Robert K. Jr.
1988 Chronister: The Missouri Dinosaur Site (Abstract) Journal of Vertebrate Paleontology 8: supplement to Number 3, pages 23A.

Saunders, Jeffrey J.
1977 Late Pleistocene Vertebrates of the Western Ozark Highland, Missouri; Illinois State Museum Report of Investigations 33: 118 pages.

Tennissen, Anthony C.
1960 Kaolin Deposits near Glen Allen, Bollinger County, Missouri Open file report of State of Missouri, Division of Geological Survey and Water Resources, 19 pages

Stephenson, Lloyd W.
1955 Owl Creek (Upper Cretaceous) fossils from Crowley's Ridge, Southeastern Missouri, United States Geological Survey Professional Paper 274-E, pages 97-140.

Worrall, W.E.
1986 Clays and Ceramic Raw Materials (second edition), Elsevier, Applied Science Publishers

Measurements of
Hypsibema missouriense
from the Chronister Site

(all measurements in millimeters*)

	length	width	height	l/w	l/ht	w/ht
1	91	87	91	1.05	1.00	0.96
2	91	86	90	1.06	1.01	0.96
3	90	85	86	1.06	1.05	0.99
4	87.5	-	-	-	-	-
5	87.5	83	78	1.05	1.12	1.06
6	87	76	67	1.14	1.30	1.13
7	86	78	-	1.10	-	-
8	85	73.5	65	1.16	1.31	1.13
9	83	69	60	1.20	1.38	1.15
10	82	67.5	60	1.21	1.37	1.13
11	79	-	57e	-	1.39e	-
12	78	65e	53e	1.2e	1.47e	1.23e
13	69	-	-	-	-	-

	length	width	height	l/w	l/ht	w/ht
A	75	56	45m	1.34	1.67e	1.24e
B	72	54	45	1.33	1.60	1.20
C	70	51	42	1.37	1.67	1.21
D	84	91a	-	0.92a	-	-

e=estimated m-minimum a=measured at anterior end

*measurements of vertebrae 1-13 from Gilmore and Stewart (1945)

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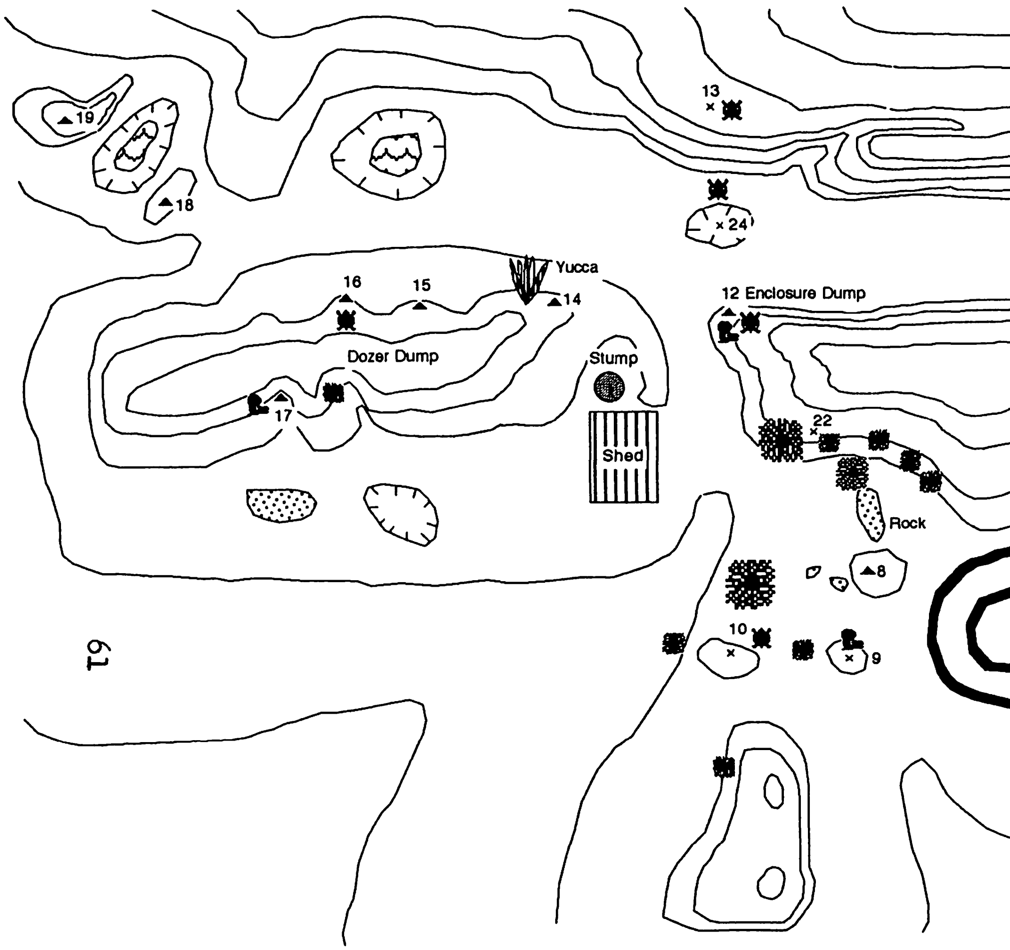

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12 Enclosure Dump
Dozer Dump
Stump
17
Shed
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Rock
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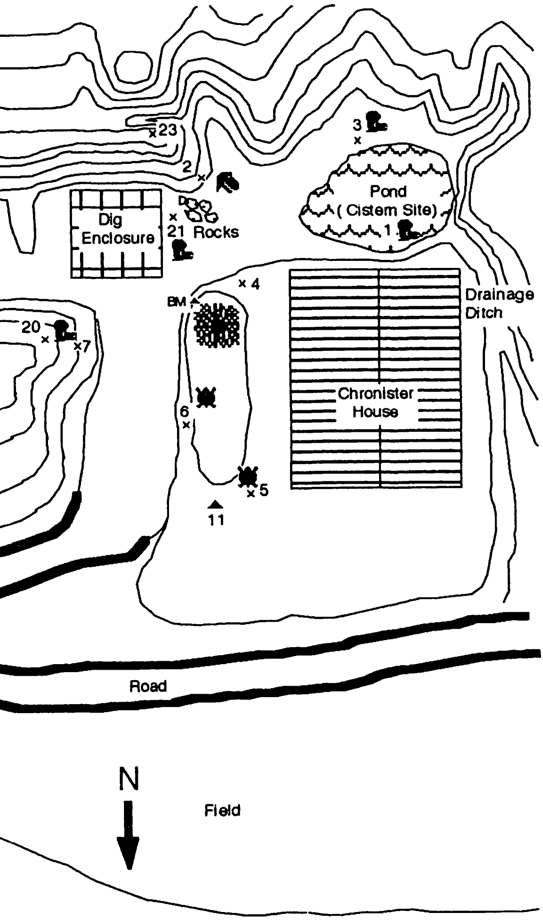
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(Cistern Site)
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Chronister
House
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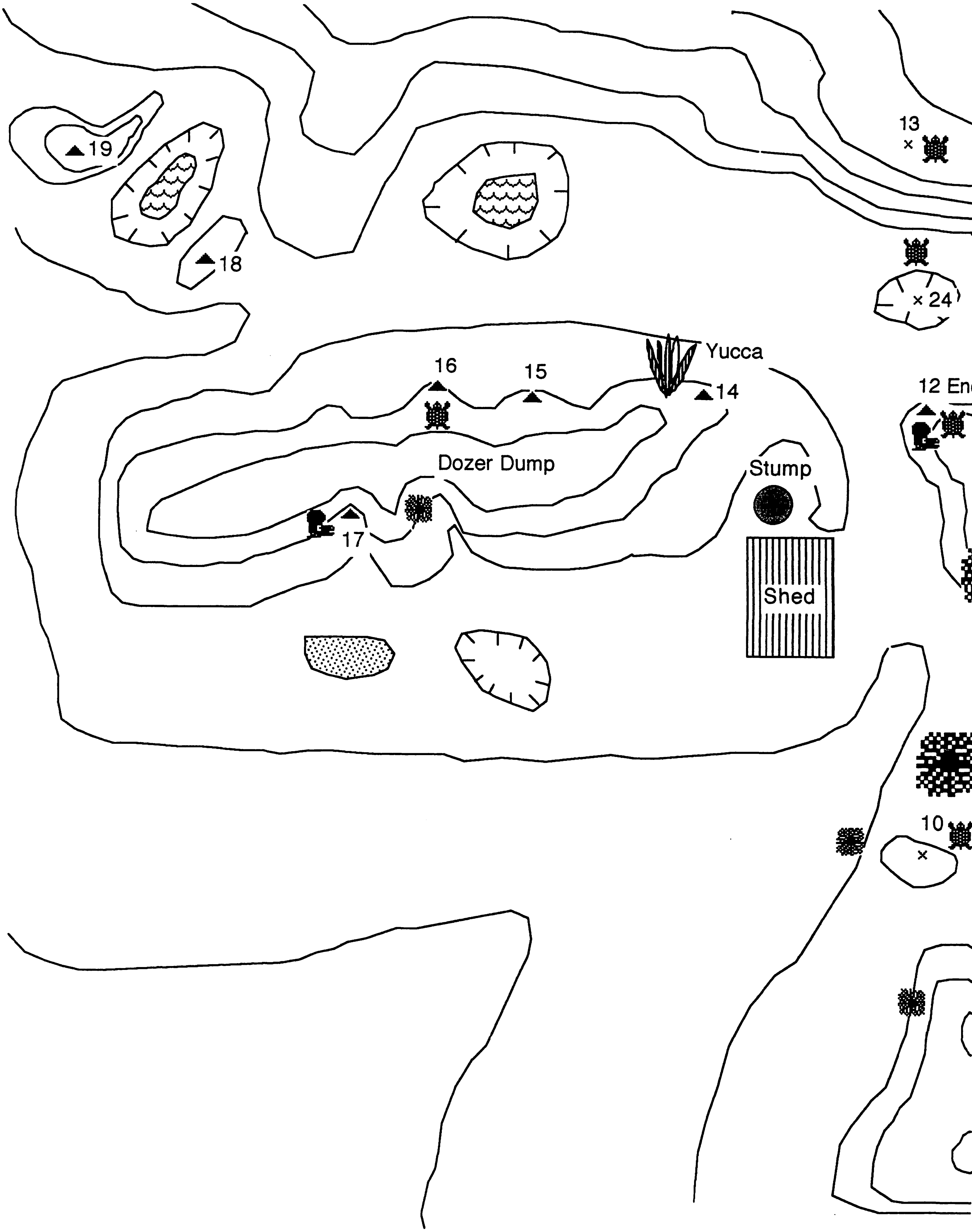
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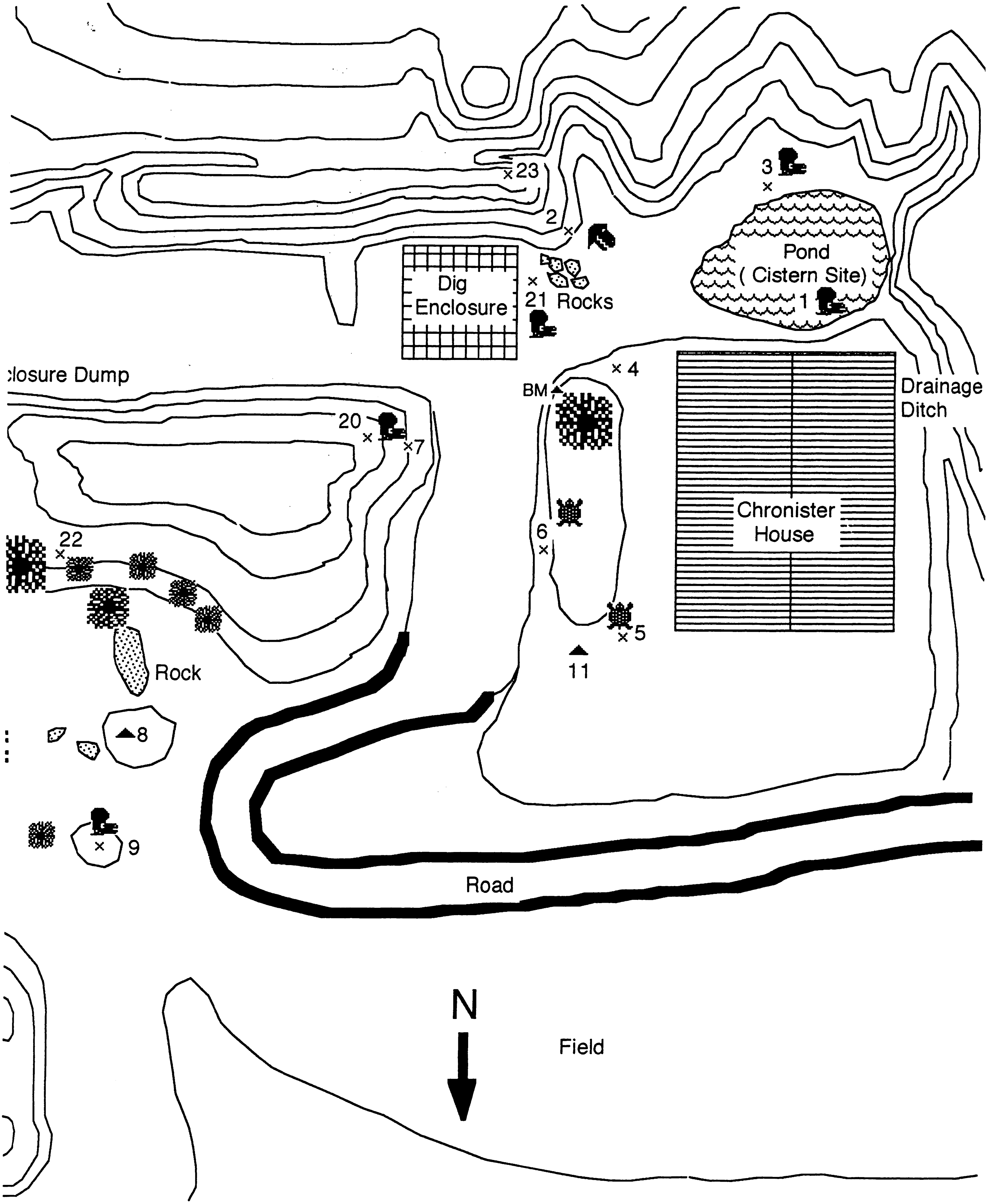

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DIG

THOSE

DINOS

To some it might seem an unusual vacation, digging for dinosaur bones under a blazing summer sun, sleeping and eating in a Blackfeet style tipi. How did this field school come to be? The story is the stuff of which books and movies are made.

In fact Michael Crichton, in his 1990 best-selling book, Jurassic Park (which was resently made into a movie patterned the book's hero after Dr. Jack Horner, and portions of the plot seemed to have been inspired by Horner's real life story in Montana. That story begins in 1978, when Marion Brandvold, owner of a rock shop in Bynum, Montana, was out walking with her son and daughter-in-law in the Willow Creek Anticline, a badlands "wrinkle" in the dry and desolate rock formations of western Montana. They were searching for unusual rocks for the shop and found some large fossilized bones. Brandvold, believing them to be dinosaur bones, called Jack Horner, then a research scientist working as a preparator of fossils at Princeton University in New Jersey.

Horner identified the bones as the femur and jawbone of a duck-billed hadrosaur, a dinosaue that lived in the area about 80 million years ago. Then Brandvold nonchalantly showed him a coffee can full of small fossil bones that turned out to be four baby dinosaurs.

A diorama at the Museum of the Rockies shows a hadrosaur (Maiasaura, or "good mother lizard") nurturing her young.

LIFE as They Knew It

The Museum of the Rockies, which opened as a 32,000-square-foot facility 21 years ago, was enlarged in 1989 with a $9.5 million, 63,600-square-foot addition, which holds a planetarium, auditorium, classrooms, new galleries and exhibition halls, and also laboratories, collection storage, and preparation areas. Exhibits tell the story of the Plains Indians, and of the pioneers and homesteaders who settled the west. Most exciting, though, is Dinosaur Hall, where excellently crafted lifesize (24 feet long) hadrosaurs "care" for nests of young; prehistoric "Quetzalcoatlus," flying reptiles with a 12-foot wingspan, "fly" around the ceiling; a lifesize robotic *Triceratops* lunges back and forth defending her turf and her two babies while emitting fearsome roars; and the real skeleton of a mighty *Tyrannosaurus rex* lies in a preparation room waiting to be pieced together.

A tour around Dinosaur Hall starts with a look at a series of enlarged photos of the Egg Mountain dig. A reconstructed embryonic skeleton of a 13-inch *Maiasaura* is displayed in a case. Other exhibits tell the story of the three-part age of dinosaurs, the Mesozoic Era that lasted about 175 million years. The Triassic age, 240 to 208 million years ago, produced small, speedy, two-legged carnivores. The Jurassic age, 208 to 145 million years ago, was a time of lumbering giants and armored dinosaurs. And the Cretaceous age, 145 to 65 million years ago, during which time *Hadrosaurus*, *Orodromeus*, and *Troödon* lived, was a time of animal diversity and low-browsing species that fed on flowering plants, also unknown before this time.

The emphasis in paleontology has shifted from merely finding and classifying the early creatures and displaying them in museums, to analyzing and reconstructing their lives. One case at the museum displays four hadrosaur thigh bone ends: a three-inch embryo size, a five-inch hatchling size, a seven-inch nestling (at this point the young hadrosaur could leave the nest), and a 30-inch full-grown hadrosaur bone. Hatchlings three times the size of embryos still found in the nest proved to Horner that the babies were nurtured by their mothers. Because the amount of growth was so dramatic, it was also clear to him that these were warm-blooded, not cold-blooded, animals. Scans of bone slices reveal far more blood vessels than a cold-blooded animal normally requires for nourishment.

Hadrosaurus was the first dinosaur found in the U.S., in 1869. Early drawings depicted the animals balancing on their tails, but now it's known that the 24-foot-long creatures stood about nine feet high at the hip, and had tails that ossified early on, and were rigid. Rather than hugging the ground, the tail served to counterbalance the 3,300-pound weight of the animal's body. Hadrosaurs stood in a birdlike posture, with the hips at the same level as the head. They were active animals, not plodding and slow, says Horner. — PS

Brandvold led an ecstatic Horner to the discovery site near Choteau, and there he found much more_ the nest where the babies had lived.

In the nests containing the small bones Horner believed, lay the key to a totally new concept in dinosaur behavior. Promoting his theories.
Horner became a pioneer in interpreting the animals' social behavior. He says, "I don't care how they died _ I want to know how they lived." Hoping to find out , Horner commenced a major excavation at the Choteau site.

In 1979, Fran Tannenbaum, A member of Horners team and a geology student at Princeton University, made yet another exciting discovery.

Tired one evening after a day of excavating, she took a shortcut back to camp, and along the way practically stumbled over a fossilized dinosaur egg. She hurried to camp and returned to the egg site with a crew to investigate thoroughly on that first_ occasion they found 11 more dinosaur eggs, plus the skeletal remains of dinosaurs and an assortment of fossilized teeth. Because of the rich array of fossils buried there, the place came to be called Egg Mountain.

The dinosaur remains found there included those belonging to a small, spry herbivore Horner dubbed *ørodromeus makelai. The makelai* was for Horner's associate, Bob Makela, and *Orodromeus* means "mountain runner."

The fossilized eggs included those of yet another dinosaur, *Troodon*, a small carnivore that laid its eggs at the periphery of nest sites of other species to assure its own young had plenty to eat.

Maiasaura means "good mother lizzard," and Horner called a duck-billed hadrosaur eventually found on the site " Maiasaura peeblesorum." Peeblesorum is in honor of John and James Peebles, owners of the land, who permitted the dig to continue until 1984.

The Nature Conservancy then purchased the site, which is only two square miles, and agreed to manage it in cooperation with the Museum of the Rockies. Plans were immediately underway to make the site "scientifically meaningful without destroying it," camp director David Swingle said.

Today, excavation at the site moves at a glacial and intensely careful pace. It is now believed that at least 10,000 *Maiasaura* died and were washed here, probably in a mud flow, but the bones are irreplaceable, not an inexaustible supply, Swingle added.

The original plan was for Makela, a high school science teacher from Rudyard, Montana, to run the Choteau camp. After Makela died, Swingle was asked to take over as director.

Week-long courses start at the Museum of the Rockies, where excellent exhibits at Phyllis B. Berger Dinosaur Hall provide a window into the past, back 80 million years. The displays also detail Horner's findings and how he arrived at his theories (see Life as They Knew it").

CAMP-OSAUR. After our visit to the Museum of the Rickies, we were eager to visit the Choteau dig and see the excavation in progress. The dig lies about 12 miles southwest of town off a gravel road that coils up into mud-colored hills like a white serpent. There are no trees, and the summer sun blasts down on the high Montana plains. The jagged peaks of purple mountains are somber on far horizons.

David Swingle was expecting us at Camp-osaur, a windblown expanse of dust reclaimed from the sagebrush and prickly pear-strewn desert. Students (on this occasion 40 science teachers from around the country), instructed by a staff of 12, live and attend classes in the Camp-osaur tipis, the biggest of which can hold 50. Everything at the camp is portable, including showers that use sun-warmed water, and all must be toted out when camp ends each year_ nothing is left that could possibly damage the desert ecosystem.

Great effort is made to create a hospitable environment, but there's little protection against sun or wind, and after five hours we were well roasted and chewing unwelcome mouthfuls of sandy grit. But any physical discomfort is made trivial by the presence of dinosaur bones lying on the hillside nearby.

Only adult dino bones emerge here. Dense layers of sediment, 1,000 feet or more, were cut away by glacial activity 1,000 years ago, leaving bones near or protruding from the surface.

This isn't the case at Egg Mountain, where egg shells were occasionally seen a century ago but always misidentified as turtle shells. Diggers must work on a 40-foot rockface made of vitrified mud stone. At Camp-osaur ice picks and similar devices are sufficient; Egg Mountain is a microsite where only the most delicate tools and procedures are employed. To take out a nest, diggers usually remove about a ton of solid-block matrix. The matrix, however, is not bonded tightly to the egg shells. Every fossil found is jacketed and sent to Bozeman.

Computer technology and CAT scans are quickly helping to build paleontological knowledge, Swingle told us. Discoveries at Choteau are codified, and more is constantly being learned about the duck-billed dinosaurs and others.

For instance: Hadrosaurs grew from embryo to adult, increasing some 3,000 percent in only four years, evidence they were warm-blooded, said Swingle. They were equipped with "something that stopped their growth and reduced their metabolism at maturity," he said. (Cold-blooded, reptiles continue to grow throughout their lifetime.) It's also believed the *Maiasaurus* evolved quickly; evolution is generally a slow process but one that can be accelerated in times of stress - in the case of these dinosaurs, stress occured as the Inland Seaway expanded on one side, and the Rockies grew up on the other, constantly shrinking their habitat (see "Why Here?"). To date, no one knows if *Maiasaurus* migrated, but they were "ubiquitous," the cattle of the Cretaceous, Swingle said.

Soon the micro screening of excavation sites, the systematic study as to what constituted the environment, will begin. Already, fossilized fish, turtles, and mollusks have been found.

In the past , as dinosaurs were discovered "a tooth here, a tooth there," it was difficult to tell if all the teeth belonged to the same animal, Swingle said. Now a computer system developed to determine circulation patterns has also revealed that animals add a micro layer to their teeth each day of life; much can be learned through a study of teeth.

So far, no genetic material has been found here, and it never will because the "area is too well cooked by volcanoes," but its possible some may be retrieved elsewhere, shedding further light on hadrosaur life.

"But overall, for learning how to recognize the various bones, and how to dissect bone beds, and for gleaning information about the social behavior of these animals, this has proven to be the world's greatest site," Swingle said. "We're beginning to have a pretty good idea as to what they were like."

DINOSAUR JACKETS. Before we left the camp, we watched staff member Carol DeFord, who during the winter months is curator of the Cranbrook Institute of Science near Detroit, and several of her students outfit a *Maiasaura* tibia with a plaster "jacket" for its trip to Bozeman. The bone had been uncovered the day before and lay on the hillside, still tight in the ground, bleaching in the sun.

While we hovered close, DeFord swaddled the long bone in water-soaked paper towels, Which she then covered with strips of burlap that had been dipped into a thick solution of plaster of Paris and water. Afterwards more soft plaster was smeared thickly over all, reaching as far underneath as possible, to make a "pedestal" for leverage.

In this land of blast-furnace sun and no humidity, a plaster jacket is fully dry and hard within three hours, but not considered removable for a full day. But we were in luck: another bone had been jasketed the day before, and was now ready to be broken free of its moorings.

DeFord knelt beside it, and holding tight to its pedestal, began gently rocking it back and forth, then with a quick jerk, wrenched it free. Flipping it over, she and her students covered its bottom side with more paper towels and plaster.

If a bone gets damaged during the process, its "integrity" can be restored by filling in gaps with Dextrin, a mix of cornstarch and plaster, explained DeFord. She quoted Jack Horner: "if you don't get into it, and risk breaking it, you don't know what you've got - glue is cheap."

Ann Sutton, an invertebrate paleontologist from Medford, Oregon, who's a staffer here each summer, said "This is a marvelous opportunity for learning, and for providing teachers with material to take back to their classrooms. An amazing amount of research is also going on here."

DeFord added, "students learn here that science is speculation based on educated guesses." They learn the scientific process: that a question gets things going, brainstorming yields possible answers, and is followed by testing of those answers, formulating more tests, drawing conclusions, and finally, by recording results. Most importantly, results must be shared, DeFord said, again quoting Horner.

" This is a wonderful , wonderful place, she added. "Anybody who's ever loved dinosaurs and dreamed of knowing them first-hand can come here and do it - for me, this is a dream come true."

Why Here?

The dinosaurs studied near Choteau, Montana, were preserved because a specific set of circumstances occured, the region, 500 million years ago, was a flat plain flooded periodically by shallow seas. By the end of the age of dinosaurs, the flooding had deposited thousands of feet of sediment.

Eventually the sediment was lifted up and folded to form the Rocky Mountains. Dinosaurs lived in the uplands and lowlands, and marine reptiles lived in the seaway. Sedimentation that accumulated in the seaway promoted fossilization. As the mountains were building, there was much volcanic activity, so its possible that a volcanic blast from far to the west (in today's Idaho) killed great numbers of dinosaurs. The animals embryos, and babies in nests, as well as adults, seem to have all died about the same time. possibly from gas or ash spewed out of a volcano. The dinosaur remains were fossilized where they lay and later swep away by volcanic mud flows to the Willow Creek Anticline - PS

This article was written by Pamela Selbert, for The Lapidary Journal
Permission granted to reprint: "Dig Those Dinos," The Lapidary Journal
July 1993

Contributed by MAPS member Randy Faerber.

OUR MOST EXCITING DINOSAUR

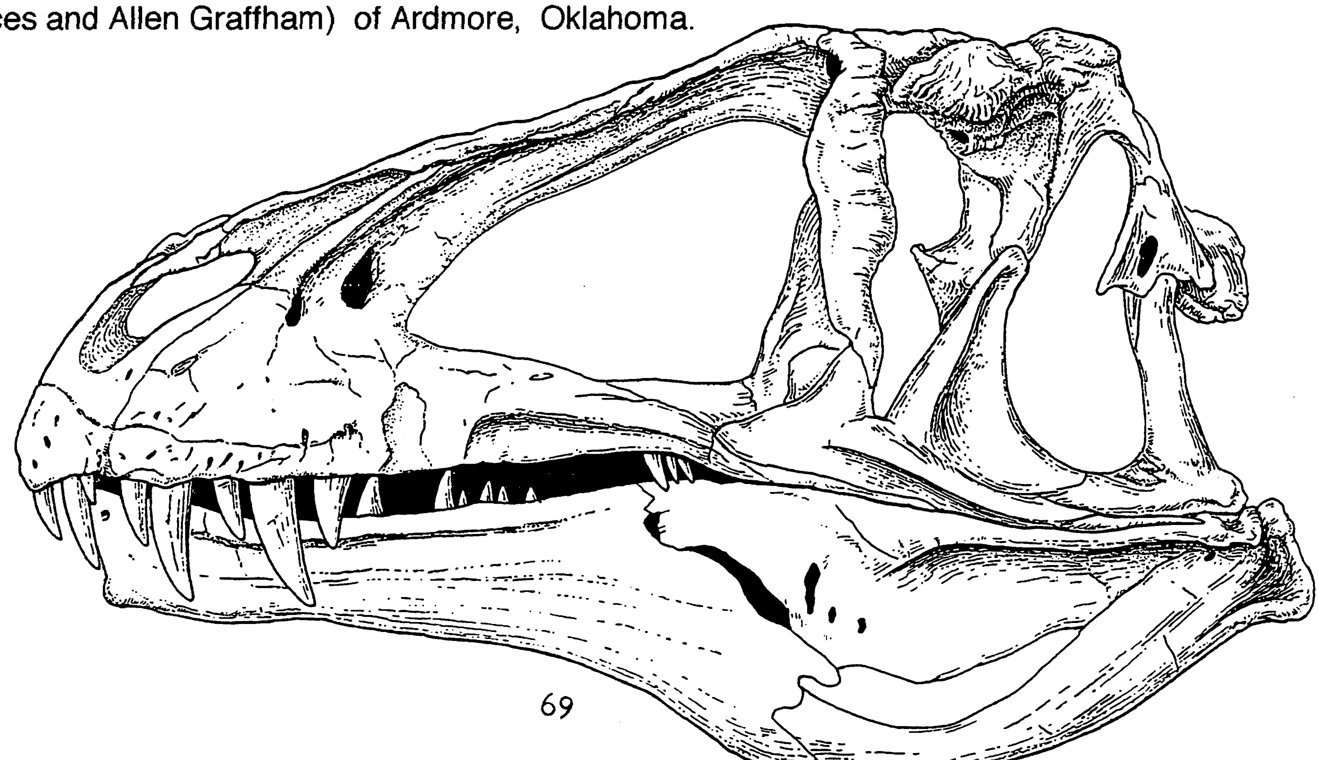
Allen Graffham
Box 996
Ardmore, Oklahoma 73402

ACROCANTHOSAURUS ATOKENSIS

Acrocanthosaurus are very large carnivores that occured in the lower Cretaceous of Oklahoma and Texas. Our specimen is from McCurtain County Oklahoma and was first found in 1983 by Sid Love and Cephis Hall and excavated by them over the next couple of years. Even though they did not have formal training they did a very good job of collecting this incredible dinosaur.

The drawing is by a scientific illustrator, Dorothy Sigler Norton and is the first drawing made of this second largest carnivore that ever lived. The dinosaur is estimated to be 85% complete and will eventually be mounted for display. The skull is now being prepared by Black Hills Institute where it has been in preparation for the past year. The size was incorrectly stated on the cover of our bulletin for '94 as five feet seven inches and actually the size is four feet 7 inches still the second largest carnivorous dinosaur skull ever found. The largest skull is from a T-rex, "Sue" which is currently in Governmental custody.

This specimen is now the property of Geological Enterprises (owned and operated by Frances and Allen Graffham) of Ardmore, Oklahoma.



DINOSAURS AND PHILATELISTS

Anthony J. Verdi
1225 Ledge Road
Hinckley, Ohio 44233

The mention of dinosaurs immediately sets our imaginations to work. All of us, old and young, wonder about this group of reptiles which roamed the earth for approximately 150 million years, during a time named the Mesozoic era.

The Mesozoic era is divided into three periods, the Triassic, Jurassic, and Cretaceous. The dinosaurs evolved sometime during the early Triassic which began about 225 million years ago. The dinosaurs prospered during the Jurassic (193 million years ago) and Cretaceous (136 million years ago) periods. The dinosaurs comprised the dominant groups of terrestrial animals. They became extinct at the close of the Cretaceous period, 65 million years ago.

These creatures have been extinct for many millions of years. All of our knowledge of the dinosaurs came from the study of fossils. As we consider dinosaurs, we must wonder: What did they look like when they were covered with skin and bone? What was their behavior like? Were they colorful? What caused them to disappear?

As a philatelist (stamp collector) I am pleased to have several hundred stamps picturing dinosaurs in my collection.

When I was an eleven-year old child, in 1935, I collected a set of dinosaur stamps (actually labels) which the Sinclair Refining Company made available each week at their gasoline stations.

The earliest postage stamp that I own picturing a dinosaur, was issued by China in 1958. The stamp pictures a *Lufengosaurus* .

In 1965, San Marino issued a set of nine stamps depicting prehistoric life. Six of the stamps pictured dinosaurs. Also in the same year, Poland issued a set of ten stamps, six of them pictured dinosaurs. In 1966, Belgium issued a stamp picturing an *Iquanodon* skeleton. This was the beginning of the dinosaurs on stamps.

During the last five years, about thirty-nine countries have issued 246 stamps picturing dinosaurs.

In 1970, the United States issued a stamp picturing part of a mural showing life in the Jurassic era. Many dinosaurs were included. This is a very attractive item.

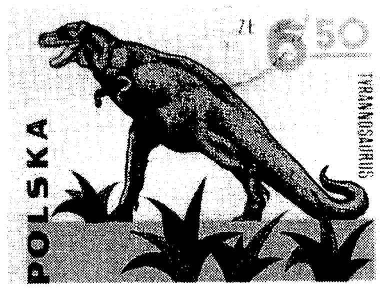
In 1989, the United States issued four stamps picturing prehistoric life, three of them pictured dinosaurs.

As I study my dinosaur stamps, I notice that some are well researched and well illustrated, while others are not well done.

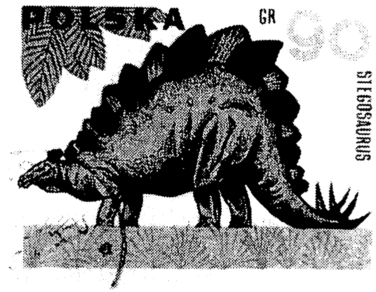
I enjoy all of my dinosaur stamps, but I feel the postal authorities should recognize our early, small fossil also.

I have just discovered that six coins picturing dinosaurs have been issued by four different countries. On the coins are *Stegosaurus, Cetiosaurus, Brontosaurus, Tyrannosaurus rex, Triceratop* and *Protoceratop.*

CHINA 1958
LUFENGOSAURUS



POLAND 1965

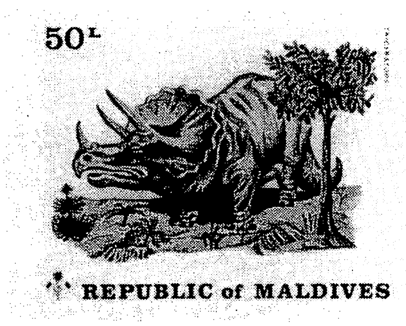


POLAND 1965

SAN MARINO 1965

BELGIUM 1966

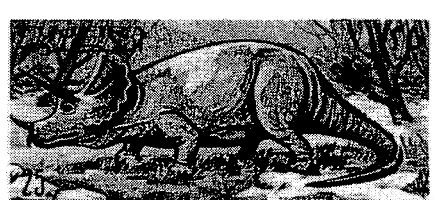
U.S.A. 1970



THE MALDIVES 1992

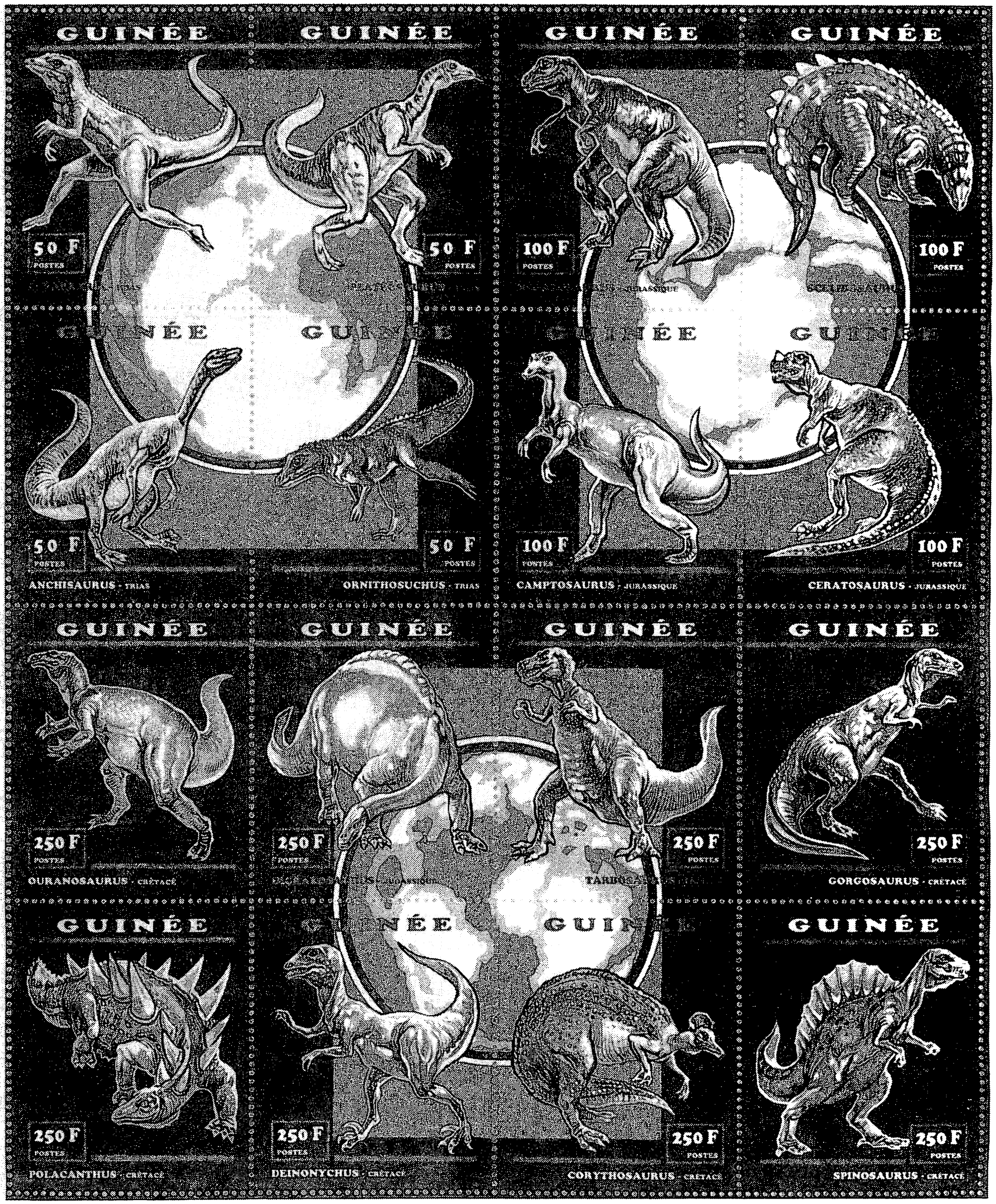
BENIN 1984

LAOS 1988



FUJEIRA 1968

LES DINOSAURES
TRIAS – JURASSIQUE – CRÉTACÉ



1993

Elongate Dinosaur Tracks

GLEN JAY KUBAN

Paper presented at The First International Symposium on Dinosaur Tracks and Traces, Albuquerque, New Mexico, May 1986.

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III Locomotion and Behavior

"Leidy and Cope had no qualms about letting their "kangaroo" dinosaurs bound after one another unchecked, and the notion of an active on occasions fast moving dinosaur took root, and has been alluded to ever since."

Desmond 1975 p. 104–105

"All dinosaurs are characterized by a "fully improved" or "fully erect" position of the limbs (not unlike that found in higher mammals) in which the limbs support the body from beneath, holding it clear of the ground."

Charig 1979 p. 18.

Trackways are an important source of information on dinosaur locomotion. Despite contrary assertions and many incorrect museum reconstructions (Wade this volume), the vast majority of dinosaur trackways indicate fully erect, non-sprawling posture (Fig 0.2 this volume). As erect reconstructions have gained acceptance, there has been much speculation about dinosaur agility and speed. While it is reasonable to infer that dinosaurs were not slow and cumbersome, as often suggested, it is difficult if not impossible to make absolute speed estimates from trackways (Thulborn this volume). The vast majority of trackways indicate walking progression. Examples attributed to running dinosaurs are rare exceptions. The example (left) of a theropod with a 531 cm stride (after Farlow 1981 Fig. 1) was reported from a site where three trackways were used to estimate running speeds of about 30–40 km/hr. Such speeds indicate considerable cursorial ability, but not necessarily the maximum speeds attained by dinosaurs.

Trackways with district metatarsal impressions also shed new light on occasional plantigrade progression by dinosaurs (Kuban this volume; Introduction Fig. 0.3). Incomplete and irregular trackways raise controversial questions about the swimming ability and behavior of dinosaurs (Ishigaki this volume; McAllister this volume).

Parallel trackways permit speculations about gregariousness and herding, or social behavior among dinosaurs (Bird 1944, Farlow and Lockley this volume).

References

Charig, A. 1979. *A New Look at the Dinosaurs.* (New York: Facts on File Inc.) 160 pp.
Desmond, A. J. 1975. *The Hot Blooded Dinosaurs.* (New York: Warner Books) 352 pp.

7 Elongate Dinosaur Tracks

GLEN JAY KUBAN

Abstract

Elongate marks made by bipedal dinosaurs include tail impressions, foot slides, toe drags, and footprints with full or partial metatarsal impressions. This paper focuses on dinosaur trackways composed largely or entirely of metatarsal footprints, suggesting that some bipedal dinosaurs, at least at times, walked in a plantigrade or quasi-plantigrade manner.

Numerous elongate dinosaur tracks with apparent metatarsal impressions occur in the Paluxy River bed, near Glen Rose, Texas. These tracks vary somewhat in size, shape, and clarity, but are typically 55 to 70 cm long (including the metatarsal segment), and 25 to 40 cm wide (across the digits). In many cases the digit impressions on such tracks are indistinct, due to mud collapse, erosion, or a combination of factors — causing some to resemble giant human footprints, for which they have been mistaken by some creationists and local residents.

Some metatarsal tracks may have been made by dinosaurs whose anatomy was especially adapted to plantigrady. However, many metatar- ·l tracks may have been made occasionally by a wide variety of bipedal dinosaurs, perhaps during behaviors in which they walked low to the ground, as during foraging or prey stalking. Most elongate tracks near Glen Rose appear to have been made by moderate sized theropods, although metatarsal tracks at other sites throughout the world include theropod and ornithopod forms of varying size and shape.

Introduction

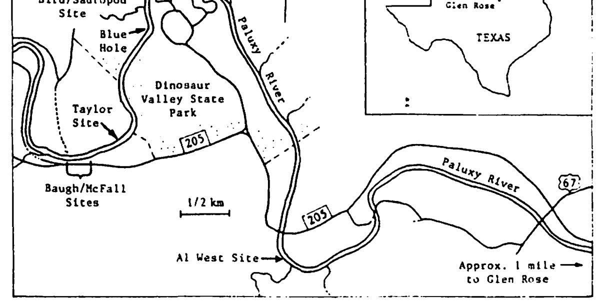
The track sites focused on in this paper occur in a section of the Paluxy River bed from 2.5 to 5 miles west of Glen Rose, Texas. The track beds are limestone and carbonate cemented sandstone layers near the base of the Glen Rose Formation, Lower Cretaceous (Langston 1979). The site locations are shown in Figure 7.1.

The Alfred West Site

This site was named for Alfred and Martha West, who lived near the site and discovered the tracks there in 1974. The site was visited in 1975 by Wann Langston, Jr., who described the elongate tracks there as problematic, and speculated that they may have been made by a dinosaur whose foot sank deeply in soft mud (Langston 1979). Creationist John Morris also visited the site (which he called "Shakey Springs") in the late 1970's. Morris, who identified similarly-shaped, indistinct tracks in other areas as human prints, stated that the elongate dinosaur tracks on the West site were unusual and deserve further study (Morris 1980). Between 1982 and 1985 I thoroughly studied and mapped the site. Much of the site is often under water, but in late summer the western half of the site usually becomes dry.

A few trackways on the West Site consist entirely of tridactyl, digitigrade tracks. These vary in size, clarity, and depth, but most are 25–45 cm in length and exhibit pace lengths and pace angles typical of other bipedal trails in Glen Rose. However, one trail (IIT, at far right of Fig.

Figure 7.1. Locations of the relevant track sites near Glen Rose, Somervell County, Texas. Glen Rose is about 70 miles southwest of Dallas, Texas.



7.2) exhibits unusually long paces relative to track length (8.48 mean pace/track length ratio), indicating an exceptional speed of about 10 m/s, using the formula by Alexander (1976). Of more pertinence to this study are the many elongate tracks on the site, as well as some possible tail marks and a few problematic traces.

Metatarsal Tracks on the Al West Site

Elongate footprints with metatarsal impressions actually outnumber the digitigrade tracks on the West Site. In some trails elongate tracks are interspersed with nonelongate (digitigrade) tracks; other trails consist entirely or primarily of elongate tracks. Trails W and IIW, which occur on the western half of the site (Fig. 7.2) will be discussed as examples of each type; other trails with elongate tracks on the eastern half of the site (Fig. 7.3) will be summarized briefly.

Trail W occurs in an area of the site that is usually dry in summer, and where the rock surface is very coarse. The trackway includes both elongate and nonelongate forms alternating irregularly, with considerable variation in pace lengths and individual print features. Shorter pace lengths (less than 115 cm) predominate; however, some of the longer paces may be due to missing tracks (for example, between tracks W9 and 10 a print may be unrecorded, or may have been marred by IIW1, or may be under the bank). The elongate prints in Trail W average 55–65 cm in length; the nonelongate ones, 35–40 cm. The digit marks on most elongate tracks in Trail W are indistinct, evidently due to mud collapse (slumping of mud back into the depressions), and later erosion. Note the superficially manlike shape of W2 (Fig. 7.4). Track W8 shows the outside digit (IV) more pronounced than the others — a common feature of elongate tracks in Glen Rose.

Trail IIW (Fig. 7.5) shows fairly long and consistent pace lengths (114–156 cm) relative to track size, and fairly large pace angles (140°–160°). All but one of the prints in Trail IIW (Fig. 7.5) are elongate, but they are slightly smaller than the elongate prints in Trail W (comparing corresponding areas of the prints). Many are indistinct, but a few are fairly well preserved. Track IIW2 shows digits splayed at a very wide angle (about 140° total divarication). Most other elongate tracks in Glen Rose also show wide, but less extreme, splaying — typically 75-90° total divarication. Several tracks in Trail IIW2 (and others in Glen Rose) show a narrow and/or raised area between the ball and heel areas, which might indicate a metatarsal "arch".

As Trail IIW approaches track IIW12 (and the area of the site usually under water), the track surface becomes smoother. Track IIW12 is very shallow and has short, blunt digit impressions (possibly due to a firm spot on the substrate), giving it an ornithopod-like appearance. However, most other tracks in the trail show more slender, pointed digits, strongly suggesting a theropod trackmaker. Track IIW13 (Fig. 7.5C), which is 53 cm long including the metatarsal segment, and 26 cm wide across the digits, is the best preserved track in Trail W, and one of the clearest on the site. The digit impressions, especially the center digit,

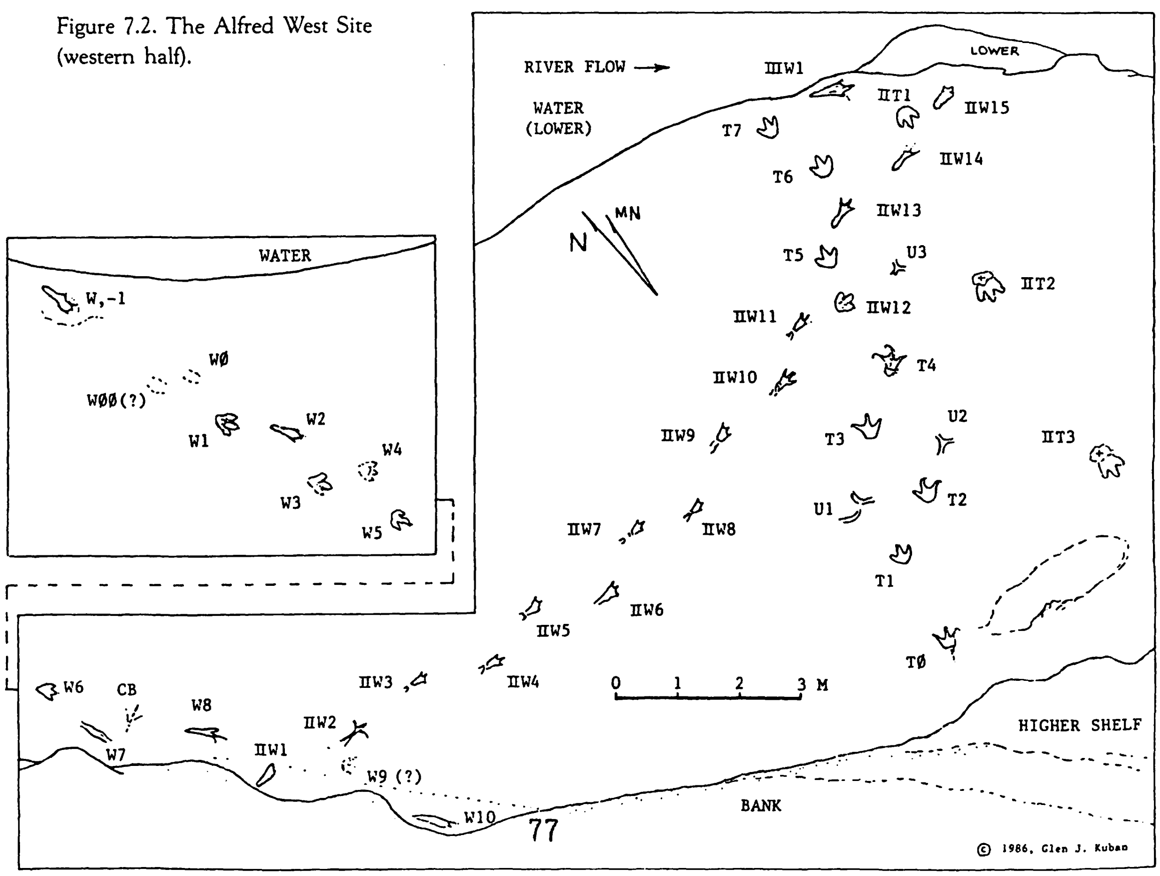


Figure 7.2. The Alfred West Site (western half).

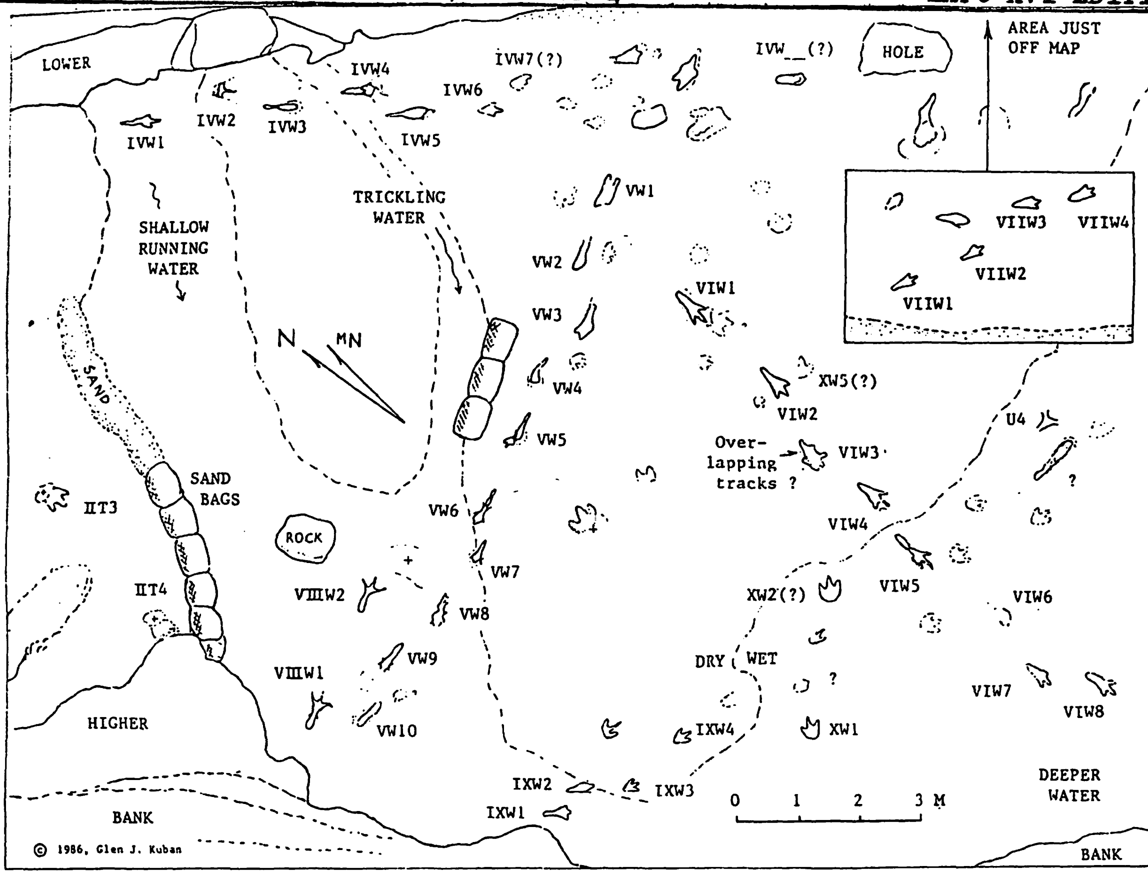
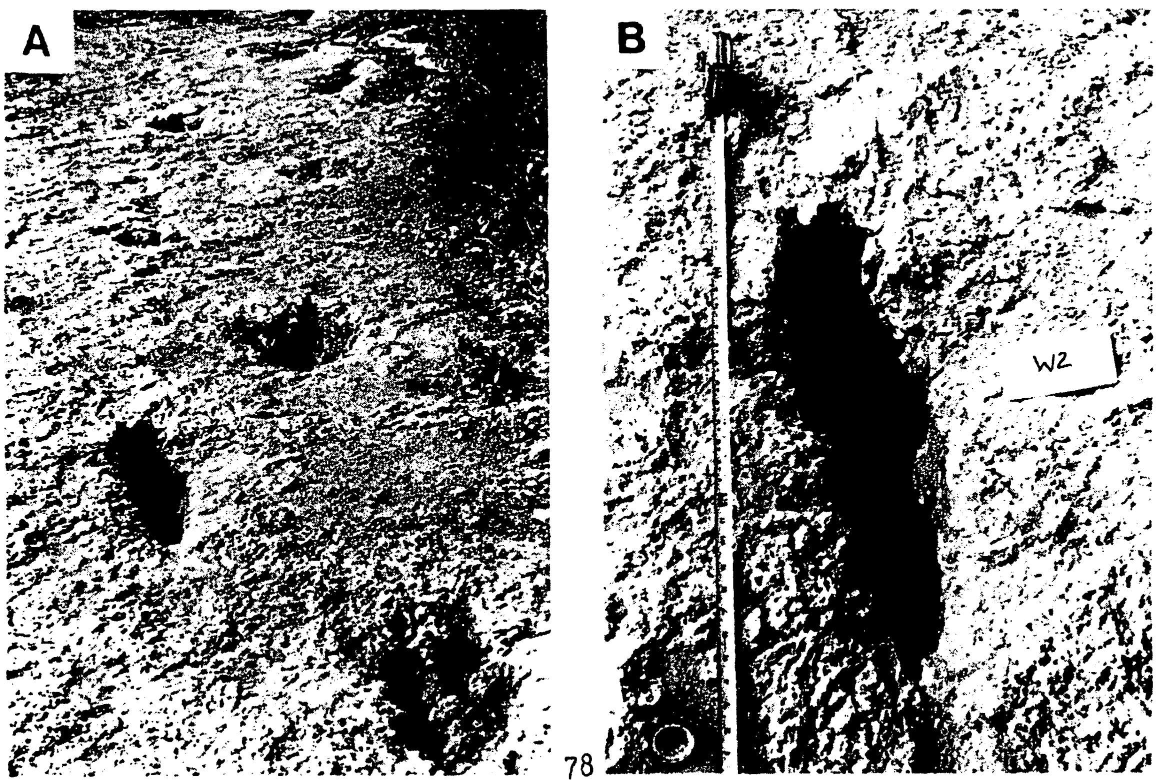


Figure 7.3. Eastern half of the Alfred West Site.

Figure 7.4. A, the W Trail on the Alfred West Site. Track W1 is at the lower right, followed by W2, W3, etc. B, track W2, showing elongate, man-like shape evidently due to metatarsal impression and mud collapse.



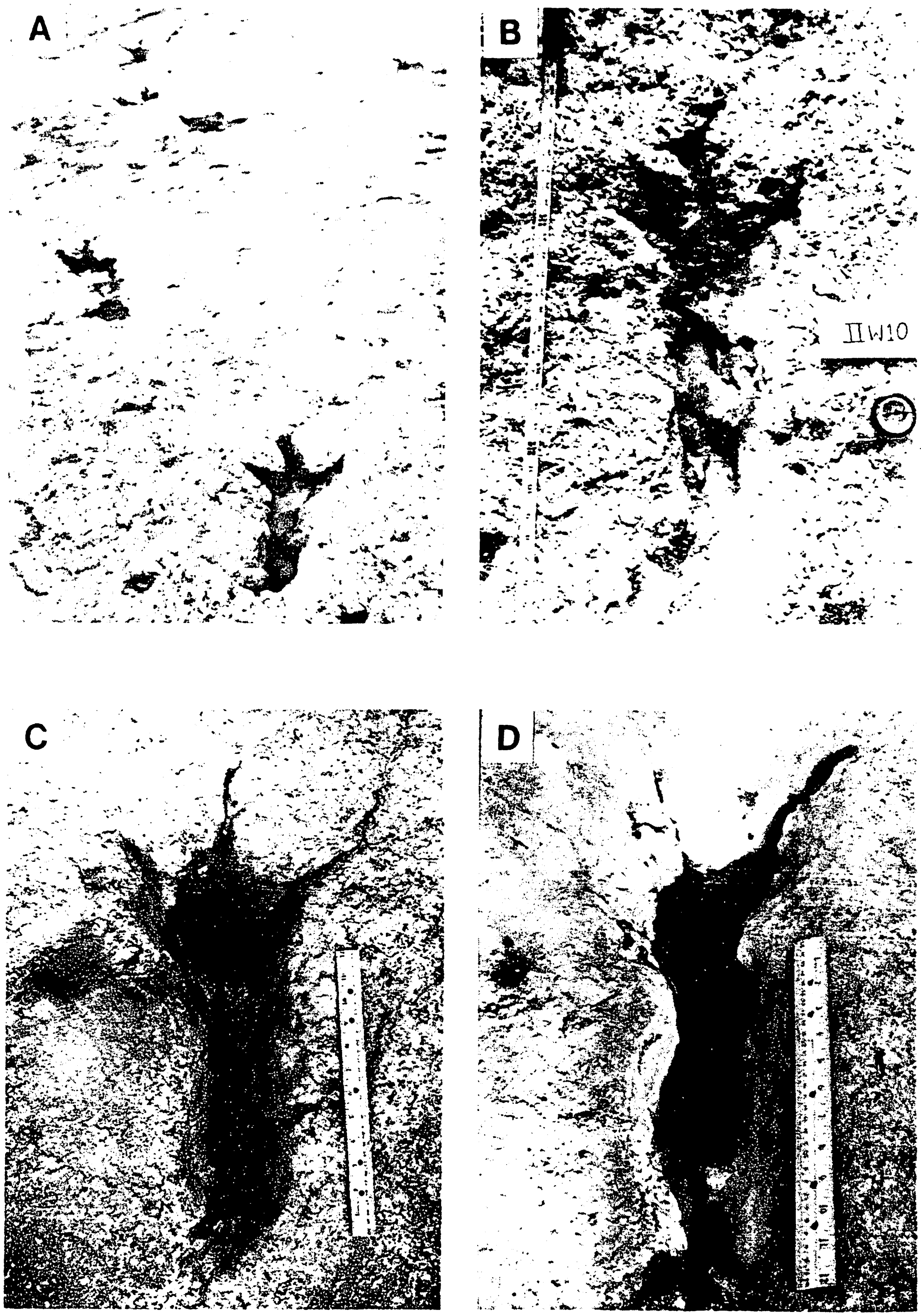


Figure 7.5. **A,** portion of the IIW Trail; track IIW10 at bottom. **B,** track IIW10. Tape measure at left is in inches. **C,** track IIW13, a well-preserved metatarsal track. **D,** track IIW14, a metatarsal track with mud collapsed digits.

are fairly narrow, apparently due to partial mud collapse. The "ball" area (metatarsophalangeal joint) is slightly more depresssed than the metatarsal and digit regions, which is typical of Glen Rose elongate tracks. The metatarsal segment is rounded at the posterior end (presumed to represent the tarsus), and narrows slightly at the center. Track IIW14 (Fig. 7.5D) is similar in shape to IIW13, but is somewhat narrower and has less distinct digits — features which may be attributed primarily to mud collapse. One can visualize how IIW13 and IIW14 would become very humanlike if the digit impressions were further obscured by erosion.

Trail IIIW is represented by a single metatarsal track near the broken north edge of the track layer, but originally may have been connected to Trail IVW. Trail IVW contains several deep elongate tracks with very indistinct (largely mud collapsed) digits, and one nonelongate track with three clear digit impressions (Fig. 7.6). This trail progresses into a very pockmarked area of the site. Trail VW contains only elongate tracks, some of which are very deep and distorted, and others of which are less deep and better preserved. Trails VIW and VIIW consist of several elongate tracks of variable clarity, but most show some indications of individual digits. Trail VIIIW comprises two well preserved metatarsal tracks, with a large pace (224 cm). Trail IXW begins with two elongate tracks near the southeast bank, then apparently becomes a digitigrade trail (the progression is ambiguous, since most of the tracks are indisinct).

Problematic Tracks and Possible Tail Marks on the West Site

Three Y-shaped depressions (U1, U2, U3) near Trail T are interpreted as possible tail marks. Each is situated about a half-meter from the midline of the trackway. The largest (U1) is about 65 cm across the longest dimension of the mark (Fig. 7.7). The Y-shape may be due to a double contact of a portion of the tail. Another small Y-shaped mark (U4) occurs in line with indistinct digitigrade tracks east of Trail VIW. Near U4 is an essentially straight elongate depression about 1 m long, and 8–13 cm wide. An apparent mud push-up on the wider end of the depression suggests that it may be a foot slide, but, since no digit marks are visible, it alternatively may be a tail mark. An unusually large trace of unknown origin is situated between tracks T0 and IIT3; this is an oblong, shallow, smooth-bottomed depression about 80 cm wide and 3 m long.

The Baugh/McFall Sites

The Baugh/McFall sites are a series of track exposures along a limestone ledge on the south bank of the Paluxy River, bordering the McFall property. The track surface is a coarse, friable limestone containing elongate and nonelongate tridactyl tracks, as well as some elongate marks of uncertain origin.

The far western end of the ledge constitutes the "Original McFall Site," a narrow exposure situated about a meter above the normal level of the river. The site features

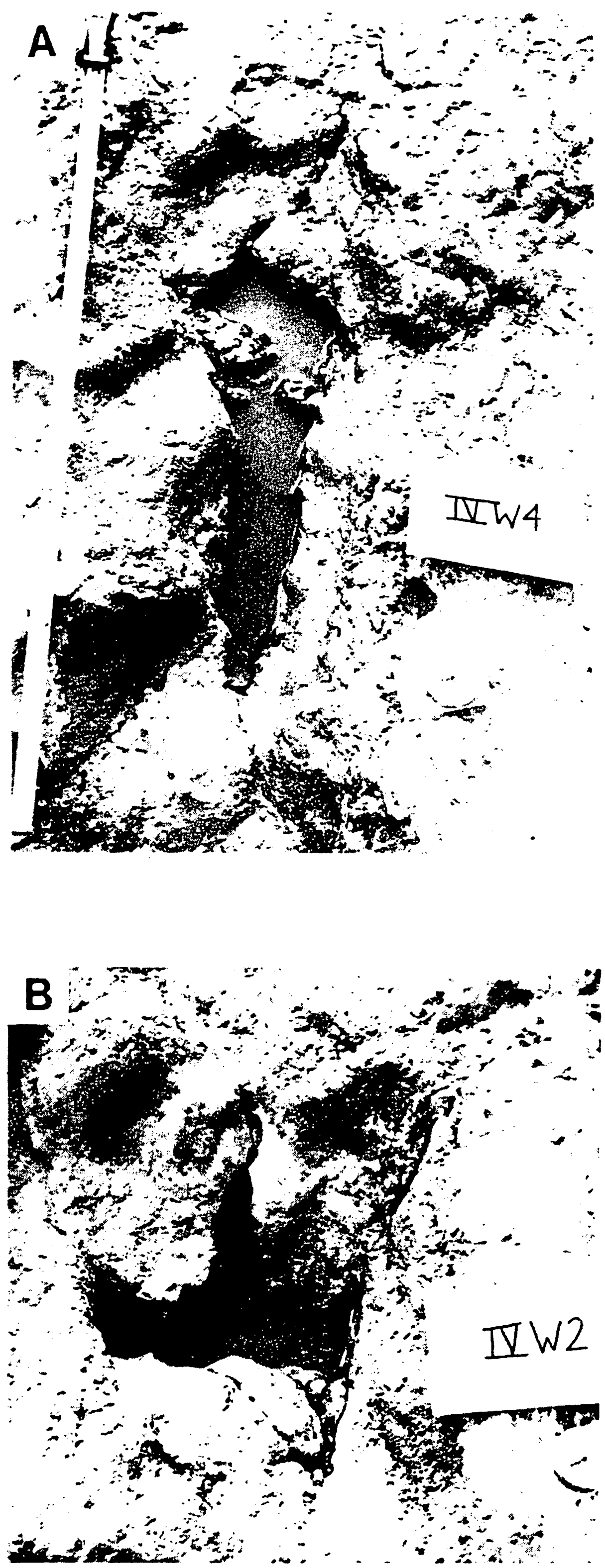


Figure 7.6. A, track IVW2, a mud-collapsed metatarsal dinosaur track with a somewhat humanlike shape, which occurred in the same trail with more obviously dinosaurian tracks, such as IVW2. B, track IVW2.

Figure 7.7. Depression #U1, a possible tail mark on the A1 West Side (see Figure 7.2 for position on site).

two long trails that contain both elongate and nonelongate tracks. The site was first studied about 1970 by a number of creationists, some of whom described the elongate tracks there as humanlike (Taylor 1971), although other creationists considered them dinosaurian (Neufeld 1975, Morris 1980). The tracks are eroded and indistinct, but most show indications of dinosaurian digits. The elongate tracks show apparent metatarsal impressions that are as deep, or almost as deep, as the ball and digit regions.

Other subsites along the Baugh/McFall Ledge have been excavated since 1982 by teams of creationists led by Carl Baugh, who claims to have found over 50 "man tracks" there. These sites were reviewed by a team of four mainstream scientists (hereafter referred to as the "C/E team") who refuted the "man track" claims (Cole and Godfrey 1985), but offered a few questionable interpretations of their own (discussed below). I began studying the Baugh sites in 1982, and in subsequent collaboration with Ron Hastings (a C/E team member) constructed detailed site maps.

The alleged human tracks on the Baugh sites involved several phenomena. Some were posterior extensions on definite dinosaur tracks, which Baugh interpreted as human tracks overlapping dinosaur tracks (Figs. 7.8, 7.9B). The extensions vary in length, but generally are smaller and narrower than those on the A1 West Site. The extensions were interpreted by the C/E team as hallux marks, but the blunt ends and direct posterior positions suggest they are more likely partial metatarsal impressions. Other elongate tracks occur on other areas of the ledge; most showed longer and more robust metatarsal segments (Fig. 7.10).

Other alleged "man tracks" on the Baugh sites included shallow, indistinct elongate marks near, but not in line with, dinosaur trackways. These marks, which are often slightly curved, are generally situated about 0.5 m

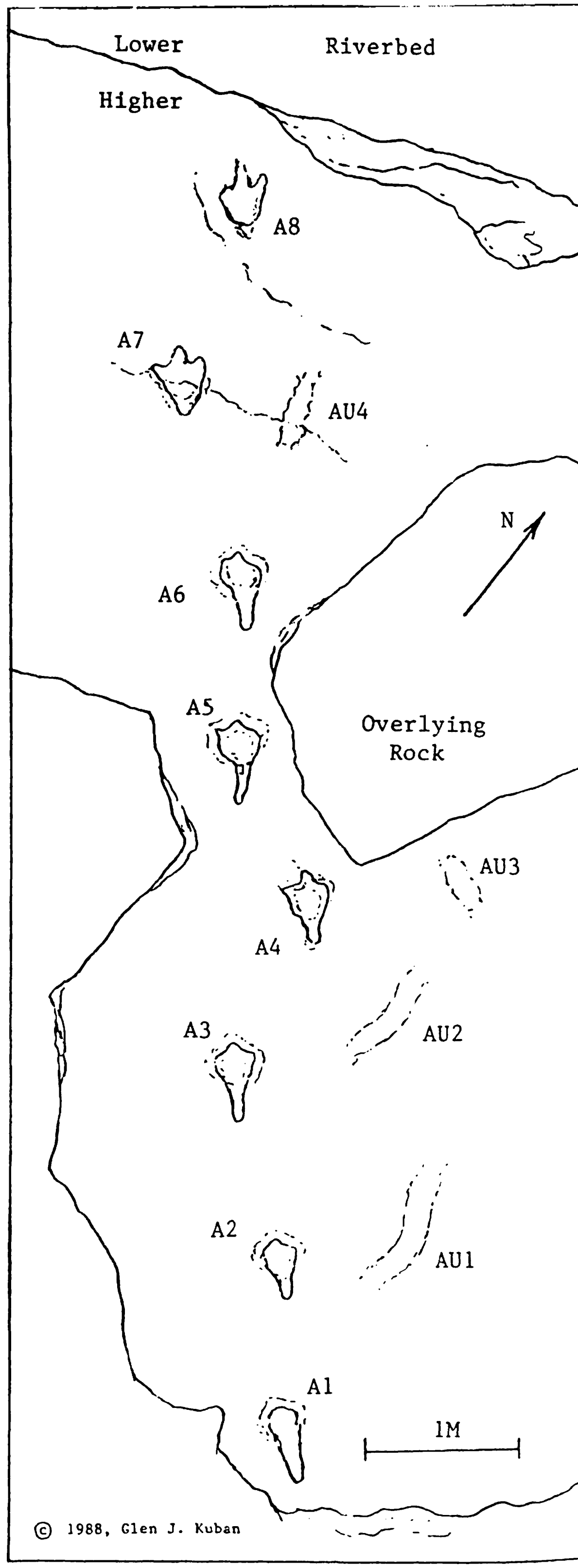


Figure 7.8. Eastern section of the Baugh/McFall ledge, containing a trail of tridactyl tracks (A1-A6) with posterior extensions (partial metatarsal impressions?), and some indistinct elongate marks (AU1-AU4) that may be impressions of the dinosaur's tail or other body part.

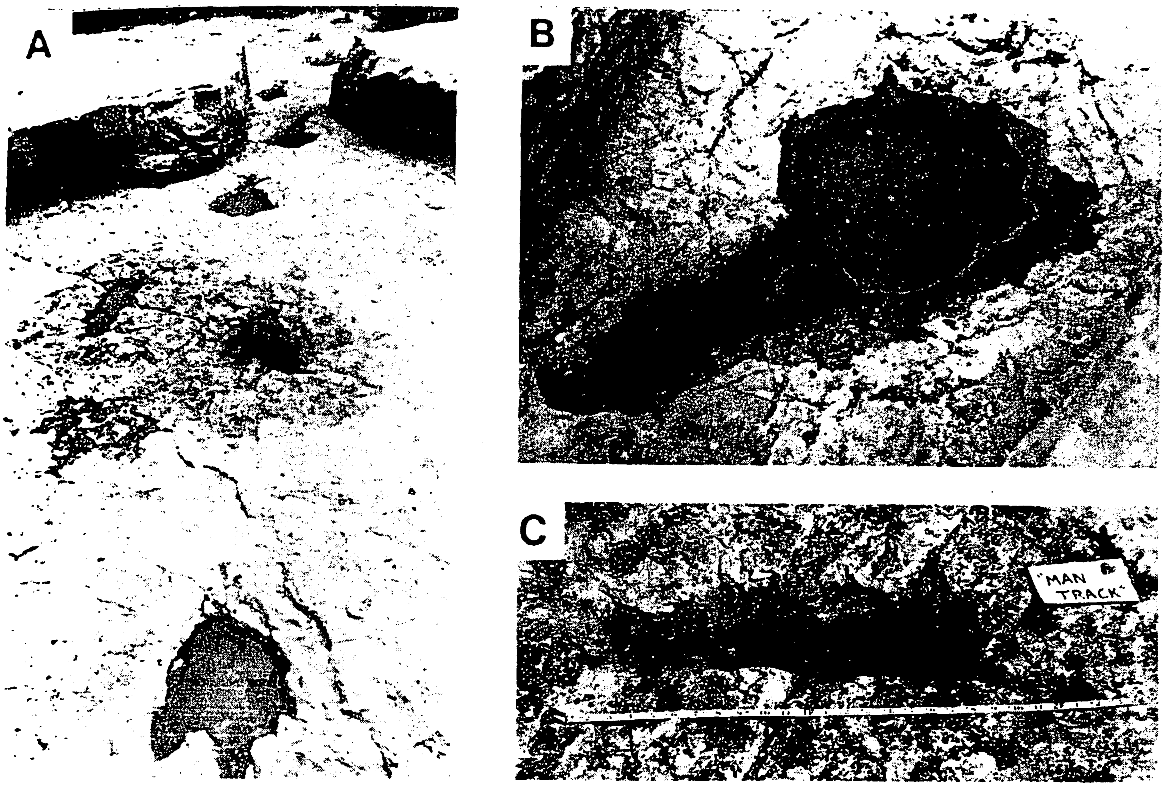


Figure 7.9. **A,** trail A on the Baugh/McFall ledge (compare to map, Figure 7.10). The oblong mark below the black plaque at the upper left is AU4, shown close-up in Figure 7.9C. **B,** track A5 from the same site. The posterior extension on this track was longer than most in the trail, but smaller than the metatarsal segments on many other elongate tracks in Glen Rose. **C,** AU-4, Creationist excavator Carl Baugh named this mark "Humanus bauanthropus," for the supposed humanoid that made it; but it shows no clear human features, and is not in a striding sequence. It may be an impression of the dinosaur's tail, toe, manus, or snout. Tape measure at bottom is marked in inches.

from the trackway midline (Figs. 7.8, 7.9A,C). Some were interpreted by the C/E team as tridactyl footprints whose side digits were poorly preserved, but the marks are not in stride with other tracks, and show no evidence of side digits. It seems more plausible that the marks were made by another part of the dinosaur's body, such as the tail, or possibly the snout or manus (the latter two possibly during food foraging). It is also possible that some of these marks may be plant impressions (recently a branch was found in such a position), or accidental gouges from excavation machinery.

Also identified by Baugh as "man tracks" were some vague, shallow depressions that appeared to be natural irregularities or erosional features on the rock surface. Some *Thalassinoides* burrows also were claimed by Baugh to be human "toes," and one abnormally-shaped "giant track" (over 60 cm long) was merely a carving in the firm marl that overlies the track surface.

Elongate Depressions in Dinosaur Valley State Park

Dinosaur Valley State Park is well known for its abundant tridactyl footprints and spectacular sauropod tracks. Not many elongate tracks occur in the park (Fig. 7.11A), but some indistinct ones usually under water occur on the east side of the park, and may relate to claims of manlike tracks in this area (Taylor 1971, Morris 1980). A few other elongate tracks occur on the west side of the park, near the Blue Hole area. These also are usually near water; they are deeply impressed and show severe mud collapse (Fig. 7.11B).

Tail marks are rare in the park, but two possible tail marks occur near the "main" tourist area in the northwest portion of the park. One of these marks is a pronounced, curved impression about 1.5 m long and 10–15 cm wide (Fig. 7.12A). Overhanging the depression is what appears to be a ridge of mud pushed up by the tail, which partially slumped back into the depression. Along the bottom of the impression are shallow, parallel striations. Several tridactyl tracks and one sauropod manus/pes set are nearby, but it is difficult to determine which trackway, if any, is associated with the curved mark. Another possible trail mark (Fig. 7.12B) which occurs nearby is fairly straight, about 3.7 m long, and is straddled by two bipedal trackways. Overlapping the apparent tail drag is a footprint of one of these dinosaurs as well as a print of a third individual. Some shallow elongate grooves behind some sauropod pes tracks near Roland Bird's quarry site were interpreted by Fields (1980) as tail drags, but they are indistinct, and may be toe drags or river scours.

Figure 7.13. A portion of the Shelf Site in Dinosaur Valley State Park, showing erosional features (highlighted with water) claimed by some to be "man tracks."

Figure 7.12. Possible tail impressions at the "Main" Site in Dinosaur Valley State Park. **A**, a deep, curved depression situated among several tridactyl dinosaur footprints (one track is visible at the upper right). The overhanging lip of rock (mud pushed up by the tail?) covered the entire depression several years ago (when the mark appeared as a narrow slit) and gradually broke away in succeeding years, revealing shallow parallel striations on the bottom of the depression. B, a long, narrow depression (tail drag?) straddled by two bipedal dinosaur trails (note tracks visible at bottom of picture). A sauropod trail crosses the elongate mark at a right angle; part of a sauropod track is visible at the far right.

The "Shelf Site" in Dinosaur Valley State Park, situated above the "main track layer," was often claimed by creationists to contain many "man tracks." However, all the depressions there appear to be erosional markings, involving river scouring, karst dissolution, and weathering. None exhibit clear human features (Fig. 7.13).

The Taylor Site

For many years the Taylor Site (Figs. 7.14–7.16) was one of the most celebrated "man track" sites among creationists, since some authors claimed that at least four human trackways (named Taylor, Giant Run, Turnage, and Ryals Trails) occurred on the site (Taylor 1971, Morris 1980). Part of the site was originally excavated by Rev. Stanley Taylor and crew between 1968 and 1970. Taylor's subsequent film *Footprints in Stone* (Taylor 1973) helped popularize the "man track" claims. During the 1970's other creationists re-exposed the site, and most affirmed that the elongate tracks were human or humanlike (Beierle 1977, Fields 1980). However, other creationists disagreed and considered the tracks to be dinosaurian; they speculated that the elongate shapes might be due to erosion (Neufeld 1975).

Until the 1980's little study of the Taylor Site was made by noncreationists, apparently due in part to inaccessibility (the site is usually under water), and reluctance to treat the "man track" claims seriously. Some authors suggested the "man tracks" were erosion marks or carvings; others attributed them to single digit impressions of bipedal dinosaurs, or mud-collapsed typical (digitigrade)

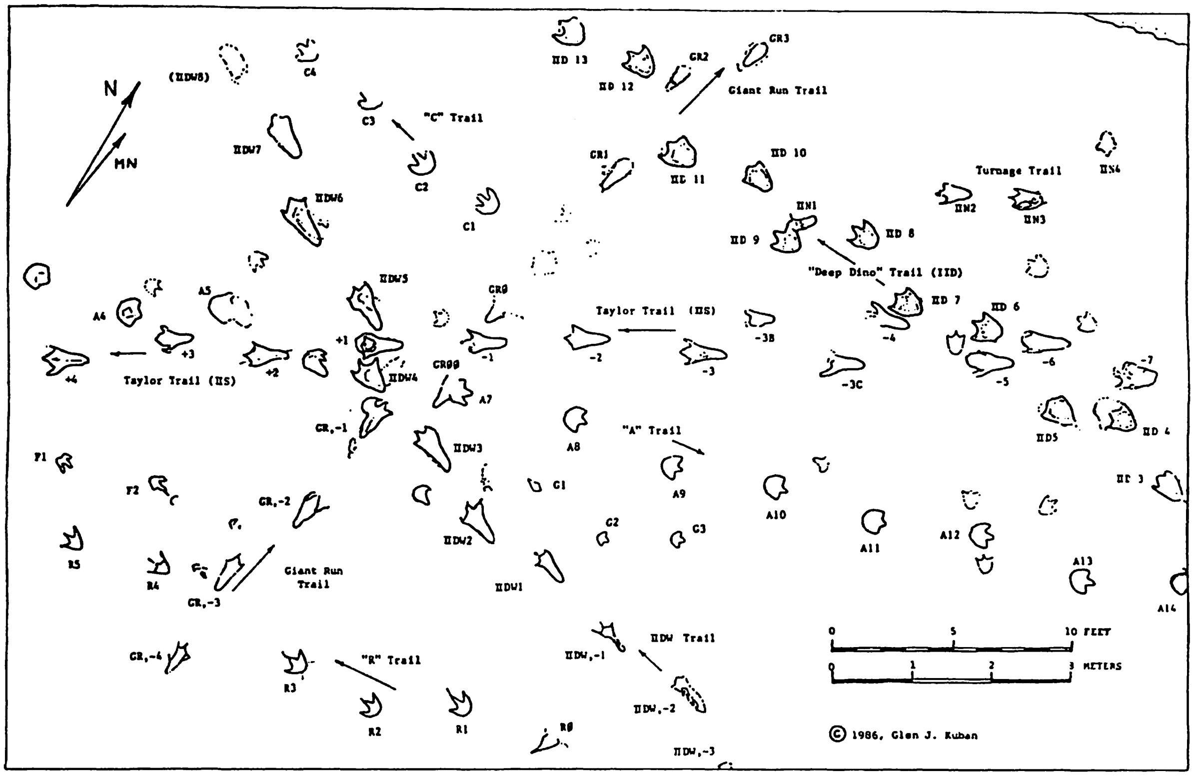


Figure 7.14. The Taylor Site (main section), based on fieldwork between 1980 and 1985. Track outlines indicate boundaries of color distinctions and/or relief differences from the surrounding substrate. The north bank of the Paluxy River occurs just past top of map. Additional tracks occur outside the map borders, including the Ryals Trail (Fig. 7.15).

dinosaur tracks. I have been studying the Taylor Site since 1980, and have concluded that the "man tracks" and other elongate tracks there are plantigrade dinosaur tracks.

The most renowned "man" trail on the site is the Taylor (IIS) Trail, containing 15 known tracks, most of which are large and elongate. The gait pattern is irregular, including some short, wide paces, and other long, narrow paces; most other trails on the site show more regular gait patterns (Figs. 7.14, 7.16). Most tracks in the Taylor Trail (Fig. 7.16) show a prominent metatarsal segment, slight mud push-ups along the sides, and a shallow anterior end with indications of a tridactyl pattern (often accentuated by color distinctions, explained below).

Other elongate tracks on the site typically show indistinct digit impressions; however, slight depressions and/or coloration features indicate dinosaurian digits on at least some tracks in each trail. The metatarsal segments are generally broad and long, with rounded heels. The ball and metatarsal sections of the track are often slightly deeper than the digit region, but most are shallow even at the deeper parts (2–5 cm in most cases). It was the basically oblong shape of the ball and metatarsal region that was often focused on as manlike, although this portion alone is typically over 35 cm long. Except for the IID Trail (comprised of deep digitigrade tracks), most nonelongate tracks on the site are also relatively shallow (some even show slight positive relief). Evidently the shallowness of the tracks, and the color distinctions mentioned above, are largely due to a secondary sediment infilling of the original track depressions. In recent years many previously unknown tracks have been documented on the Taylor Site by virtue of the color distinctions, including the extension of the IIDW Trail, containing over 20 metatarsal tracks in sequence. The coloration phenomenon is discussed further in Chapter 50 in this volume.

Elongate Tracks in Other Areas

In the Connecticut Valley of New England, tridactyl tracks of the ichnogenus *Anomoepus*, which show metatarsal impressions (Fig. 7.17A), were described over a century ago (Hitchcock 1848). Hitchcock was uncertain as to what type of animal made the tracks (dinosaurs being little known at that time), and speculated that they may have been made by a froglike or kangaroolike creature. Later work clarified their dinosaurian origin and elucidated the locomotor behavior of the trackmaker (Lull 1953, Olsen 1986). Metatarsal *Anomoepus* tracks evidently occur as resting traces only; in striding trackways the animal assumed a digitigrade gait.

Apparent metatarsal dinosaur tracks in striding trails have been found at several sites besides those in Glen Rose; some of these are discussed below, with examples shown in Figure 7.17.

Trails of elongate tracks similar to those in Glen Rose have been observed at a Cretaceous site in Bandera County, Texas, by James Farlow (pers. comm. 1986), and by me and

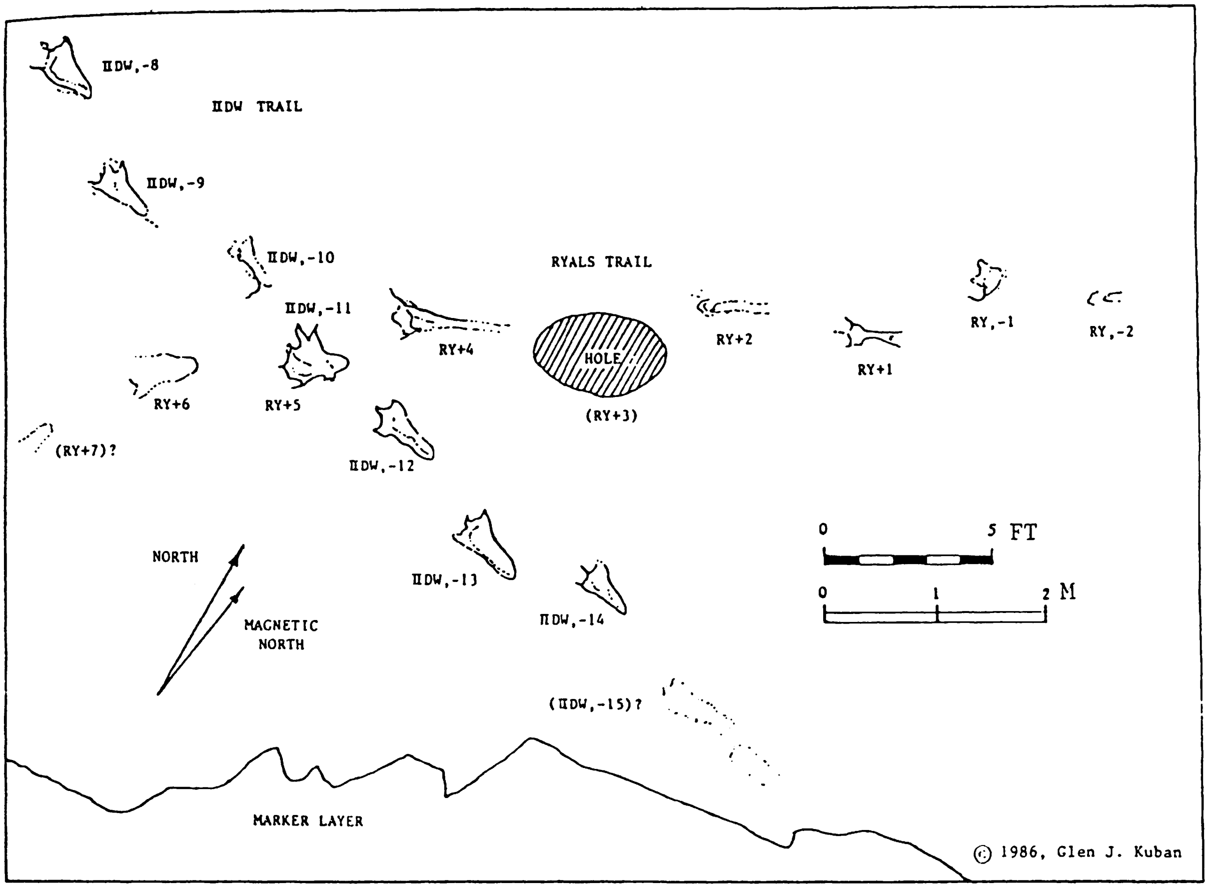
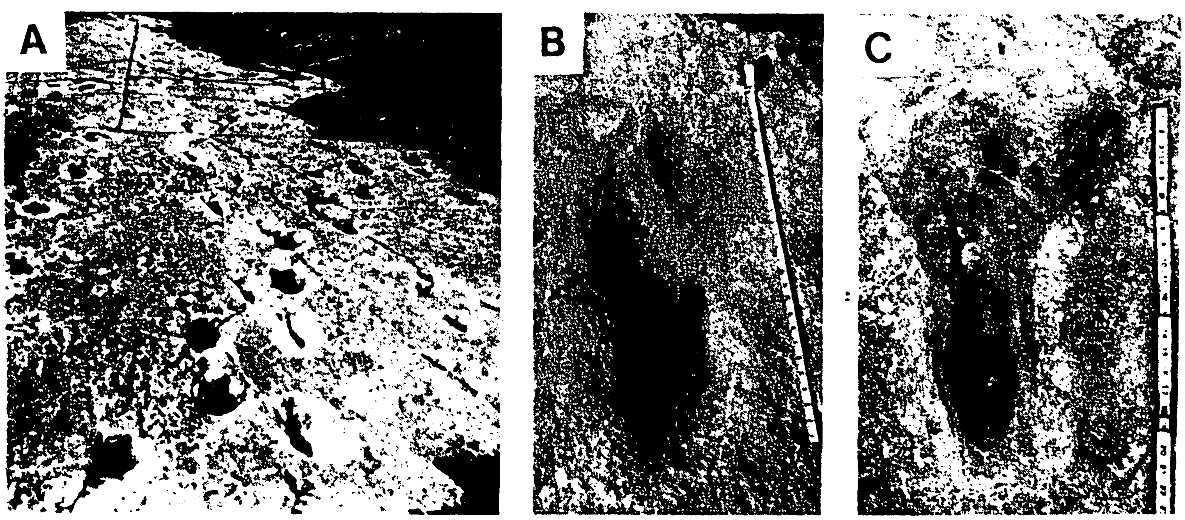


Figure 7.15. Map of the Ryals Trail section of the Taylor Site, which occurs just east of the area shown in Figure 7.14. Intersecting the Ryals (RY) Trail is the IIDW Trail, a long sequence of metatarsal tracks which traverses the entire riverbed, and intersects the Taylor Trail near the north bank (compare Fig. 7.14).

Figure 7.16. **A,** high overhead view of the main section of the Taylor Site, facing southwest (1984). The Taylor (IIS) Trail proceeds from bottom-center to upper left. It is crossed by the IID ("Deep Dino") Trail, proceeding from lower left to upper right. Other trails are visible in background (compare Fig. 7.14). **B,** Taylor Trail Track IIS,-2. Note faint indications of a tridactyl pattern at the anterior end. This photograph was taken in 1980, at which time the substrate was very dry, reducing the color contrasts later observed on many of the Taylor Site tracks. **C,** Taylor Trail Track IIS,+3. This track showed the unusually rounded anterior end (possibly due to the way the mud was pushed up by the middle digit), but still showed indications of a tridactyl pattern. This photograph was taken in 1984, when the color distinctions, ranging from blue-gray to rust-brown, were more vivid than in 1980, but less vivid than in 1985 (see paper on color distinctions, Chapter 50).



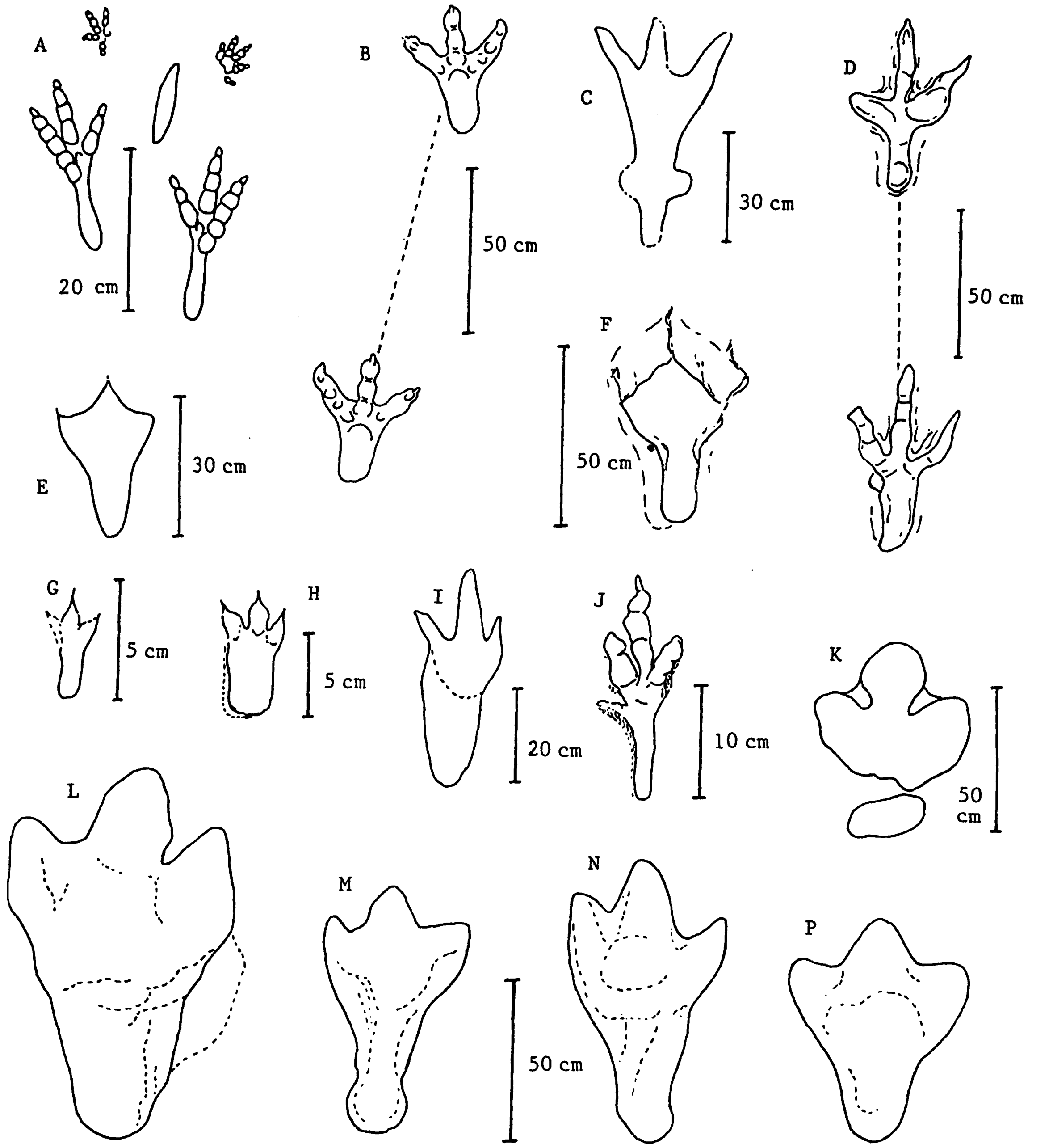


Figure 7.17. Elongate tracks outside Glen Rose, Texas. Note: the ichnological names included below are those assigned by the author(s) mentioned; no judgment is made concerning the validity of these track names. **A,** *Anomoepus scambus* tracks, made by a squatting dinosaur, from the Connecticut Valley, Lower Jurassic (redrawn from Lull 1953). **B,** *Moraesichnium barberenae*, from an Upper Jurassic/Early Cretaceous site in Paraiba, Brazil. Redrawn from Leonardi (1979). **C,** one of a series of elongate tracks from the Late Cretaceous of Spain, attributed by R. Brancas to *Ornitholestes*. Redrawn from Brancas (1979). **D,** trackway from the mid-Jurassic of Morocco. Redrawn from drawing by Shinobu Ishigaki (pers. comm. James Farlow 1986). **E.** one of a sequence of elongate tracks from Clayton Lake State Park (Lower Cretaceous), New Mexico, attributed by Gillette and Thomas (1985) to a web-footed theropod. **F,** one of a series of indistinct elongate tracks from the Schmidt Site at Hondo Creek, Bandera, Texas. Redrawn from photograph by James O. Farlow (pers. comm. 1986). **G,** one of a trail of small elongate tracks from Essex County, New Jersey, pictured in the *Audubon Guide to North American Fossils* (Thompson 1982). **H,** *Skartopus australis* (metapodial form), from the Winton Formation (mid-Cretaceous) of Australia. Redrawn from photograph in Thulborn and Wade (1984). **I,** *Dinosauriens theropodes*, from a site at Agadir, Morocco. Redrawn from Ambroggi and Lapparent (1954). **J,** *Jialinapus yuechiensis* from Yuechi, Sichuan (Upper Jurassic), redrawn from Zhen et al. (1983). **K,** unnamed, isolated track attributed to a hadrosaur. Redrawn from Langston (1960). The elliptical posterior depression was interpreted by Langston as a supporting pad under the metatarsus. **L,** *Dinosauropodes magrawii*, a huge elongate track from a Cretaceous coal mine in Utah. After Strevell (1940). **M–P,** other *Dinosauropodes* tracks from coal mines in Utah, after Strevell (1940).

others at another Cretaceous site in Comal County, Texas, although the tracks at both sites are indistinct (Fig. 7.17F).

Many large, blunt-toed tracks with apparent metatarsal impressions have been found in Cretaceous coal mine roofs in Utah (Fig. 7.17L–P); one such track was over 130 cm long (Strevell 1940). At the opposite end of the size spectrum, Thulborn and Wade (1984) described (5–10 cm long) tridactyl tracks of the ichnogenus *Skartopus* at a mid-Cretaceous Australian site and indicated that a few *Skartopus* tracks possessed what appeared to be metapodial impressions (Fig. 7.17H). Thulborn and Wade noted that metapodial *Skartopus* tracks usually occur as isolated prints, although one series of three such tracks was found.

Several trails of elongate dinosaur tracks occur at a Lower Cretaceous site at Clayton Lake State Park, New Mexico (Gillette and Thomas 1985). Gillette and Thomas interpreted some of these tracks as webbed-toed theropod tracks with metatarsal pads (Fig. 7.17E), and others as ornithopod tracks whose elongation was due to slippage in the mud.

Striding trails of tridactyl tracks with widely splayed digits and posterior extensions (Fig. 7.17B) were reported from sites in South America by Leonardi (1979), who tentatively interpreted them as plantigrade ornithopod tracks, although I consider them theropod tracks. Similar tracks (Fig. 7.17D) have been reported by Shinobu Ishigaki at a Jurassic site in Morocco (James Farlow pers. comm. 1986).

Interesting elongate tracks were reported from a Late Cretaceous site in Spain (Brancas et al. 1979). Near the track heels are curious lateral protrusions that may be "ankle" impressions (Fig. 7.17C).

The Plantigrade Interpretation vs. Alternate Explanations

Traditionally bipedal dinosaurs have been viewed as strict digitigrade walkers, since the vast majority of known tridactyl dinosaur tracks are unquestionably digitigrade, and the anatomy of most bipedal dinosaurs appears well suited to digitigrade locomotion. Perhaps for these reasons there has been a tendency to ascribe most elongate tracks, especially in Glen Rose, to phenomena other than metatarsal impressions, such as foot slides, erosion marks, hallux marks, or middle digit impressions. Although some elongate tracks may be due to these phenomena, and others are too indistinct to diagnose, there is much evidence that many elongate tracks are actually metatarsal footprints.

In many cases the length, shape, and position of the long posterior segment of elongate tracks rules out a hallux interpretation. A simple foot-slide explanation is also incompatible with the shape and details of many elongate prints, especially those with "pinched-in" centers. Further, although foot slides do occur, they generally show significant distortions, such as a mud "pile-up" at the anterior; whereas most mud push-ups, where present on elongate tracks in Glen Rose, usually are more pronounced at the sides than the front of the track. The above features also confirm that most elongate tracks in Glen Rose are not simply eroded digitigrade tracks, especially since many are oriented contrary to river flow.

The idea that the posterior extensions may have been a thick "metatarsal pad" supporting an essentially digitigrade foot, as in elephants (or as suggested for an isolated hadrosaur track by Langston 1960), is inconsistent with the length and narrowness of many of the posterior extensions.

Roland Bird, who examined a limited number of elongate dinosaur tracks during his well-known sauropod studies in Glen Rose, proposed that such tracks may have been made when a dinosaur pressed its toes together upon withdrawing its foot from soft mud (Bird 1985). However, this would suggest considerable distortion within the track, especially at the back, which is inconsistent with appearance of the better-preserved elongate tracks, especially those which show a narrowing in the "arch" region, and a rounded tarsal element at the posterior.

A popular hypothesis in the past for elongate tracks in Glen Rose was that they were middle digit impressions. This concept has several variations, one of which holds that only the middle digit might register if the substrate were firm, or if the track were an overtrack or undertrack. However, on most elongate tracks one can see at least some indications of all three digits, and these digit marks are consistently located at the front of the track, not emanating from the back and sides as would be the case if the body of the print were a middle digit. Further, on well-preserved Glen Rose tracks the middle digit is about the same depth as the side digits.

Another variation of the middle-digit concept holds that in soft mud the side digits of a digitigrade track might collapse, leaving only the middle digit. However, this is contradicted by the same observations as those described above, as well as the mechanics of mud flow. When moist mud slumps back into a depression, it generally does so about equally from all sides, and therefore would not likely bury the side digits while leaving the middle digit intact (Fig. 7.18A). However, by the same principle, mud collapse would be likely to convert an already elongate (metatarsal) dinosaur track into an oblong — even "manlike" shape, since the relatively large metatarsal segment would be less completely buried than the smaller digit impressions, leaving a vague oblong depression (Fig. 7.18B). Such marks may be further subdued by erosion or other factors (Fig. 7.18C), fostering a "manlike" shape.

Although the above evidences establish that many elongate tracks are metatarsal tracks (recording at least part of the metatarsus), whether they are also "plantigrade" tracks raises a question of terminology. Although some workers may define a "plantigrade" track as one that records any of the metatarsus, others (including me) may wish to restrict the term "plantigrade" to tracks exhibiting complete or nearly complete metatarsal impressions oriented in a largely horizontal manner, or require that several such tracks occur in succession. In any case, some trails in Glen Rose and elsewhere do show several full metatarsal tracks

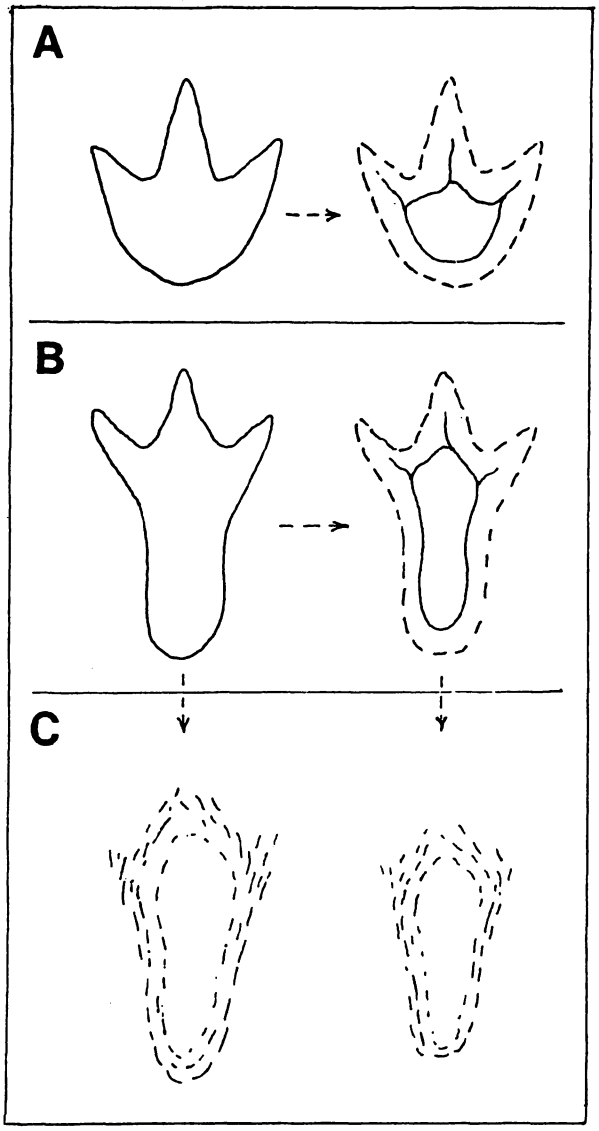


Figure 7.18. A, a typical tridactyl dinosaur track (left), and the common shape resulting from mud collapse (right). B, a typical metatarsal dinosaur track (left); and the common result of mud collapse: an elongate depression that somewhat resembles a large human footprint (right). C (left), the features of a metatarsal dinosaur track also may be subdued by erosion, a firm substrate, ghost impressions (over- and under-tracks), or a combination of factors, resulting in an indistinct elongate depression that roughly resembles a "giant man track." C (right), if a metatarsal dinosaur track is first mud collapsed, then less erosion is necessary to foster a humanlike shape, and even the size of the depression may be close to that of a normal human print.

in sequence, and therefore, even by strict definition, may be considered "plantigrade" or at least "quasi-plantigrade," the latter allowing for variations and uncertainties in the behaviors and environmental factors involved (discussed below).

Possible Causes of Metatarsal Impressions by Bipedal Dinosaurs

Although *Anomoepus* tracks record a resting, squatting posture, most other metatarsal tracks were clearly made during active locomotion. One may consider whether sediment consistency may have related to the making of such tracks (at least in some cases). One possibility is that even a foot held in a normal digitigrade fashion might incidentally record some or all of the metatarsus if the foot sank deeply in soft sediment. This may have occurred on some partially-elongate prints that show relatively short metatarsal segments or where the digit depression is much deeper than the metatarsal region. However, most elongate tracks show only a slightly deeper "ball" area, and rarely is there a steep angle toward the anterior end. In fact, some elongate tracks indicate an essentially horizontally impressed metatarsal segment. One might propose that some dinosaurs normally held their metatarsi at a low angle, but many deep digitigrade tracks are found, and indicate metatarsi held at a steep angle. Nevertheless, if the metatarsus were at times positioned at a low angle, a soft substrate would record more of the foot than a firm substrate; and sediment consistency may have contributed in other ways to metatarsal impressions (discussed below).

A soft and/or slippery sediment may have encouraged a dinosaur to lower its metatarsi onto the sediment in order to gain firmer footing. However, if this were a primary cause of metatarsal tracks, one might expect such prints to show relatively short paces, reflecting more cautious steps. In contrast, many elongate tracks in Glen Rose have moderate to long paces and pace angles. A few elongate trackways do show erratic gait patterns that might be construed as evidence that the trackmaker was contending with a slippery substrate, but similar gait patterns can be seen in some nonelongate trackways as well.

Another possibility, which might help explain the typically long paces found between elongate tracks, is that some dinosaurs may at times have traveled in a saltatory or "bouncy" manner, causing the tarsal joint to fold more than usual as the foot contacted the substrate (in a shock-absorbing function), bringing the metatarsus into contact with the sediment.

Perhaps the most plausible explanation, however, is that plantigrade tracks may have been made occasionally by a variety of bipedal dinosaurs whenever they walked low to the ground, which would decrease the angle between the metatarsus and the substrate (Fig. 7.19B). A low posture may have been assumed whenever a dinosaur foraged in mud flats or shallow water for small food items (such as molluscs, insects, crustaceans, amphibians, fish, eggs, or edible plant material); when stalking larger prey, or when approaching other dinosaurs.

That any pathology was involved in causing most metatarsal tracks seems unlikely in view of the relatively efficient stride patterns in most elongate trackways, and the great abundance of metatarsal tracks in some areas, such as Glen Rose.

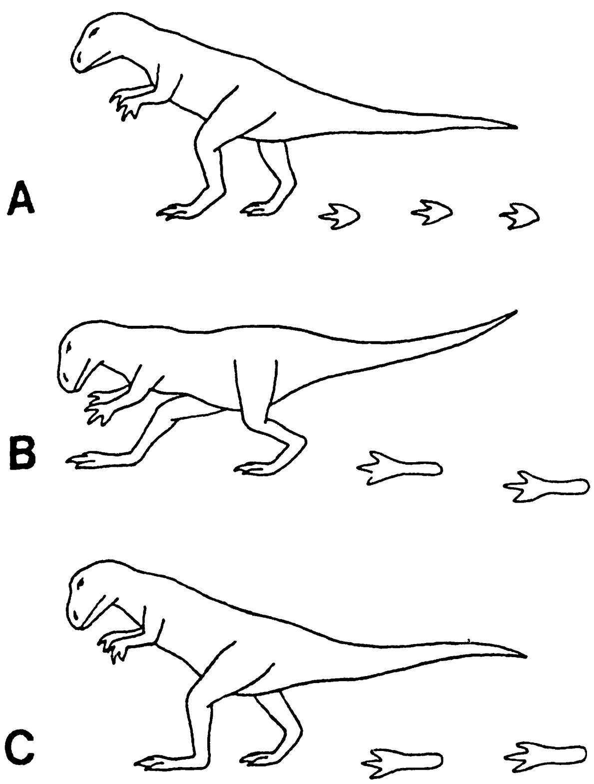


Figure 7.19. **A,** typical bipedal dinosaur walking in a digitigrade mode. **B,C,** possible postures assumed by bipedal dinosaurs during plantigrade locomotion.

It may be that some bipedal dinosaurs may have had leg anatomy more suited to plantigrady than others, although it is unlikely that any were obligatory plantigrade walkers, since most trails with elongate tracks also contain some nonelongate tracks. However, determining with certainty what caused such tracks is difficult, especially since more than one of the factors discussed above (and others) may have acted singly or in combination to foster metatarsal impressions.

Most metatarsal tracks near Glen Rose appear to have been made by moderate sized theropods; however, the variety of elongate tracks in Glen Rose suggests that more than one species in that area made them, and the additional varieties of metatarsal tracks found in other areas further suggests that plantigrade or quasi-plantigrade walking may have been a fairly widespread (though intermittent) behavior among both theropods and ornithopods.

Conclusions

Striding trackways composed partially or largely of elongate footprints suggest that some bipedal dinosaurs, at least at times, walked in a plantigrade or quasi-plantigrade manner. Some alleged "man tracks" in Glen Rose are indistinct metatarsal dinosaur tracks, whose digit impressions are obscured by mud collapse, erosion, or other factors. Other elongate depressions in Glen Rose include erosional features and possible tail marks, some of which also have been mistaken for human tracks.

Acknowledgments

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References

Alexander, R. McN. 1976. Estimates of speeds of dinosaurs. *Nature* 261:129–130.

Ambroggi, R., and Lapparent, A. F. de. 1954. Les empreintes de pas fossils du maestrichtien d'Agadir. *Morocco Service Geologique* 10:43–57.

Beierle, F. 1977. *Man, Dinosaurs, and History* (Perfect Printing) 67 pp.

Bird, R. T. 1985. *Bones for Barnum Brown: Adventures of a Dinosaur Hunter.* Schreiber V. T. (ed.). (Texas Christian University Press) 225 pp.

Brancas, R., Blaschke, J., and Martinez, J. 1979. Huellas de dinosaurios en Enciso. *Unidad de Cultura de la Excma* 2:74–78.

Cole, J., and Godfrey, L. (eds.). 1985. The Paluxy River footprint mystery — solved. *Creation/evolution* 5 (1). (with articles by Cole, Godfrey, S. Schafersman, and R. Hastings.)

Fields, W. 1980. *Paluxy River Explorations,* revised edition. (Privately published) 48 pp.

Gillette, D. D., and Thomas, D. A. 1985. Dinosaur tracks in the Dakota Formation (Aptian–Albian) at Clayton Lake State Park, Union County, New Mexico. *New Mexico Geol. Soc. Guidebook, 36th Field Conf., Santa Rosa.* pp. 283–288.

Hitchcock, E. 1848. The fossil footmarks of the United Sates and the animals that made them. *Trans. Amer. Acad. Arts Sciences* Vol. 3, 128 pp.

Langston, W. Jr. 1960. A hadrosaurian ichnite. *Canada National Museum Nat. Hist. Paper* 4:1–9.

1979. Lower Cretaceous dinosaur tracks near Glen Rose, Texas. *In Lower Cretaceous Shallow Marine Environments in the Glen Rose Formation.* Amererican Association of Stratigraphic Palynologists. Field Trip Guide 12. Annual Meeting, pp. 39–55.

Leonardi, G. 1979. Nota preliminar sobre seis pistas de dinossauros Ornithischia da bacia do Rio do Peixe, en Sousa, Paraiba, Brasil. *Academia Brasileira de Ciencias* 51 (3):501–516.

Lull, R. S. 1953. Triassic life of the Connecticut Valley. *Connecticut Geol. Nat. Hist. Surv. Bull.* p. 81.

Morris, J. D. 1980. *Tracking Those Incredible Dinosaurs and the People Who Knew Them.* (Creation Life Publishers) 240 pp.

Neufeld, B. 1975. Dinosaur tracks and giant men. *Origins* 2 (10):64–76.

Olsen, P. E. 1986. How did the small Ornithischian trackmaker of *Anomoepus* walk? *In* Gillette, D. D. (ed.). *First International Symposium on Dinosaur Tracks and Traces, Abstracts with Program.* p. 21.

Zhen S., Li J., and Zhen B. 1983. Dinosaur footprints of Yuechi, Sichuan. *Mem. Beijing Nat. Hist. Museum* 25:1-20.

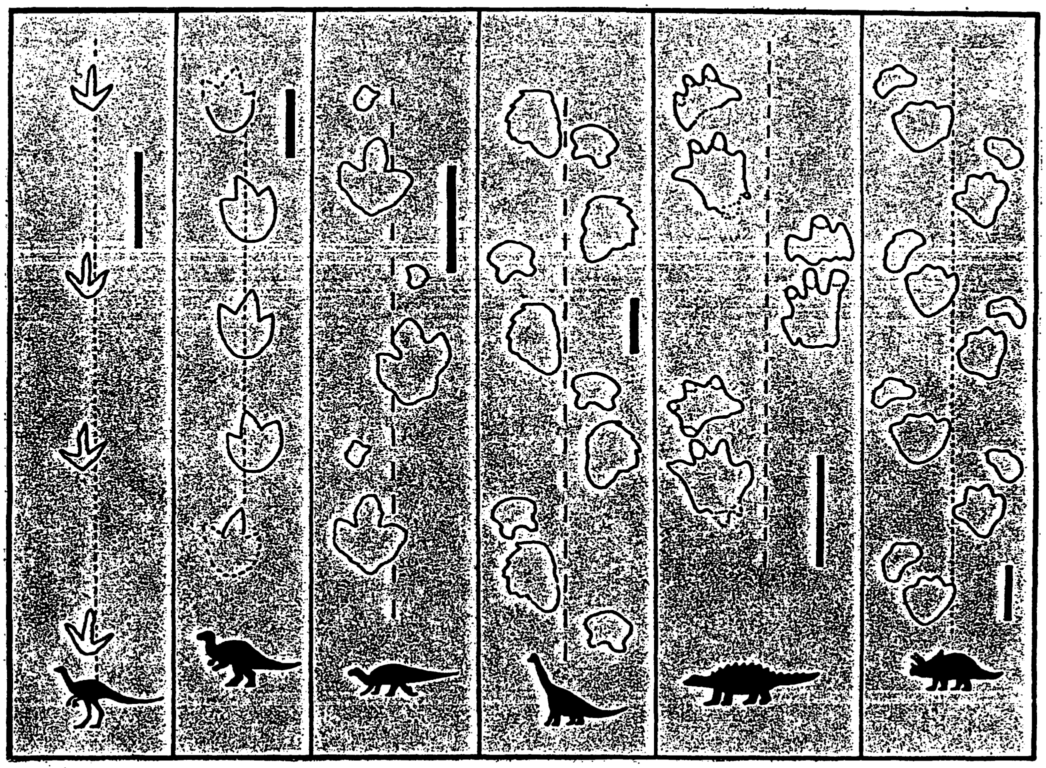
Strevell, C. N. 1940. *Story of the Strevell Museum.* (Salt Lake City Board of Education) pp. 7-15.

Taylor, S. E. 1971. The mystery tracks in Dinosaur Valley *Bible-Science Newsletter* 9 (4):1-7.

1973. *Footprints in Stone.* (film) (Films for Christ Association)

Thompson, I. 1982. *The Audubon Guide to North American Fossils.* pl. 472.

Thulborn, R. A., and Wade, M. 1984. Dinosaur trackways in the Winton Formation (Mid Cretaceous) of Queensland. *Mem. Queensland Museum* 21 (2):413-517.



ARE THE DINOSAURS COMING BACK TO LIFE?

William W. Morgan

At Fossilmania XI, I promised Margaret Kahrs that I would write an article on dinosaurs for the 1994 MAPS Expo bulletin. Since that time I have struggled to come up with a topic that was both original and of interest to sophisticated amateur fossil enthusiasts. All of the publicity generated last summer by Stephen Spielberg's movie Jurassic Park has many people anxiously waiting for dinosaurs to start appearing the local zoo. Therefore, in the next few paragraphs, I will draw on my experience both as a scientist who routinely utilizes molecular biological techniques and as an amateur paleontologist to address in a very cursory way the feasibility of resurrecting the dinosaurs. As a background for my article, I did read Michael Crichton's Jurassic Park and will refer to sections from it in my article. At the same time, I must confess that I have not seen the movie.

There are, at the very least, 3 enormously complicated and broad problems associated with restoring a dinosaur to a living breathing state. The first is obviously finding intact DNA; not just a short sequence, a strand or even a "thread" of DNA but a complete complement of all of the coded information necessary to synthesize a fast, snarling, ravenous, intelligent *Velociraptor*. As for all "higher" complex organisms, this complete complement must consist of 2 copies of each chromosome. Further, in order to assemble a normal functioning dinosaur, there must be just enough of the right DNA. Too many or too few copies of any gene is usually catastrophic and lethal. The commonly known genetic abnormalities in humans, for example Down's Syndrome or Klinefelter's Syndrome, actually represent the least severe situations where the abnormality is mild enough to allow the individual to survive. In truth, the vast majority of genetic abnormalities lead to death of the developing embryo long before birth.

In molecular biology, we often refer to DNA as being practically immortal. However, this merely means that the stuff hangs together if kept under sterile conditions and frozen at -20° C. Expecting DNA to survive in any kind of intact form for 65 million years or longer is asking a lot of an complex organic molecule. The entrepreneurs in Jurassic Park overcame this problem by extracting DNA from dinosaur blood cells found in the abdomens of Mesozoic fleas, flies and presumably mosquitoes which were themselves preserved in amber. In the context of the story, these insects had siphoned this blood out of the dinosaurs in life, and it had remained preserved in their abdomens in amber for millions of years. This is truly an ingenious approach as amber manifests excellent preservative qualities; however, the chemistry responsible for inducing this preservation are presently unknown (Science 262: 655, 1993). A short DNA sequence has been successfully extracted from a 120-135 million year old (Cretaceous) weevil which was preserved in Lebanese amber (Nature 363: 536, 1993) and from a 25-35 million year old (Oligocene-Miocene) termite (Science

257: 1993, 1992). Still, the DNA obtained was very severely degraded, and the sequences that were determined averaged less than 300 base pairs. By comparison, the complete DNA complement of large vertebrates including dinosaurs consists of roughly 3 X 10^9 base pairs.

In order for the Jurassic Park approach to be successfully, it would be necessary to determine the entire sequence of the insect DNA, presumably collected from somewhere else on the animal, in order to separate insect from dinosaur DNA sequences in the sample collected from the abdomen. If the insect feasted on the blood of more than one species, it would be difficult in the laboratory to separate the blood of one dinosaur from another. Further, if the investigators were really unlucky, the insect might have just had a meal of mammalian blood which was also available through out the Mesozoic. One can imagine the disappointment of cloning an opossum rather than an *Apatosaurus*.

Dr. Wu, the molecular biologist in Jurassic Park who has accumulated the technology to restore the dinosaurs, commented that in order to save time they concentrated only on the regions of the DNA in the various dinosaurs which were most different between species. Apparently, they were repairing the divergent regions of DNA and splicing amphibian "filler" DNA in between. Unfortunately, this is probably the exact opposite of what they should have done. The vast majority of the DNA sequence is nonsense in that it represents the code for nothing. Since mutations in these nonsense regions are of no consequence to the organism, alterations in these regions of the DNA are not selected against and thus accumulate with time. Thus, these nonsense regions are likely to represent by far the most divergent between species. The actual number of genes that differentiate one species from another, particularly reasonably closely related ones, actually represents only a small portion of the total number and would be almost impossible to detect based on sequence alone. For example, it is estimated that only 2 percent of the DNA which is used to code for a chimpanzee is different from that which codes for a human. Therefore, Dr. Wu was carefully collecting nonsense DNA from dinosaurs and filling in with much less divergent, conceivably sense DNA from amphibians. This approach would probably not recreate dinosaurs but with a little luck might generate some killer frogs or salamanders.

If the intact, complete and exact amount of dinosaur DNA were obtained, the second and even more difficult problem is that DNA alone simply will not provide a sufficient "code" to assembly a complete *Stegosaurus*. It is becoming increasingly obvious that the nucleus of a cell is not merely a tiny bag filled with chromosomes, but is rather an incredibly highly organized factory for assembling the templates for the synthesis of every protein needed by the organism. The nucleus of the fertilized egg, that is the zygote, from which all other cells of an individual arise is pluripotent. In other words, it has the capacity to give rise to every cell type required for the generation of the complete organism. At the present time, science knows almost nothing about what makes that zygotic nucleus pluripotent or what happens to cause cells which arise from that first cell to differentiate apparently irreversibly into liver, muscle or nerve cells. Clearly, an understanding of these fundamental processes is a must before the most perfect dinosaur DNA in the world can be stimulated to generate a tourist attraction or to quote Dr. Grant in the book "the end of paleontology as we know it".

The third problem is the shear cost of such an undertaking. In Jurassic Park essentially one highly motivated scientist armed with some highly sophisticated DNA sequencers and two super computers recreated 15 species of dinosaurs within 5 years. By comparison, it is estimated that it will take more than a decade to sequence the human genome alone, and this is with the dedicated application of numerous laboratories with a large number of personnel and with the financial resources provided by the American taxpayer. Michael Crichton was probably right when he concluded in his book that the funds for such a project could only be generated in the context of the entertainment industry.

So, will it be possible to bring back the dinosaurs? If the DNA can be found, conceivably, but certainly not with the technology that is presently available. However, if one accepts the sarcastic comment of Dr. Malcolm in Jurassic Park that scientists believe that all things are capable of being understood, then maybe someday in the distant future. But even then, someone will have to be willing to pick up the tab?

MAJOR DINOSAUR DISCOVERIES IN AUSTRALIA

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with imput by Simon & Robert Thomas

Australia remains one of the last frontiers in the search for dinosaur remains. To date little in quality or quanity has been found and that which has been found has been fragmentary and widely scattered throughout the continent.

SAURISCHIAN

Prosauropod material is limited to a single fragmentary specimen "*Agrosaurus macgillivrayi*" found in 1981.

Sauropods have been found in both the Jurassic and Cretaceous.

Theropod material is very scrappy and much less complete than Sauropod remains, mainly being single bones.

ORNITHISCHIAN

Ornithischian dinosaurs on the other hand come in a wide variety of forms, although relatively few in number.

MAJOR FOSSIL DINOSAURS FOUND IN AUSTRALIA ARE:

ALLOSAURUS theropod, family Allosauridae.

Early Cretaceous_ found Cape Patterson Victoria.

Type specimen is an ankle bone of a juvenile of about 6 metres long and was more robust than its North American counterpart.

ATLASCOPCOSAURUS loadsi , Rich and Rich (Ornithopod) family Hypsilophodont.

Early Cretaceous_ found Dinosaur Cove, Otway Rang Victoria. Named after a mining company Atlas Copco, who financially assisted its excavation. It was a man sized plant eater with strong bulky hind limbs and an elongated tail.

AUSTROSAURUS mackillopi Longman (Sauropod) family Cetiosauridae.

Early Cretaceous _ found near Maxwelton North Queensland

Several types of *Apatosaurus* are known to have inhabited Australia but their remains are so scattered, incomplete and difficult to interpret. This is also true of *Austrosaurus* whose remains are a few large vertebrae (up to 30 cms in length) and ribs.

CHANGPEIPUS bartholomaii Haubold (Theropod) family indeterminate.

Middle Jurassic_ found Westvale No.5 Colliery South East Queensland. This is a 'form genus' for a particular footprint type representing a large meat eating theropod first described from China

FULGUROTHERIUM australe von Huene (Ornithopod) family Hypsilophodont.

Early Cretaceous_ found Lightning Ridge, Northern N.S.W.

Type specimen was an incomplete femur but since then better preserved bones of Hypsilophodonta have been found in Southern Victoria and west of Lightning Ridge N.S.W.

KAKURU kujani Molnar and Pledge (Theropod) family Coeluridae.

Early Cretaceous_ Opal field of Andamooka South Australia.
A single crushed tibia and toe digit bone (opalized) is all that remains of this Theropod.

LEALLYRASAURA amicagraphica Rich and Rich (Ornithopod) family Hypsilophodont.

Early Cretaceous_ found Otway Ranges Southern Victoria
A man sized plant eater, named after a school girl, Laellyn Rich, who helped find its bones.
A juvenile which stood about 1 metre high with small front legs, large eyed and large brained for an Ornithopod. Remains includes both the skull and cast of the brain, also limb bones, ribs and vertebrae.

MINMI paravertebra Molnar (Ankylosauria) family Nodoisaurida.

Early Cretaceous_ found Mini crossing, north of Roma, Queensland.
A plant eater, armoured dinosaur about 4 metres long, known only from part of a rib cage, vertebral column, a foot and belly armour.

MUTTABURRAURUS langdoni Bartholomai & Molnar (Ornithopod) family Iguanodontidae.

Early Cretaceous_ found Thompson River, near Muttaburra Central Queensland.
Australia's best known and most complete dinosaur. A large *Iquanodont* about 9 metres long. It had a spike thumb which was rather large and flattened. It also had a curious hollow chamber on its snout and a bump on its nose which may have been a horn or a horny pad.

RAPTOR ornitholestoides von Huene (Theropod) family Coeluridae.

Early Cretaceous_ found Lightning Ridge Northern N.S.W. Type specimen is a single metacarpal about the size of a young adult, about 9 metres in length.

RHOETOSAURUS brownei Logman (Sauropod) family Cetiosauridae.

Middle Jurassic_ found in Roma District, Queensland.

Australia's most complete Sauropod. Less than half the complete skeleton was found but the bones weighed over a ton. A plant eater about 12 metres long with a hip height of 4 metres. It weighed up to 20 tons and was one of the earliest Sauropod. It had a very long neck and a whiplash tail

WALGETTOSUCHUS woodwardi von Huene (Theropod) family indterminate.

Early Cretaceous_ found Lightning Ridge Northern N.S.W.
Type specimen is a poorly preserved tail vertebral centrum of a probable Theropod.

There are also a number of dinosaur Tracks and Trackways but the best one is of the Cretaceous and is found near Winton in Queensland.
It is a good indication that there were a large number of dinosaurs living in Australia at that time. The Trackway represents over a 130 individuals.

References:

"Dinasaurs of Australia" by John Long.
"The Antipodean Ark," edited by Suzanne Hand and Michael Archer.
"Vertebrate Paleontology of Australasia," edited by Patricia Vickers Rich, J. Monaghan, R. Baird and Thomas Rich.

A FEW SPECULATIONS ON THE SKULL CRESTS OF SOME DUCK-BILL DINOSAURS

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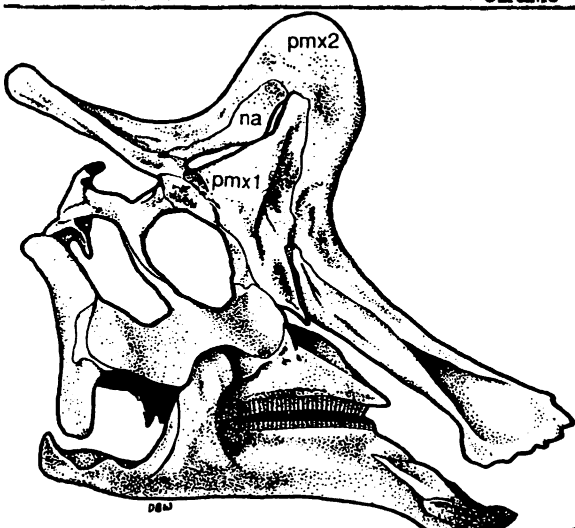
Bring a group of Vertebrate Paleontologists together, whether at a formal gathering or an after-hour bull session, and you can be sure the conversation will get around to "what was the purpose or function of the fancy crests that some duck-bill dinosaurs had on the tops of their heads?"

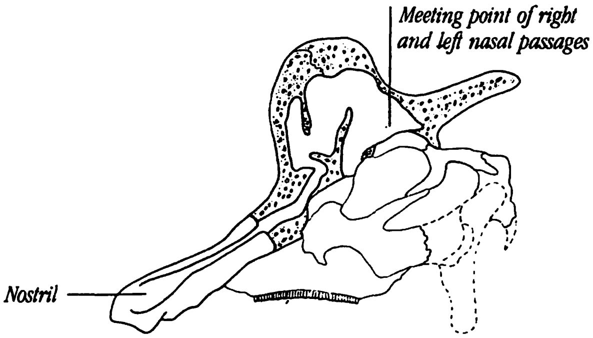
Duck-bill dinosaurs are members of the order Ornithischia and sub-order Ornithopoda. All are grouped in the family Hadrosauridae. The sub-family or tribe with the hollow skull crests are called lambeosaurines. The name "lambeosaura" is given in honor of Lawrence Lambe, a Canadian paleontologists who was active in collecting and describing the Cretaceous dinosaurs of western Canada in the early years of this century.

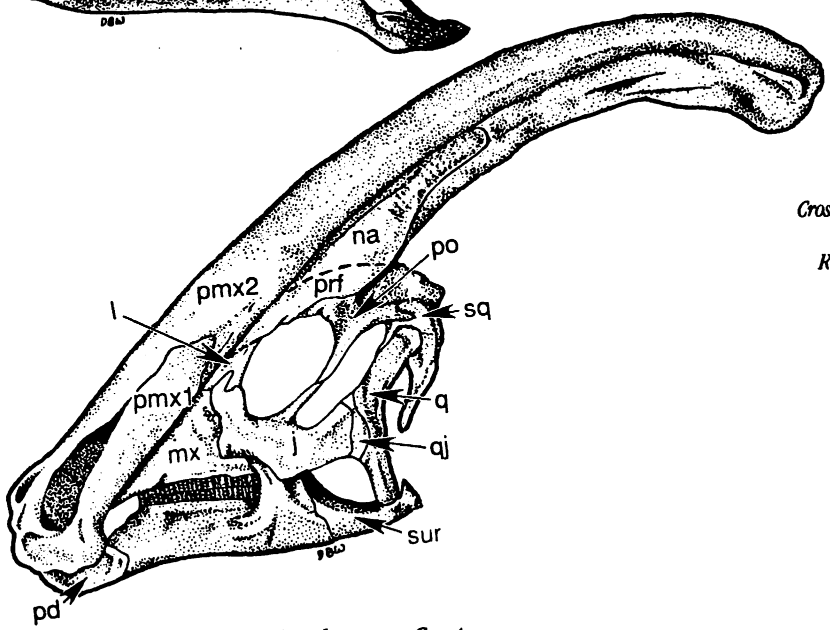
The most familiar members of the lambeosaurine crested duck-bill tribe are Corythosaurus, Lambeosaurus, and Parasaurolophis. All lived in North America during the last 15 million years or so of the Cretaceous period. Skulls of these three are pictured on the next page, along with views of the internal structure of the crests. The remarkable feature of the crest is that it is not a solid plate of bone, but is hollow in order to conduct the nasal passages from the nostrils to the throat. What could be the purpose of carring the nasal passages on a circuitous route through this large, fragile, hollow structure rising over the top of the head?

The modern analogy to skull crests that comes first to mind is the brightly-colored combs and wattles on the heads of chickens. A crest might have carried colorful scales, or a covering of soft tissue that could change color for territorial or breeding-season display. The objection to this theory to account for lambeosaurine crests is that the nasal passages inside the crest could do nothing to contribute to its presumed display function. A solid plate or frill of bone, like that of ceratopsians, could support a "cock's comb" for display just as well.

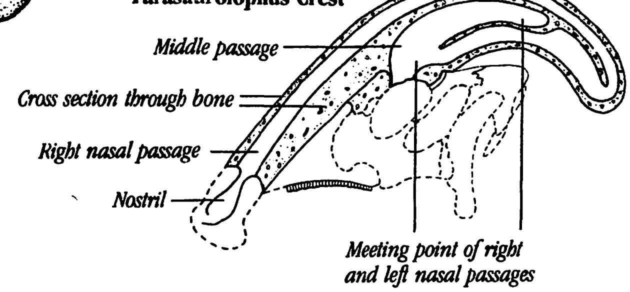


Lambeosaurus Crest

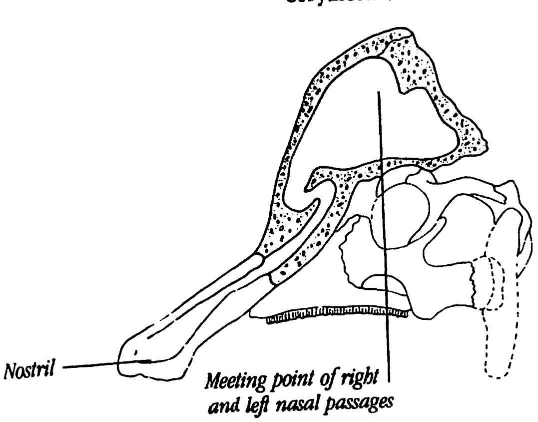


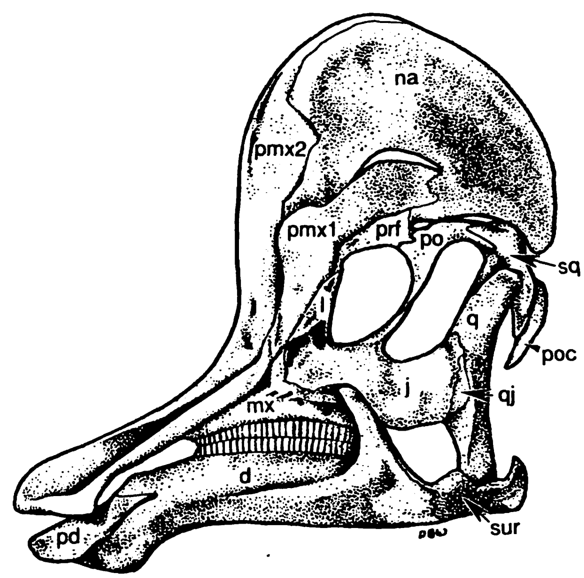


Parasaurolophus Crest



Corythosaurus Crest





Lambeosaurine skulls, with views of internal structure of crests.
Top, Lambeosaurus sp. Middle, Parasaurolophus sp. Bottom, Corythosaurus sp.
bar scale, 10 cm. or 4 inches

Another idea about the function of the crest is that it could hold a volume of air, and so block water from getting into the airway, while the dinosaur's head was submerged to drink or to feed on aquatic vegetation. Is such a complicated structure needed for this purpose? Most reptiles and mammals that pursue aquatic food items have flaps of skin or muscle inside the nostril to keep water out of the nose when the head is submerged.

Still another theory about the skull crest function, and probably the most popular idea of all, is that they could produce sounds when air was exhaled through them. It is exciting to imagine the variously-shaped crests producing a range of sounds like a trombone, or an organ, or the air horn on a diesel locomotive. This idea may be questioned when we note the great variety of vocal sounds made by modern birds and mammals, none of which need special bony structures outside of the throat, mouth, or muzzle to do so.

One more possible reason for lambeosaur skull crests arises from the need of this tribe of animals to cope with an environment having a severe climate. The local habitat of some of these late Cretaceous dinosaurs may have been well-timbered and well-watered, in the valley bottoms of rivers flowing out of mountain ranges nearby. At the same time and place, though, the climate may have been very dry and subject to wide ranges of temperature. Animals and people living in the drainage of the Colorado River and its tributaries on the "Colorado Plateau" experience these conditions today. Large animals, living an active, swift-running lifestyle, might have needed specialized structures in the nasal passages to humidify the dry air and moderate its temperature before it reached the lungs. The large chamber inside the lambeosaur skull crest, lined with a moist mucous membrane and served by a copious blood supply, could have answered this purpose. Modern mammals take care of this need with "turbinal" scrolls of delicate bones inside the snout, which function to present a large area of moist mucous membranes in a very small space.

The question still arises that the lambeosaurines needed their high skull crests while the rest of the duck-bill dinosaur family got along well without them. A faunal survey of the late Cretaceous formations could determine the percentage or proporation of crested lambeosaurs in the duck-bill population at a given time, and what changes in skull form took place over a long interval. Fossil plant life, and the presence of animal fossils "mummified" by dry heat before burial, could give evidence of climatic conditions, which could be correlated with the proportion of crested lambosaurs in the dinosaur population.

And by the way--what did these lambeosaurine hadrosaurs do when they caught a cold in the head, and there wasn't a box of kleenex anywhere in the world?

References:

The Dinosauria, edited by D.B. Weishampel, Peter Dodson, Halszka Osmloska. University of California Press, Berkeley, Calif. 1990

Illustrated Encyclopedia od Dinosaurs by David Norman. Crescent Books, N.Y.1985

Drawings taken from D.B. Weishampel, Nasal Cavity of Lambeosaurine Hadrosaurids Comparative Anatomy and Homologies: Journal of Paleo.,1981, vol.55 pp 1046 -1057 Reprinted in the Dinosauria, editors. Weishampel, Dodson, Osmolska University of California Press, 1990.

STAN'S PLACE

Kristin Donnan
Lapidary Journal

Jurassic Park sparked a dinosaur frenzy throughout the world, causing even the most diehard dinosaur curmugeon to steer secretly through the McDonald's drive-through for a "Jurassic Meal." However, in the beautiful desolate Hell Creek badlands of South Dekota, Stan Sacrison hasn't even seen the movie. Tonight is the last showing in the nearest city, across the border in North Dakota, but Stan doesn't budge. "I'm sure I'll be able to see it sometime," he says quietly, shoveling.

You see Scrison is busy excavating his second *Tyrannosaurus rex,* with help from the Black Hills Institute of Geological Research in nearby Hill City. As far as records show, he is only the second individual ever to have found two *rex* skeletons. The other, Harley Garbani of California, an excellent amateur paleontologist who has provided numerous dinosaur specimens for scientific study, found both of his in the same hole back in 1966 - an adult and a juvenile.

Taking nothing away from Garbani, Sacrison " is one of the best searchers in the Hell Creek, "explains Peter Larson, friend, business associate, and president of the Black Hills Institute. And he should know - the Institute bought Stan Sacrison's first *rex,* nicknamed "Stan," in 1992, and they've been in touch ever since.

Pounding the Prairie. Some people find the Great Plains a forbidding place, but not Sacrison, who was born and raised in Buffalo, South Dakota, population about 500. The prairie and fossil-rich badlands provided the perfect country for the young loner who liked to look for bits of the past. "I looked for arrowheads, but that was disappointing. I couldn't find anything ," Stan says. "But when you look for fossils, you definitely find something!"

That is about all the elaboration one gets from Sacrison on any given subject. He is quiet and thoughtful, volunteering little with his minimalist Dakota dialect. One can see in Sacrison's eyes that there is plenty more beneath the surface , but he rarely lets it out, except in occasional philosophical lightning bolts and jokes.

Sacrison found his first dinosaur bone, a *Triceratops* vertebra, when he was eight. He later spent several years doing carpentry, electrical and plumbing work, and studying Geological Engineering At the South Dakota School of Mines and Technology. Now thirtysomething he has become "Rex King" to the Black Hills Institute, and to Harding County, a close-knit population of ranchers who have found bones in their land for as long as they can remember.

"Looking for dinosaurs is fun. I like to kick around by myself, kind of get lost," Sacrison explains. But once you find them, dinosaurs are work!" So much work - and fun - that the locals fear the profession will lure Sacrison into the field full time. Rancher Gary Clanton jokes, "You're pretty well ruining a good electrician!"

Indeed, Sacrison's hands tell the story; their permanent coating of abrasive dust comes from particles of the Hell Creek sediments deposited at the very end of the age of dinosaurs. If he's installing a water pipeline, you can rest assured Sacrison is thinking of preparing a fossil found near the famous K-T Boundary, where geologists can actually mark dinosaur extinction.

Not much of the K-T Boundary has been preserved on the planet, and less is exposed, according to Larson. So how did Sacrison find it? "I heard there was supposed to be a time when dinosaurs died out," he says. "I kept kicking around until I found the section, and that's where I look."

Larson fills in what Sacrison outlines with his understatements. " We focus on this time period in order to study possible causes of dinosaur extinction," he explains. "Sixty percent of all animals and plants died forever then, and this opened up niches for other life forms, especially mammals, to take over."

Sacrison nods vigorously thoughout this explanation, gesturing with his pick towards Larson in agreement: I think it's incredible that they existed!" His eyes are sparkling.

It was 1987 or so (no one is really sure, and no one much cares) when Sacrison spied several massive vertebrae and part of a pelvis protruding from a cliff on one of his usual haunts. His face lights up a bit when he recalls it. " Most things you find out here are just scraps of bones. This was the first thing I'd seen that I thought, 'Hey! This looks like a dinosaur!"

He called the Museum of Geology in Rapid City, searching for an expert to take a look. In what could have been a disastrous misidentification, Sacrison was informed that his find was a *Triceratops* - and not worth digging. Was he disappointed? "Yeah, yeah, I'd have to say I was," Sacrison recalls.

It turned out that "Stan" the dinosaur sat tight for several years, until Stan the man happened to mention to a bridge club friend that he'd found a skeleton. Sarah Parsons and her husband Don "do" fossils , and they referred Sacrison to Larson. At that time, Larson's Institution was working on "Sue," the largest , most complete and now "most wanted" ***rex*** ever found. Larson came to see Sacrison's find, immediately identified structures in the bone that meant T *rex*, and "Stan" was reborn.

The excavation occured in April 1992, after appropriate arrangements with the landowners. Out here on these long stretches of paririe, though, "the landowners" isn't such a simple concept. Ranches meander in odd shapes, with sections clumped together irregularly. Furthermore, many owners lease pasture from their neighbors and build fence lines, not necessarily where the property lines lie but where it is easiest to cut through the badlands portions. "Stan" lay in no-man's land. No one was positive whose ranch it was -especially the two ranchers in question. It was a collection of quiet, soft-spoken people discussing the fate of an ancient beast as though it were a stray sheep. They drank plenty of iced tea, like they usually do when their neighbors come by.

To be fair, the Institute decided to pay its usual fee three times: Once to Sacrison and once to each of the ranchers. When it was all over, Sacrison's and one rancher's portion were applied to Sacrison's mother's quadruple bypass, which had occured a couple of months earlier.

Not only was "Stan" a godsend for the Sacrison family, but it also provided Stan Sacrison with the training he needed to advance to the next square in his paleontological skills. "The guys from Hill City (the Institute) showed me how to collect the big stuff," Sacrison says. "I had been collecting bits and pieces, remnants of bones, before then, but when I attempted bigger ones, I had been unsuccessful. They broke up, and I couldn't do much with them."

"Bones in the Hell Creek are among the hardest to find, and to dig," Larson chimes in. "In this particular formation, the bones are not mineralized; there is no natural cement to hold them together. They break into millions of pieces and fall apart, unless you use glues and hardners."

Sacrison learned the Institute's state-of -the-art collecting techniques on the "Stan" dig and made one of his philosophical pronouncements years later, with plenty of experience under his belt: "Super Glue doesn't make collecting easy - it makes it possible."

He also learned that there are people who love dinosaurs as much as he does. Sacrison's entire family pitched in enthusiastically, especially twin brother Steve, who is an expert Bobcat (earth mover) operator. He cut roads and cleared away overburden. Steve's wife, Ginger, and their children also became instant dinosaur diggers. Then free-lance documentary maker Dan Counter joined the group from Montana to videotape the proceedings. He, too, enjoys the collection of free spirits and hard workers. "These aren't regular people," he says, smiling. "there's no red tape to deal with."

Since the collection of "Stan", much has occured in the lives of this small group. Immediately after the dig, the Institute's "Sue" was seized by the government in a scandal that has been broadcast worldwide. The controversy has escalated onto a full-blown investigation in which no charges have been filed, as of this writing. The Institute maintains there has been no wrongdoing on its part.

Sacrison received his own notoriety as the discoverer of one of the world's then-12 known *rex* skeletons. He was approached by several paleontological groups, who recognized his trained eye and excellent territory. But, regardless of the "Sue" controversy, the Institute had proven itself to Sacrison, and he declined the offers. In his inimitable way, he explains, "Let's face it, the're local."

AND THEN THERE WERE TWO. Sacrison continued the methodical searching of his friends' ranches that contain the exposed Hell Creek Formation. "I keep hitting the same places over and over, doing the same round each year," he explains. "It's over 100 acres of breaks, (broken land cut by gullies and erosion) and although it's impossible to look at all of it, I just keep checking."

This Calm, tireless approach has landed Sacrison one partial *Triceratops* skeleton, one rare and exquisitely preserved crocodile skull, and a 60 percent complete baby duckbill skeleton. He has also located, but has not had the time to excavate , one small theropod, the family to which *T-rex* belongs, another *Triceratops* scull, an adult duckbill and what may be a whole crocodile skeleton. Struck by Sacrison's enthusiasm, his brother Steve and his children, along with partner Don Miller, joined in and spotted three more *Triceratops,* a "raptor-like" claw and a giant piece of amber (see box "Cretaceous Park"). All this on weekends and short vacations from Sacrison's current electrical/plumbing maintenace job. 'Whew'.

"Stan is an excellent collector due to several factors," Larson asserts. "He has experience in knowing what to spot, he is thorough, and he is persistent. It's very easy to get frustrated looking in the Hell Creek, since most things you find are tiny fragments. He simply never gives up."

Sacrison agrees in his own way: "A guy doesn't find many skeletons, that's the problem." Problem, indeed. Sacrison's latest discovery, surprisingly near "Stan" and within 20 meters of the K - T Boundary, very near the end of the time of the dinosaurs, is his second and the Institute's third *T- rex,* "Duffy." "Duffy" was postively identified in the summer of 1993, but Sacrison saw some fragments as early as, oh, he's nor sure, 1990? If I see a few shards of bone, I leave them there, in case more comes out, " He says. "Most times, I just see remnants at first, and I don't know where they're coming from."

Sacrison has several spots like this, where he simply maintains the site, pouring hardners and preservatives on exposed bone to protect it from the elements. He checks the places a few times per year until natural weathering exposes enough for him to see what's going on. "I wait for an *in situ* bone, a bone still in place and not washed away from where it was buried," he explains. Then he digs. Obviously, this whole process can and does take years - and patience.

When Sacrison called the Institute about "Duffy," he had learned enough to bet it was a *rex.* With "Stan," he had only known it looked big. Confirmation came when Larson arrived to see the pelvic bone, ribs, and vertebrae that were exposed and carefully preserved by Sacrison. "There are certain qualities theripod bones have - and these bones had them," Larson explains. "Vertebrae have large cell spaces, and the bones have a sort of laminated surface. We were thrilled!"

This beast was named "Duffy" in honor of "Sue's" defense attorney, who also represents the Institute. "We often name important fossils arter their discoverers, but in this case, Stan and I agreed that the man who had given so much of his energy to liberate "Sue" deserved a special recognition, " says Larson.

Video shooter Dan Counter returned to the crew, and is shoveling mud from the site along with everyone else (except me, at the moment) after unseasonably heavy and repetitious rains. His tripod is filthy, but he laughs about it, and donates his time and creativity in order to do his part to help the Institute through its harrowing legal battles. " I plan my vacation around their annual digs," he says.

"It's great: I get sunburned and carry heavy gear into impossible places." Counter, a former geology student himself, loves creating documentaries around dinosaurs, and hopes to finish his various Institute projects when the respective skeletons are finally mounted.

Sacrison's brother and his family also returned. Steve carved another *T-rex* notch in his Bobcat's handle.

The "Duffy" dig has come to an unusual pause. From the mapping of the site, the group realized that the parts of "Duffy's" skeleton that have been unearthed actually washed away from the main body mass when an ancient river flooded. "However, the random orientation of bones, plants, and sedimentary particles means these items have provided none of their usual clues about the direction the river flowed - and therefore, which way to dig," Larson laments.

"Evidence suggests that the limbs, most of the pelvic girdle, and much of the skull buried, and have not already weathered away," he adds. Plus, the uncovered bones are in good condition, which indicates they probably did not travel far from the rest of the skeleton. But distance is relative: "The missing items could be one inch or 50 feet from the quarry!" Larson says.

The first step was to dig several feet away from the last bone in every direction; the first will be to enlist the aid of remote sensing devices currently used in other scientific fields. "It's never been done successfully, despite what we saw in Jurassic Park," Larson assures us. Sacrison will be privy to this cutting edge in paleontology, something he did not envision when this all began. His goals are personal and modest. He hopes to tap into the surrounding area even more, and eventually find one lacalized spot, such as a bone bed, that is particularly rich in fossils. 'I'd like to make an area available to amateur enthusiasts to come and dig, " Sacrison explains. "The locals have already shown me lots of cool bones." Ideally, the amateur would pay a fee to learn how to dig bones, and go home with a sample.

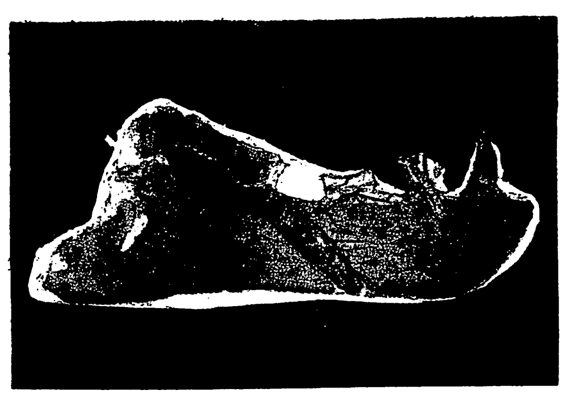
Regardless of the details, it looks like dinosaurs will someday write plumbing and electrical out of Sacrison's future. His collection and work place requirements have already outgrown his small shop at home, and Sacrison is expanding his operation into a new building in town. The former newspaper office will provide both work and display areas.

The Institute supports Sacrison limitless enthusiasm for paleontology not only because he loves fossils, but also because it adds to his - and the world's - scientific knowledge. "Stan's discovery of two new *T-rex* skeletons will add greatly to our knowledge of this well-known but little-understood dinosaur, " says Larson. Indeed, even though "Duffy's" skeleton is only 20 percent accounted for, and his skull 10 percent, the specimen already contains the only complete *rex* shoulder blade available to science. ("Sue's" two complete blades are unavailable to scientists until her case is settled.)

And don't forget the Sacrison group's undescribed "raptor-like" claw. "If we could get Stan out collecting full time, there is no limit to the number of scientifically important discoveries he could make," Larson asserts. "He's the best."

At the moment, Sacrison seems satisfied with what he has, and with who he is. Each day at the "Duffy' dig, his philosophy of life becomes more clear to the rest of us. Of course, it embarrasses him when we comment on it. Our collectively favorite moment?

It was a dark and stormy night, complete with brilliant bolts of lightning striking in both north and the south. Commercial paleontologists and co-philosopher Leon Theisen couldn't decide which way to look. "I'm afraid if I look over here, I'll miss the lightning behind me, " he lamented. Sacrison casually answered, "well, it's a whole world, and we gotta live in all of it."



The partially prepared lower jaw (dentary) with adjoining bones and tooth of "Stan." Stan Sacrison's first T-rex find. Photo: Ed Gerken.

WHO FINDS THE DINOSAURS?

The great majority fo all discoveries in the field of paleontology are attributable to the collecting efforts of amateurs, according to Peter Larson, president of the Black Hills Institute. "We professionals depend upon the work of amateurs in order to continue our studies," Larson affirms. "Science owes a great debt to these foot soldiers who log thousands of hours for the love of fossils".

Over a dozen "foot soldiers" participated in the latest dig initiated by fellow amateur Stan Sacrison's find of "Duffy," his second T - rex discovery. "Stan has showed us that the amateur is the most valuable asset to the field of paleontology," says Neal Larson, vice - president of the Institute.

In this case, the amateur troops came from all over the world, and pitched in through wind, rain, hail and lighting storms, and an unusually high number of mosquitoes and gnats. The regulars lived in a makeshift camp of tents and trucks, and were astounded and pleased at the presence of "Porta-potties," a rare luxury out in the field.

Bob Cassaday, a retired naval lieutenant commander - and dedicated amateur paleontologist from California - is definitely used to roughing it, "I recommend digging dinosaurs to anyone," he exclaims. "You're missing a lot if you're not getting dirty and finding something from the past."

Many of the "Duffy" amateurs were locals, who became interested in dinosaurs when Sacrison discovered his first T rex. Bobcat driver extraordinaire Steve Sacrison (Stan's twin), his wife Ginger, and their three children Finn, Drew, and Ian, were permanent fixtures. Finn's teacher , Janet DeBow, and her brother, Allen Bartell each found a vertebra, and local carpenter John Carter contributed shoveling, fossil finds, and plenty of jokes.

The Larson family members and their closest friends are also experienced amateurs. Brother John Larson and friend Robert "Tater" Tate took a break from farming to stop by, while veteran amateurs from Indiana Victor and Dee Ann Porter, jeweler and salon owner, respectively, joined the dig for their entire vacation. Victor also proved spectacular at creative wheel barrowing. (I even discovered my first rex bone, a rib, with the expert help of 13- year- old Sarah Farrar, daughter of Institute co-owner, Bob Farrar.)

The efforts of all these regulars, along with help from a rotating list of daily visitors, resulted in the location and excavation of 11 teeth, four vertebrae, several ribs, a couple of skull bones, and various sundry bits and pieces. The experts found the rest. Sacrison, of course, found the first clues that "Duffy" was there, including partially exposed vertebrae, ribs, and a pelvic bone. During the dig, he located one of the most scientifically valuable parts so far, a complete shoulder blade.

Visiting from Japan, amateur dino expert Yishio Ito, who brought two groups of editors, writers, and photographers to visits and dig, almost tripped over a pes (foot) claw from a carnivorous dinosaur! Institute scientists explained that so little is known about this group that, thus far, the claw is unattributable to any known beast. There is always another mystery when digging dinosaurs.

"Dinosaurs were on the earth as vital creatures for 140 million years - we've been here for only 500,000," Bob Cassaday explains. "It helps you put yourself in perspective. You learn something about humility." Bob's humility lessened a bit, however, after he'd displayed his fifth tooth find. (Hopefully his humor is intact!)

Clearly the energy of the amateurs on this dig - guided by the wisdom and encouragement of the experts - sped up the "Duffy" process. Peter Larson also emphasizes the importance and calibre of amateur work in broader strokes. "For example, of the 14 skeletons of Tyrannosaurus rex found to date, only one was discovered by a degreed paleontologist," he says. "Many of the specimens displayed for the public in museums around the world are provided by private individuals, and therefore these people are greatly responsible for our understanding of past life on this planet."

Neal Larson agrees. "Amateurs are the lifeblood of this science!" - KD

CRETACEOUS PARK

No one begrudges the creative license used in Jurassic Park's Book and movie when a combination of dinosaurs from both the Jurassic and Cretaceous periods bounded and screeched and expectorated their way through our imaginations.

However, the fact is that only two of the genera were Jurassic in age - Brachiosaurus (the huge, long-necked vegetarians) and Ditophosaurus (the frilled, spitting carnivores). Technically, "raptorlike" relatives did exist in the Jurassic, but not the Velociraptor depicted.

In Stan Sacrison's real-life South Dakota Cretaceous Park, he, his family, and his partner have uncovered evidence of many of the Cretaceous beasts we flooded the theaters to see. Among their numerous finds, the group has collectively discovered all or part of several creatures we saw on the celluloid: five Triceratops, two Tyrannosaurus rex, two duckbills , and parts of the bird-mimic ornithomimosaurs (the ones in the movie who ran in a herd away from the rex).

Sacrison's partner, Don Miller, made one of the most thrilling finds in Cretaceous Park - A huge claw, four inches in length, so far, no recorded animal sports the large dimensions necessary to fit into this glass slipper. . . which means the South Dakota crew has probably found evidence of a new species.

Could it be that a relative of Steven Spielberg's creation? In order to find out, a collection of Black Hills Institute brains, including Peter Larson, Robert Farrar, and David Burnham, flipped around long latin words and pages of technical dinosaur manuals. Identifying something new is exciting but tedious, and in this case involves comparing apples to oranges: there is just nothing exactly like this claw in the age in which it was found. This is the closest they could come as of this writing.

Paleontologists have found that Jurassic "raptor" relatives evolved onto the Cretaceous Velociraptor and these relatively small animals may have evolved further. Although ti's no secret that Spielberg more than doubled the measurements of real Velociraptors to make his creation scarier on screen, it's not out of the question that the beast in the movie may really have existed. eventually, size and all.

Then, during production of the film, a large version from the Cretaceous was newly discovered - Utahraptor (but it was probably more primitive than the pretend movie version". In any event, these "raptor"claws don't match the new South Dakota one.

So whose claw is it? One guess comes from the noted paleontologist Dr. Robert

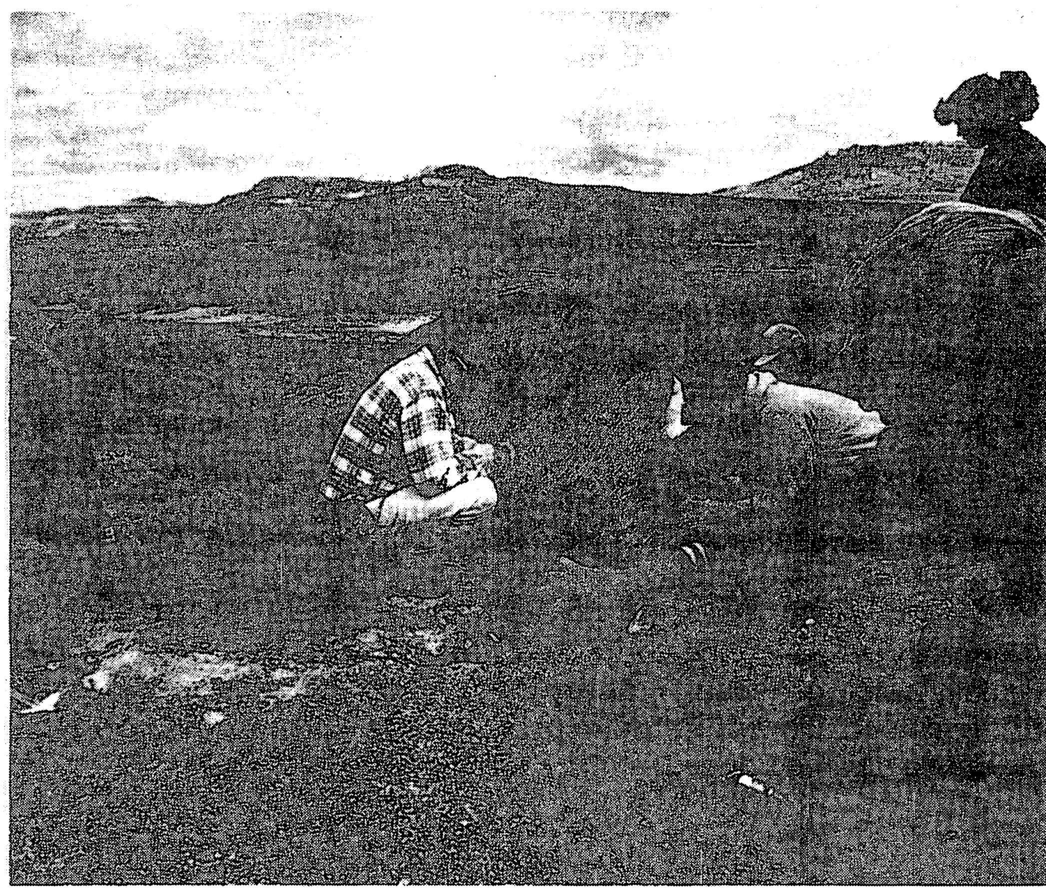
Bakker, who thinks the find could be a manus (hand) claw from a never before seen relative of Oviraptor, a toothless member of the Velociraptor line. After the pages settled down in the Institute, another option was suggested: perhaps it represents a new species of Chirostenotes, whose claw has been found before but in much older sediments. No matter what, Sacrison has something amazing in his workshop.

And there is more! You'll recall that dinosaur blood frozen in time in the body of an amber-encapsulated mosquito was the source of dino DNH In Jurassic Park. Sacrison's nine-year-old nephew, Finn, discovered a large, broken piece of amber on a trek with Stan. Stan's twin brother (Finn's dad, Steve) and Pat Larson. Amazingly, 10 months after Finn's find, dad Steve retraced their steps and recovered the recently exposed other half! This makes the whole specimen, 2.8 x 1.7 x 0.8 inches, one of the largest pieces of Cretaceous amber ever found!

Finn is pleased that no one will need to cut up his find in an effort to uncover blood-sucking insects. It turns out that bone preservation is no good in Cretacaous Park that some scientists like Peter Larson have already begun to retrieve genetic information directly from the bones in the area. Someday, you may be visiting a real dinosaur amusement park - in South Dakota! - KD

This article was prepared for The Lapidary Journal, by Kristin Donnan. It appeared in the November 1993 issue; and is reprinted here by permission from Greg Landry, with The Lapidary Journal.

Contributed by MAPS member Randy Faerber.



Stan Sacrison (foreground) and Peter Larson lead the crew in surface collecting before the real digging begins. Photo: Ed Gerken.

THE LATE CRETACEOUS HELL CREEK FORMATION OF THE NORTHWESTERN SOUTH DAKOTA AND ITS FAUNA

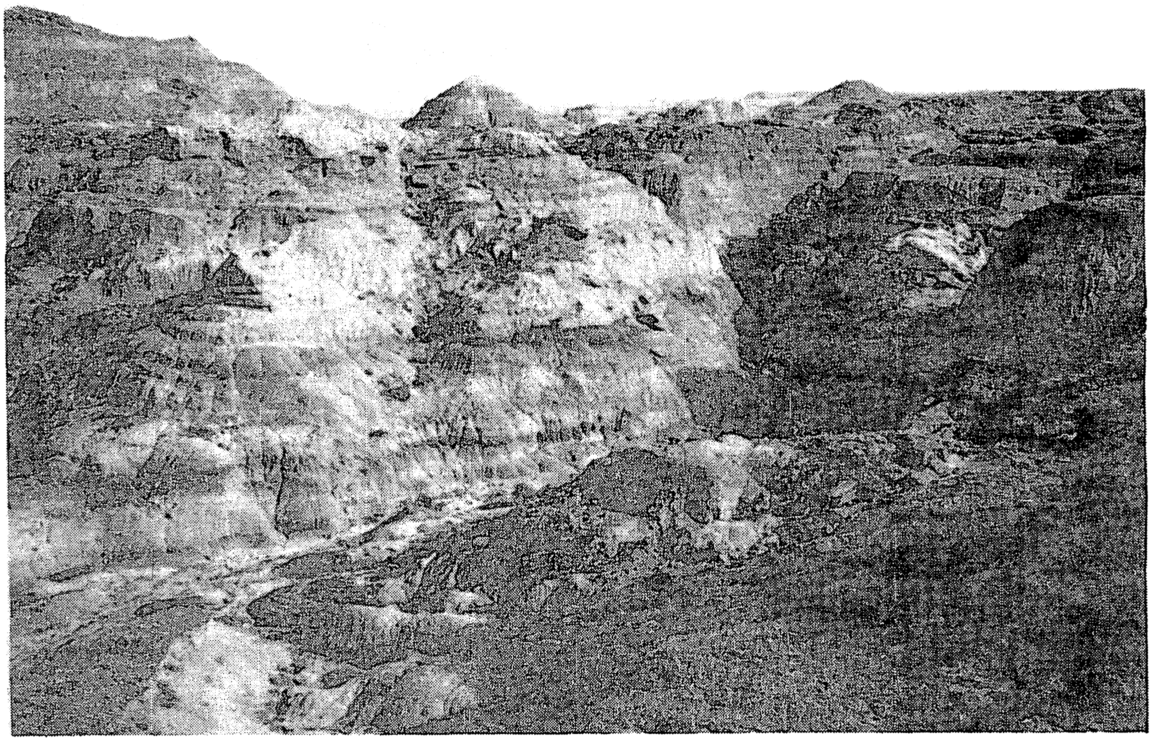
Tim Stenerson, Red Wing, Minnesota
Cameron O'Conner, Colden, New York

The Upper Cretaceous, Hell Creek Formation signifies the crown of the dinosaur era as well as the beginning of a great change in the ecology of the earth. We have long been interested in collecting invertebrate fossils in our respective states, but in 1989 the process to explore the potential to collect dinosaur and other vertebrate remains from the Hell Creek Formation began. After much leg work collecting geologic, topographic and range maps and then securing the permission of various landowners we were able to begin the task of looking. We found that finding the fossils was just a beginning and that the interpretation and identification of the fossil represented the greater challenge.

Hell Creek Formation. The Hell Creek Formation is made up of fine grained terrigenous sediments; such as clays, shales, silts, and fine sands. The sediments are generally lignitic (in North Dakota) and bentonitic (Frye, 1969), and vary from unindurated to mederately lithified. The clays tend to be slightly indurated and non-fissile (Moore, 1976). The clays and shales are often carbonaceous, frequently contain carbonized plant remains, and often bentonitic, producing a "popcorn" weathering surface. The silts tend to behave like clays due to their high clay content (Moore, 1976). The sands, which make up 51% of the formation (Frye, 1969), are generally weakly cemented but can also be tough and hard. The sands are fine- to medium-grained, often crossbedded, and may be cemented by clay, silt, zeolites, or calcareous or siliceous cement (Frye, 1969).

Brown to metallic gun blue to black siderite nodules are common and tend to accumulate at the botton of slopes as the less resistant sediment erodes away. Sperical, iron sandstone concretions are present, as well as log-like sandstone concretions (Frye, 1969). The color of the Hell Creek sediment ranges from shades of dark grey, olive grey, yellow-grey, grey-brown, and light grey. The Hell Creek Formation strata have often been referred to as the "somber beds" because of the predominance of the darker colors, in contrast to the lighter hues of the overlying Tulloc and Ludlow Formations.

Lithologically the Hell Ceek Formation is extremely variable, both vertically and laterally. According to Hares (1928), the Hell Creek Formation is structually heterogeneous, crossbedded, and seemingly oderless. Individual beds tend to pinch out laterally or interfinger with other beds, giving the sediments a slumped appearance.



HELL CREEK FORMATION - NORTHWESTERN SOUTH DAKOTA

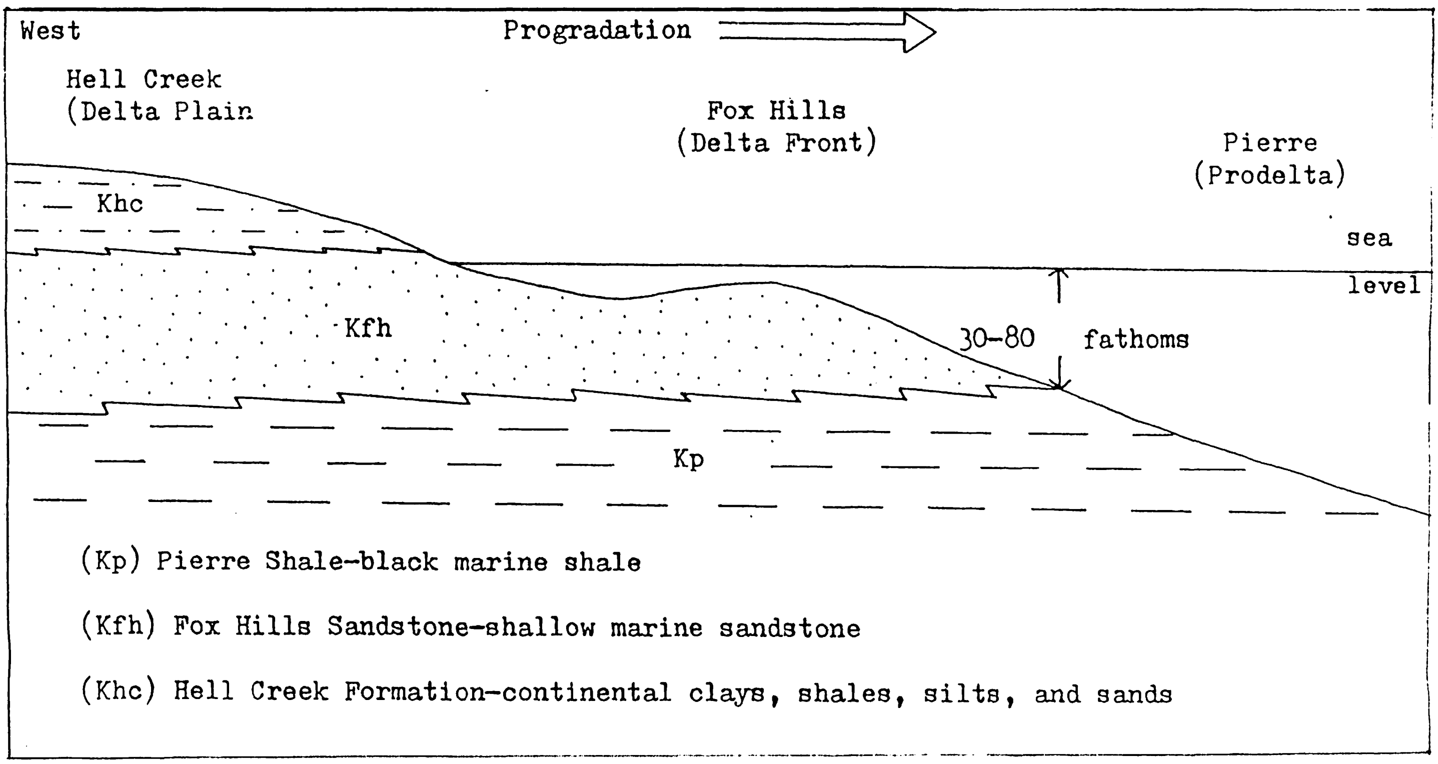


Figure 3. Hypothetical cross-section of the Late Cretaceous sediments in eastern Montana and southwestern North Dakota showing the relationship between the formations and their depositional environments. (Modified from Weimer and Land, 1975; and Feldmann, 1972)

Fauna

The Hell Creek Formation has well documented material of vertebrate life forms which have been uncovered. In addition to the dinosaurs, other life forms such as amphibians (frogs and salamanders), crocodiles and alligators, lizards, snakes, champsosaurs and mammals are present. Currently recognized forms include the following:

SYSTEMATIC PALEONTOLOGY
- Class Chondrichthyes
  - Order Selanchii
    - Family Hybodontidae
      - Lonchidion selachos Estes
  - Order Batoidea
    - Family Dasyatidae
      - Myledaphus bipartitus Cope
- Class Osteichthyes
  - Infraclass Chondrostei
    - Order Acipenseriformes
      - Family Acipenseridae
        - Acipenser eruciferus Cope
      - Family Polyodontidae
        - Paleopsephurus wilsoni MacAlpin
  - Infraclass Holostei
    - Order Amiiformes
      - Family Amiidae
        - Amia fraqosa Jordan
    - Order Lepisosteiformes
      - Family Lepisostidae
        - Lepisosteus occidentalis Leidy
  - Infraclass Teleostei
    - Order Perciformes
      - Family Scianidae
        - Platacodon nanus Marsh
    - Order Incertae sedis
      - Family Palaeolabridae
        - Palaeolabrus montanensis Estes
  - Teleostei incertae sedis
- Class Amphibia
  - Order Caudata

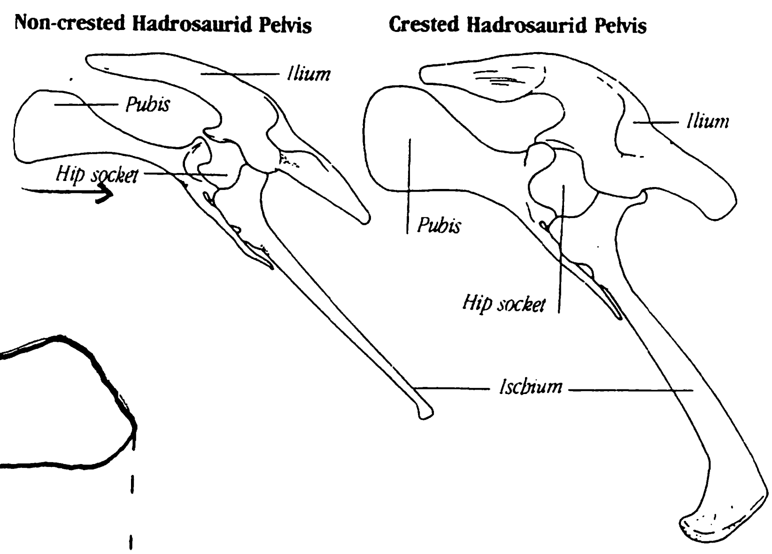
Suborder Ambystomatoides
Family Scapherpetontidae
Scapherpeton tectum Cope
Lisserpeton bairdi Estes
Family Prosirenidae
Prodesmodon copei Estes
Family Batrachosauroididae
Opisthotriton kayi Auffenberg
Family Sirenidae
Habrosaurus dilatus Gilmore
Order Salientia
Family Discoglossidae
Scotiohpryne pustulosa Estes
Class Reptilia
Order Testudinata
Family Baenidae
Palatobaena bairdi Gaffney
Compsemys victa Leidy
Family Dermatemydidae
Adocus sp.
Basilemys sp.
Family Trionychidae
Trionyx "A"
Trionyx "B"
Trionyx davidi n. sp.
Trionyx sp.
Helopanoplia distincta Hay
Order Eosuchia
Family Champsosauridae
Champsosaurus sp.
Order Lacertilia (Sauria)
Family Teiidae
Chamops segnis Marsh
Leptochamops denticulatus (Gilmore)
Family Parasaniwidae
Parasaniwa wyomingensis Gilmore
Paraderma bogerti Estes
Provaranosaurus sp.
Order Serpentes
Family Aniliidae
Coniophis precedens Marsh
Order Crocodilia
Family Crocodilidae
Subfamily Crocodilinae
Leidyosuchus sp.

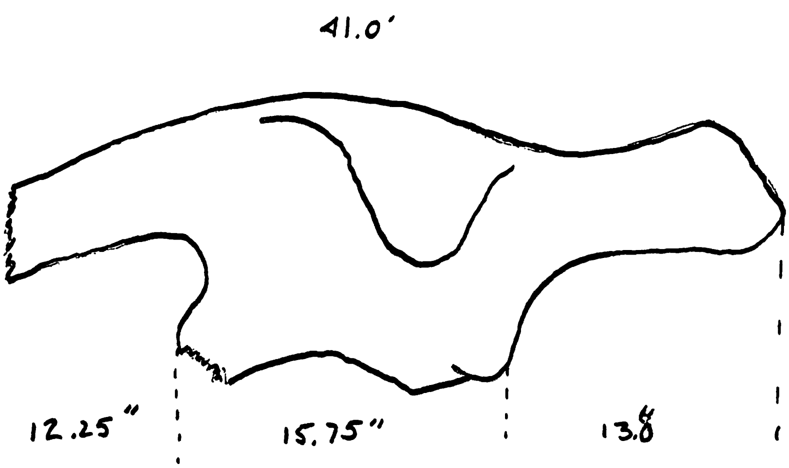
Subfamily Alligatorinae
Brachychamps sp.
Order Saurischia
Suborder Theropoda
Family Coelurosauridae
Coelurosaur

Family Dromaeosauridae
Dromaeosaurus albertensis Matthew and Brown
Family Saurornithoididae
Saurornithoides sp.
Paronychodon lacustris Cope
Family Tyrannosauridae
Albertosaurus lancensis (Gilmore)
Tyrannosaurus rex Osborn
Order Ornithischia
Family Hypsilophodontidae
Thescelosaurus neglectus Gilmore

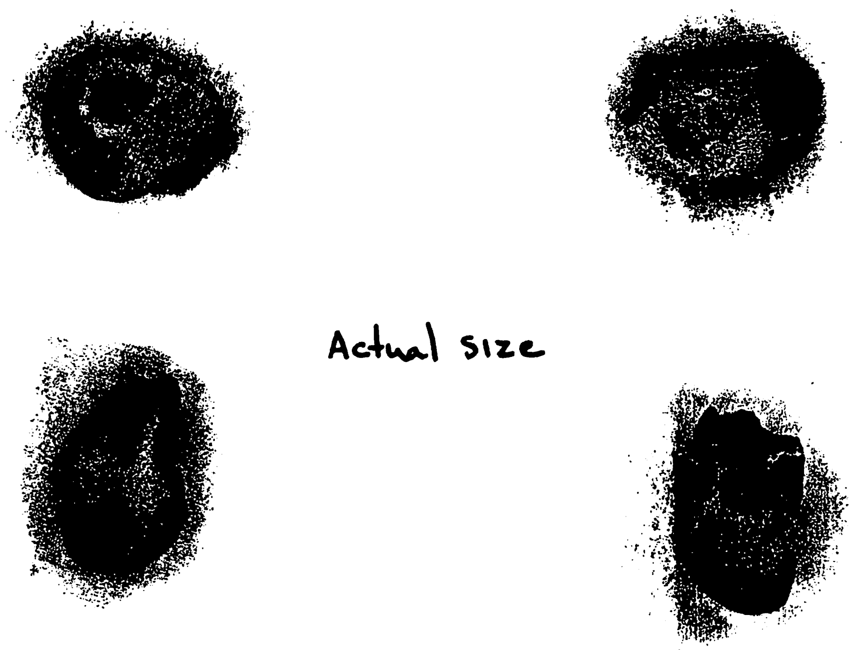
Family Hadrosaurinae
Subfamily Hadrosaurinae
Edmontosaurus copei Lull & Wright
Suborder Pachycephalosauria
Family Pachycephalosauridae
Suborder Ankylosauria
FamilyNodosauridae
Palaeoscincus sp.
Suborder Ceratopsia
Family Ceratopsidae
Triceratops Porsus Marsh
Class Mammalia
Subclass Metatheria
Order Marsupialia
Family Didelphidae
Pediomys florencae Clemens

While exploring the Hell Creek Formation, we have found fossil material of the order Ornthischia: Thescelosaurus sp. (vertebras, scapula, limb bones, foot elememts), numerous bones of Edmonotosaurus sp., isolated ankylosaur teeth and Ceratopsian material (teeth, frill, horns and vertebrae). Of possible significance is a large ilium of a crested Hadrosaur (Parasauophus sp. ?)





Although less numerous, we have found of the order Saurischia: Dromaeosaurus sp. (claw, teeth), ornithominid material (metatarsal, ungulal), and Albertosaurus sp. (teeth and foot bones). Although not confirmed, it is believed that a partial toe bone of a juvenile tyrannosaurid was found.



Exploring the different strata of the buttes is rewarding; however, former channel deposits in the area also provide hours of productive collecting. These deposits yield numerous dinosaur teeth and small isolated bones as well as fossils of turtle, lizard, crocodile, fish and mammal bones.

Conclusion

The collection of vertebrate material from the Hell Creek is exciting, rewarding and above all frustrating. In many cases dinosaur descriptions are based on a few bones and fragmentary material. New genera are described when in fact the remains are from the same animal at different growth stages. In other cases, bones from one animal are similar to another and can be told apart only by a few specific bones such as pelvis, toes, claws and teeth. (Note: we have found that counting serration density in theropod teeth does not definitely identify a particular dinosaur.)

It is our hope that continued collecting by enthusiasts like ourselves in collaboration and in friendly dialogue with professionals will add knowledge to the science of paleontology.

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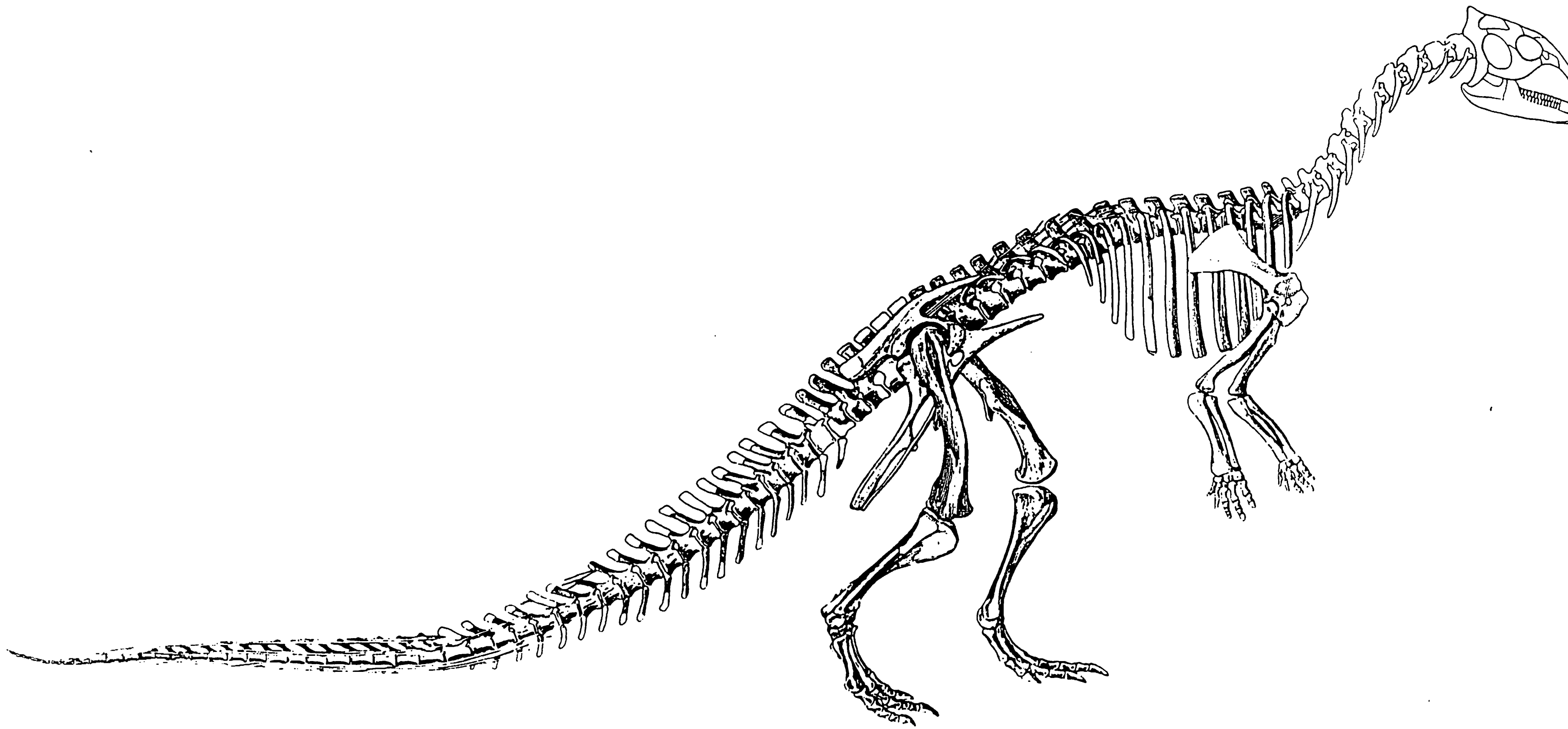
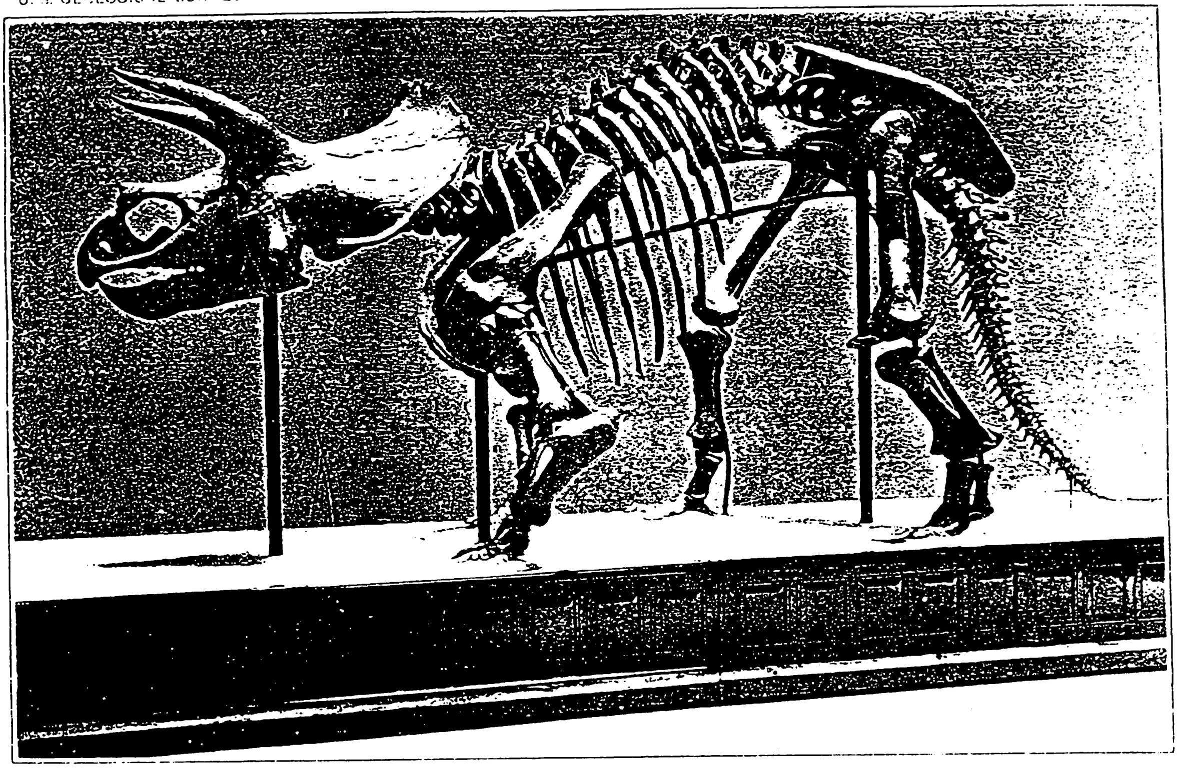


RESTORATION OF THE SKELETON OF THESCELOSAURUS NEGLECTUS.

FOR EXPLANATION OF PLATE SEE PAGE 615.

U. S. GEOLOGICAL SURVEY MONOGRAPH XLIX PL. XLIX



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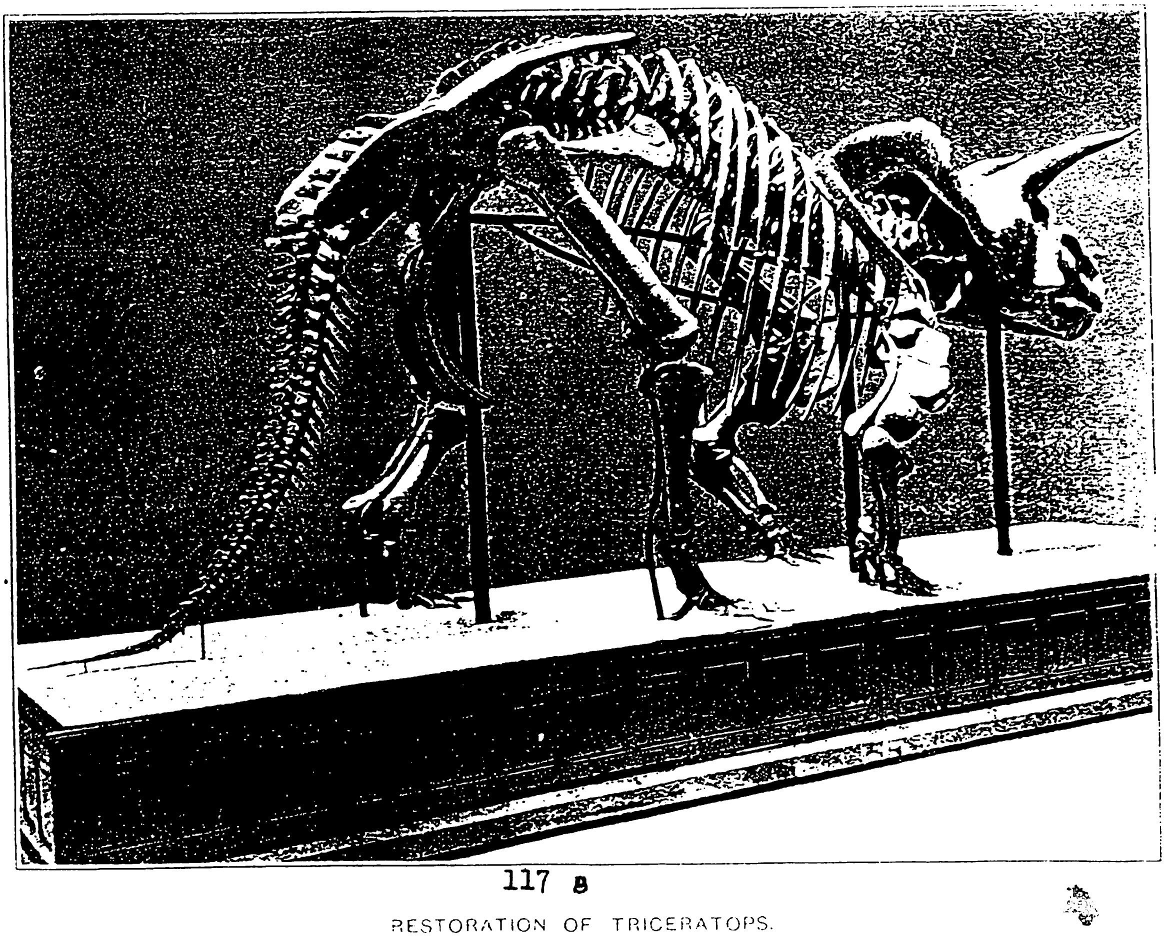
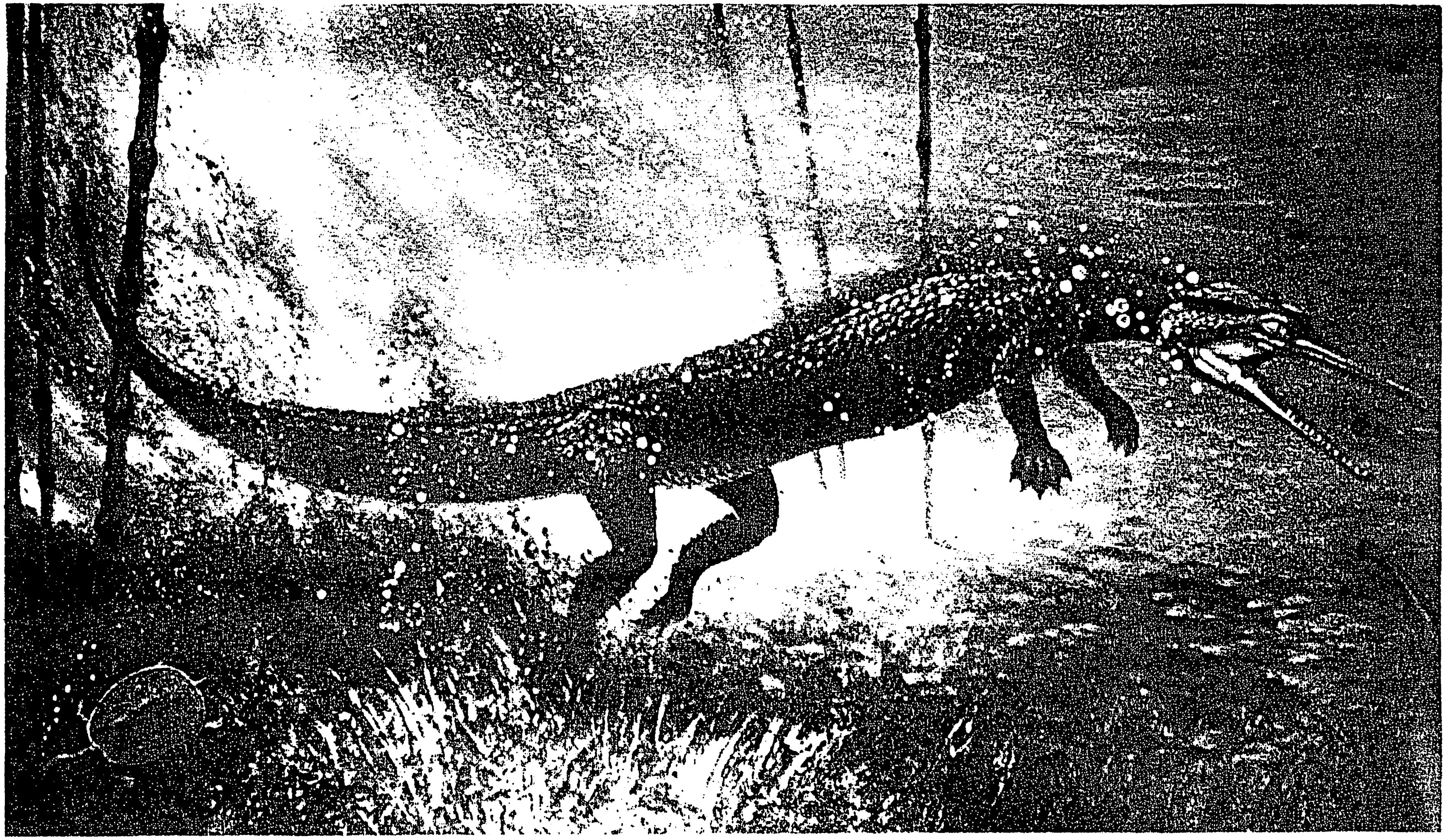


 B

RESTORATION OF TRICERATOPS.

Views of mounted skeleton in United States National Museum. A, Side view. B, oblique [illegible]



Photograph By James Wagoner

LIFE RESTORATION OF CHAMPSOSAURUS HUNTING.

Painting by Jerome Connolly in The Science Museum of Minnesota

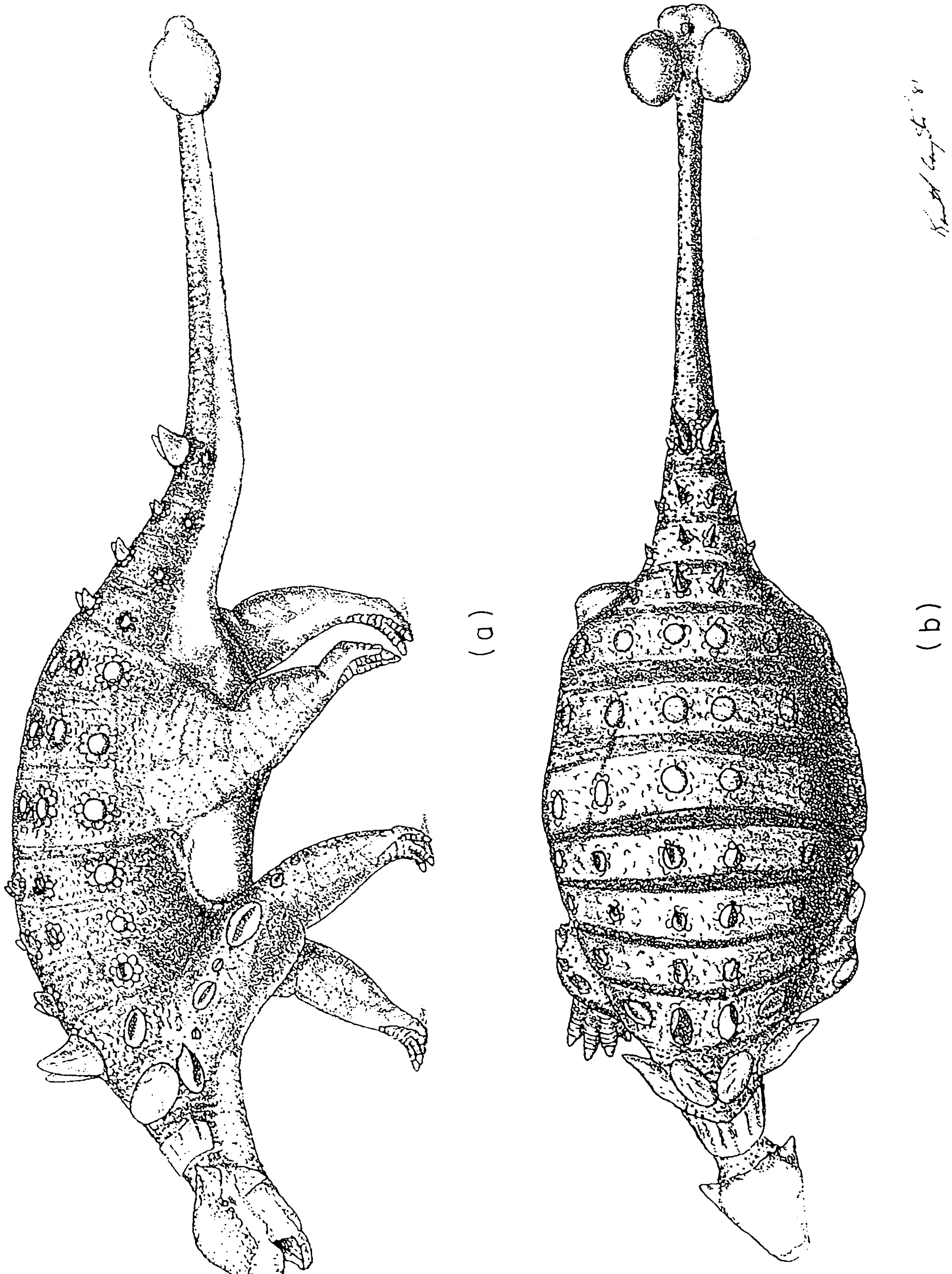


FIG. 3. Life reconstruction of *Euoplocephalus tutus*: (*a*) lateral view; (*b*) dorsal view.

REFERENCES CITED

Ager, D. V., 1963. Principals of paleoecology: An introduction to the study of how and where animals lived in the past. MCGraw-Hill BooK Co.

Biship, G.A., 1965. The paleontology and stratigraphy of the upper Cretaceous Pierre Shale on the Cedar Creek Anticline, southeastern Montana. Proceedings South Dakota Academy of Science, 44:91-96.

Brown, B., 1907. The Hell Creek Beds of the upper Cretaceous of Montana, Amer. Mus. Nat. Hist. Bull., 23:823-845.

Dobbin, C. E. and J. B. Reeside, Jr., 1924. The Lance-Fox Hills contact in eastern Montana and the Dakotas. Wash. Acad. Sci. Jour., 14:165-166

Norman, D. The Illustrated Encyclopedia of Dinosaurs.

PERRY
THE STORY OF A PLIOSAURS DISCOVERY

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The spring of 1993 was very fruitful for Doug Tingwall and myself. What began as a typical day of fossil collecting ended with the promise of an unusual accomplishment in the future. What Doug found that day, which I had the good fortune to take a part in, was a most substantial specimen.

The story began in the fall of 1991 when Doug was a member of an archaeological survey crew, surveying a proposed pipeline which was to run through the width of Montana. As an amateur fossil collector this presented Doug with the good fortune of exploring a wide range of Montana fossil areas. Doug would use most of his off time exploring for fossils on private lands. Exploring during his lunch break in southwest Montana, on an unusually warm and sunny November day, he discovered several fossil teeth and a vertebra in a small exposure on an immense north south running ridge. He was not sure exactly what the fossils were as he had seen nothing like them before. During his rapid collection, he did not have time to explore the area thoroughly and had to run feverishly to get back to work on time, as his co-workers were honking a pickup horn to hasten his return.

Doug did not feel that the teeth and vertebra were his best find of the year, he had a beautiful caramel colored *Albertosaurus* (a smaller carnivore than *Tyrannosaurus,* but similar in body shape, from an earlier time period) which was just over four inches long. Teeth this large are practically unheard of in such exceptional quality, most dinosaur teeth decompose or crack into many pieces before they are found. 1991 was a good year for Doug. He had just begun seriously collecting vertebrate fossils that spring, and before the snow covered the badlands that winter he had a substantial collection. I was a bit envious as I had been collecting for five years and my first year was not even close to being as successful as Doug's first year.

In January of 1992 Doug and I planned an expedition back to the place where he had found the teeth and vertebra. We had deduced that the formation which he was in was an early Cretaceous marine formation. I had not collected in such a formation and was anxious to see what was there. The vertebra that Doug had found the previous year was very unusual. I, like Doug, had seen nothing like it before. We decided that it must have been a dinosaur vertebrae since it did not conform to any marine creature veretebrae, which are very distinctive. Dinosaur bones in deep sea environments may sound unusual but apparently they are often found in such formations, perhaps the result of dinosaur carcasses floating out to sea. The teeth were just as unusual. Some were shark and fish teeth, but most of them were long recurved cone shaped teeth that resembled crocodile teeth. They were not crocodile teeth though, due to unusual striations along the tooth. We would not find out what kind of brute they belonged to until much later.

By February of 1992 we took advantage of the good fortune of a warm winter. We drove nearly 200 miles from Bozeman to the site. A friend of ours, Matt Groce, who had not collected before came along out of curiosity. When we got to the area we talked with the landowner, Perry and Elaine Newton, and found them very amiable and helpful. We drove down a typical Montana two track road toward the site, not an easy task in Doug's Honda Civic. We finally decided to park, as the bottom of his car was receiving an unwelcome beating from the large rocks in the road. The three of us walked nearly a mile through a beautiful expansive sage brush filled valley toward the ridge that the fossils were on. On the way we encountered a work crew laying the pipeline that Doug had surveyed for in the previous fall. We received several strange looks from the crew as we leapt over their trench and pipes. Intent on our task, we waved and moved on.

At first, Doug could not find the exact spot he had been to before as we began exploring. Matt and I stayed together, exploring small exposures as Doug got increasingly farther away in his search for the lost site. Finally Doug disappeared from sight. Matt and I found nothing for what seemed an eternity. I began to sense that Matt was regretting coming along and that he thought fossil hunting was not what we told him it was. Luckily I found a vertebra before Matt considered mutiny. It was just like the ones that Doug found the previous year, but it had A shark tooth encrusted in some matrix attached to the bone. We also found a few isolated shark teeth, but the site did not produce much.

Matt and I decided to find Doug and show him our fossils. He was nowhere in sight, but he left tracks in the shale where he had been. We trailed him for at least a mile before we found him. As he came toward us we noticed that his shirt was off and he was carrying it as if it were a bag at his side. When he got to us he was grinning like a man possessed. Without a word, he set his shirt on the ground and 7 beautiful vertebrae rolled out. I was awestruck. There was apparently three varieties of vertebrae, all in excellent shape. Doug had found his old site. In a flash we were practically running, following Doug to the site. He told us on the way, that there were plenty of fossils there and that he had not explored the area completely.

When we got to this area, we found a flat bare area nestled between two high shale slopes overlooking the expansive sage filled valley we had previously crossed. Doug showed us where he had found the vertebrae. He had found them isolated on the surface after they had been redeposited. They were of different sizes and shapes , and apparetnly belonged to different dinosaurs. Doug also showed us where to find the strange crocodile-like teeth. We spent at least two hours on our hands and knees picking up tooth after tooth. Some of the fossils were fimiliar to me; shark teeth, gar scales, and fish vertebrae. The majority were the strange teeth though. They were so dense in areas that at one time Matt accused us of setting him up, by planting the fossils there, so he would enjoy fossil hunting more. We assured him that this was not a normal site.

By the time we got back to the landowners house it was dark. We proudly showed them our fossils and told them tales of what some of the creatures were like. They were interested in what we had found and told us that we were welcome to come back. We assured them that we would and drove off into the night already making plans for our return. Little did we know what our next visit would reveal.

By the spring of 1993 Doug and I were ready to get out and fossil hunt again. We had spent most of the previous summer working in various areas (Montana, Washington and Alaska) as field archeologists. We had no time to fossil hunt in the fall either, as we were both attending Montana State. We were fortunate to attend a veretebrate paleontology class during the spring semester taught by Jack Horner. When the weather broke we were definitely ready to get out in the field.

We decided to go back to Doug's area as it was fairly close to Bozeman and also not completely explored yet. We contacted the Newton's and got permission to fossil hunt on their ranch again. Doug and I were the only expedition members this time as Matt unfortunately could not come. The ride along the two track road to the site was a bit smoother this time as we opted to take my pickup. We made it to within a quarter of a mile of the site after some white knuckled driving across a few dry washes. Immediately after we got our gear ready and began walking through the sage and up the ridge we started finding bone fragments. One of these fragments was a part of a Pliesiosaur humerus. We did not realize it, but this was an ominous bit of foreshadowing. We searched for more to no avail and headed to the site.

The site we explored the previous year was suprisingly productive. We found no complete vertebrae, but plenty of teeth. Doug found one of the crocodile-like teeth which was nearly an inch and a half long, reminiscent of a vampire canine. Doug eventually wandered off in search of new ground as I continued exploring on my hands and knees. I eventually heard Doug on the top of a ridge calling to me. He was a long way away and there was a breeze, so I had a hard time deciphering what he was saying. Apparently he was saying something about fused vertebrae and was holding a large mass in his hand. I let him know, by yelling and waving my arms, that I would be along shortly, and after comprehending my message he disappeared back over the crest of the ridge.

I found Doug in the bottom of a deep ravine on his hands and knees. He showed me what caused his excitement. It was a line of four vertebrae in perfect articulation. They were not fused, but appeared that way due to the matrix surrounding them. I recognized two distinct holes in the bottom of their centrums and realized that they were Pleisiosaur vertebrae. Doug described how he had found them loose on the side of a shale slope. We went to the slope and could find nothing on the surface. It seemed to us that such a cluster of vertebrae would have been attached to more vertebrae, but we could see nothing. Eventually, out of frustration, I began scaling the steep slope and poking at the loose shale with my pick. As if there had been a kind of divine intervention, my pick struck bone.

As soon as I realized I had hit bone, I lost my footing and went skidding down the slope to Doug. I let him know that I had found something of consequence and skittered back up to the slope. My boots finally found a purchase in the loose shale and I began exposing the fossil. As I uncovered the bone I realized that it was the rest of the vertebral column of Doug's beast. I excitedly told Doug, in a phrase full of expletives, of our good fortune. Doug climbed to the level that I was on and, as I did, slid back to the bottom. The loose shale slope was definitely steep and difficult to stay on. After several quick trips to the bottom of the ravine, I dug footholds to the right of the vertebrae and proceeded to dig the overburden from the fossil. After also sliding down the hill several times Doug started to secure a foothold with his pick to the left of the fossil. Divine intervention struck the shale with Doug's pick at this time also.

As Doug created his foothold he also struck bone. I was intent on exposing the vertebral column which was curving back into the hill when Doug showed me his find. What he had exposed was a large flat bone. We were not sure what it was. I joked that it was a *Triceratops* frill due to the flatness of it and its wavy periphery. We each continued exposing our finds in gleeful moods, occasionally thanking the fossil gods and yelling with joy at the top of our lungs. As Doug exposed his fossil he realized that it was actually the paddle to his *Pliesiosaur.* I could not believe such good fortune. All of the individual finger bones were just as they had been when the critter was alive. There was even a thin layer of gypsum covering the bones, giving one the impression that they were covered by skin.

After exposing fourteen vertebrae we realized that we had something of importance. We decided to cease excavation for the time and cover it back up. Before covering it we examined it closely. The vertebrae were laying on their sides in perfect articulation. Each vertebra had a perfect neural spine on the top and chevrons coming off the bottom. There was no sign of any distortion anywhere, which is highly unusual for such fossils. Even more important was the fact that we deduced that the vertebrae were cervical (neck vertebrae) and that they were pointing into the hill toward the skull. It seemed possible that the skull would be there, especially after seeing the condition of the paddle, but skulls are very rarely found attached to necks, especially in marine reptiles. We covered the fossils up, after laying canvas bags over them, and gathered the loose fossils that had eroded out from the *Pliesiosaur.* We headed back to Perry and Elaine's ranchhouse once more planning a return trip.

We told the Newtons about Doug's find with vigor. They were as usual, interested in what we had found and amazed that such a creature had once swam in an ocean over their land. They had company at their house at the time, and Doug and I put on another good show telling tales about dinosaurs, giant sharks and swimming reptiles. They asked where we had found doug's swimming reptile and we described it to them. Doug and I were a little disappointed to learn that we had strayed off of Perry and Elaine's land and on to a small quarter section of BLM land. Even before we knew it we was on public land, Doug and I were going to make sure that the creature would go to a museum. It was a beautiful specimen, and deserved to be on display somewhere. We were disappointed due to the possibility that we may not get to take part in the excavation if we showed our find to a museum official. We weighed the chances of our involvement with the *Pleisiosaur,* already dubbed :Perry"; after the landowner, on the ride back. By the time we got back to Bozeman and were causing havoc in the local bars, we had a plan.

A person needs a permit to dig on BLM land. I did not have such a permit and acquiring one is difficult. I did know someone who did have a permit though, Ken Olsen. His permit would allow him to excavate fossils on BLM land if he were to add them to the collections at the Museum of the Rockies. I had known Ken for a long time and he taught me a great deal about fossil hunting. When I showed him the few loose vertebrae that we collected, he was anxious to see what was there. Having had similar experiences before, Ken was not sure that Doug and I had found the neck or the tail of the creature. Doug and I were sure that it was the neck and Ken tentatively believed us. I then began to make arrangements to excavate the creature in the fall.

Doug and myself, were busy during the summer. Fall was the only time that we could get time to excavate "Perry". In late September I called the Newtons and inquired as to who leased the BLM land for grazing. Ranchers can lease BLM land, but the land is still open to the public. I wanted to let the leasee know that we would be there, the last thing I want to see is a landowner angry at a fossil collector. The leasee was helpful, but busy in ranching tasks such as harvesting and moving cattle. It was a bad time of year to be bothering him, but Ken was very constrained at the time also and needed to get to the creature soon. After a few phone calls and cancellations on excavation dates, we made it back to Newtons in October, this time with fellow collector Pete Pratt and Ken.

The excavation seemed maddeningly slow. We first removed the paddle and then a massive amount of overburden. Doug and I, having forgot gloves, gained some impressive blisters. Our wounds did not concern us as we finally began exposing the creature. Ken was finally convinced that we had the neck of the creature, especially when we found the back of the skull. As we carefully excavated the skull it tapered down to a very narrow muzzle. It almost looked like it had a beak, but its "beak" was filled with long, slender interlacing teeth. The same crocodile-like teeth that we had found elsewhere.

After we had the creature in a plaster cast and safely back at the Museum of the Rockies we (Doug, Ken and myself) visited with the preparator who was to work on it, Pat Druckenmiller. Doug and I had met him before, in Horners class, and he appeared to be a very knowledgeable paleontologist. Horner came by and looked at the beast. He was apparently impressed but he jokingly gave Doug and I a hard time. He said that marine reptiles were all right, but we should have brought in a dinosaur.

Pat had a different reaction, marine reptiles were his forte. He had a similar reaction that Doug and I had when we first found the creature. His excitement was not unwarranted, the creature was apparently not a *Pleisiosaur,* but a less common *Pliosaur* . In fact it seems that there are no other *Pliosaurs* from the early Cretaceous in North America.

Doug and I have been following what has happened to "Perry" for the past couple of months. His head was sent to San Francisco to be cat -scanned and Pat showed us the remarkable computer images that were sent back. The preparation work on the skull is apparently proving to be difficult as it was somewhat distorted and is delicate due to the destructive effects of the gypsum. Doug and I also have encountered some problems in a small museum publication, which did not give Doug credit for the beasts discovery, which is partially a reason for this paper.

All things considered this has been an exciting process for me. and I am sure it is even more exciting for Doug. The *Pliosaur* will prove to be a valuable specimen for science, and we are glad it is in capable hands.

FOSSILS, ROCKS AND ANCIENT ENVIRONMENTS OF THE LATE CRETACEOUS FOSSIL FOREST LOCALITY, SAN JUAN BASIN, NEW MEXICO; COMBINING SCIENCE AND EDUCATION

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INTRODUCTION

Paleontology is the science concerned with study of fossils, the remains or traces of ancient organisms preserved in the rocks of the Earth in an effort to understand the history of life and environments on this planet. In recent years, paleontology has experienced an almost incredible burst of popularity with students, teachers and the public in general. It is clear that paleontology is the most popular of the geological sciences and for many people, paleontology is geology. A strong case could be made for the fact that paleontology is the most familiar and popular of any of the sciences and it has been a long time since a science captured the attention and interest of so many people. This interest in paleontology can also provide the vehicle for providing science education enhancements for teachers and students. This is because paleontology is a bridging science; it is truly interdisciplinary and provides a fertile field for the interplay of concepts from geology, biology, chemistry, physics, geography and mathematics (Wolberg and Chavez, 1993). Perhaps it is this interplay of sciences as much as the fascination for long ago worlds that explains the interest in paleontology.

In New Mexico the Upper Cretaceous of the San Juan Basin of northwestern New Mexico, combines an abundance of marine, freshwater and terrestrial fossils, excellent rock exposures, and opportunities for contributing to science. Beginning more than a decade ago, a program was initiated to provide hands on experience in New Mexico's San Juan Basin in field and laboratory research in paleontology for science teachers as well as graduate students. One area in particular, known as the Fossil Forest Study Area, was of special interest to us.

The Fossil Forest study area is located south of Farmington, New Mexico and north of Chaco Caynon, known for its spectacular archeology (Figure 1). The Fossil Forest Study Area includes portions of secs 13, 14, 22, 23, 24 and 26 T23N R12W, and is included on the U. S. Geological Survey 1:24,000 Pretty Rock Quadrangle. The NE 1/4 sec 14 is private land, as is the N 1/2 sec 13; the S 1/2 sec 13 is State of New Mexico land. The Fossil Forest has been designated a Research Natural Area (RNA) and access for collecting is by permit only. A total of 2770 acres are included within the RNA, but only about 1000 acres are of paleontologic interest, the rest of the area is included as a protective buffer (Figure 2).

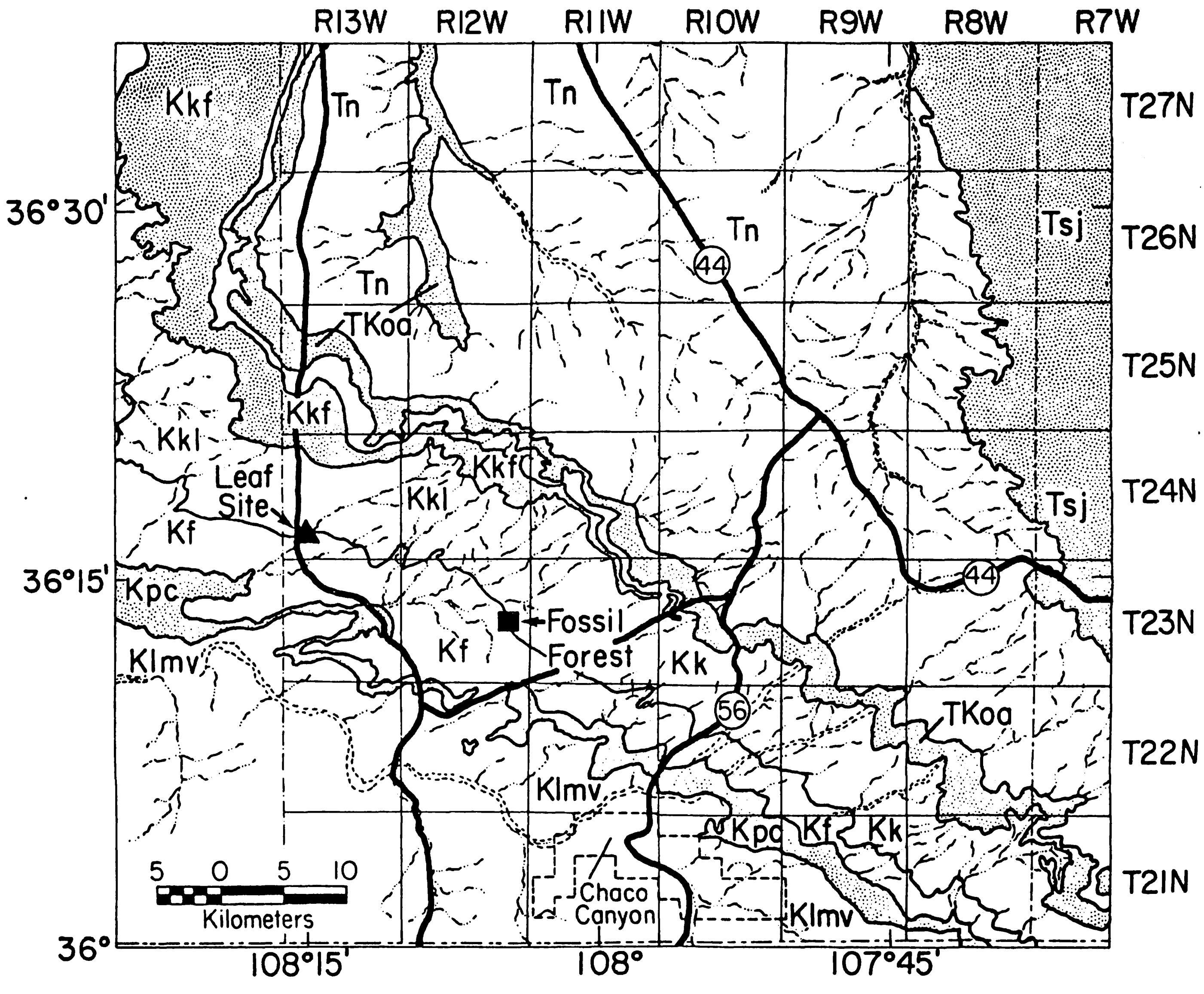


FIGURE 1.--Index and geologic map of the Fossil Forest Study Area in relation to major landmarks. The fossil leaf locality of Robison, Wolberg and Hunt (1982) in the Bisti Badlands is also shown. Abbreviations of rock units from highest to lowest are: Tsj, San Jose Formation (Eocene); Tn, Nacimiento (Paleocene); TKoa, Ojo Alamo (variously Cretaceous or Paleocene); KkF, Farmington Sandstone Member of the Kirtland Shale; Kkl, lower shale member of the Kirtland Shale; Kk, undifferentiated Kirtland Shale; Kf, Fruitland Formation; Kpc, Pictured Cliffs Sandstone; Klmv, undifferentiated Lewis Shale and Mesaverde Group. (After Wolberg and others, 1988) .

The area takes its name from the presence of numerous in situ fossil tree stumps and isolated logs (Plate I, Figures b and c) that occur at five stratigraphic levels in the exposed strata. The badlands exposed in the Fossil Forest (Plate I, Figure a) consist largely of Fruitland Formation coals, shales, mudstones and sandstones that represent the upperpart of the Fruitland. Isolated and thin remnants of the overlying Kirtland Shale occur in the study area. Fossil leaf, invertebrate and vertebrate localities are restricted to the middle portions of the stratigraphic sequence in the Fossil Forest, above the highest coal and below the highest sandstone sequence. The Fossil Forest lies within the east-central portion of the Navajo Section of the Colorado Plateau (Hunt, 1956).

The Fossil Forest lies at an altitude of between 5980 ft and 6100 ft and is drained by Coal Creek and its tributaries, eventually joining the De-na-zin drainage to the southwest. Although climatological data in the area is poorly documented, 35 years of record at Chaco Canyon National Monument indicate a mean annual precipitation of slightly less than 9 inches, most of which falls between July and October (Gabin and Lesperance, 1977). Although infrequent, storms traversing the area may be intense. Badlands development in the Chaco drainage basin is the result of Holocene climatic fluctuations and occurred rapidly in response to base-level lowering (Welles, 1983). However, the geomorphology of the landscape of the central basin Coal Creek area may have developed more in response to drainage-basin processes independent of lithology. Eolian mantling of the Fossil Forest hilltops and mesas show dune orientations that trend northeast-southwest and which parallel drainage orientations (Smith, 1983).

FOSSIL FOREST SOILS

The soils seen in the Fossil Forest is like that of 15% of San Juan County, Badland (BA) (Keetch, 1977; Himes, 1989). The Badland soil association is characterized by non-stoney, barren shale uplands dissected by intermittent drainages with a great deal of piping developed. Slopes vary from 5%-80% (Baltensperger and Maker, 1974). The Badlands part of the association supports very little vegetation and has limited livestock use. The Badlands-Rock part of the association supports some native grass cover and brush with livestock and wildlife potential. Included in the Badlands-Rock association are Farb soils, shallow over shale, but with some deep loams of the Shiprock series. Maker and Keetch (1973) indicate that the Fossil Forest consists of 89% Badland-Rockland, 4% Shiprock-Shepard, 4% Doak-Shiprock and 3% Werlow-Fruitland-Turley associations.

Himes (1989) notes that the Shiprock-Shepard association consists of gently sloping to gently rolling hills usually seen south of the San Juan River. Soils are sandy and underlain by sedimentary rock. The Doak-Shiprock association is usually found on the tops of gently sloping benches or mesas, where soils have

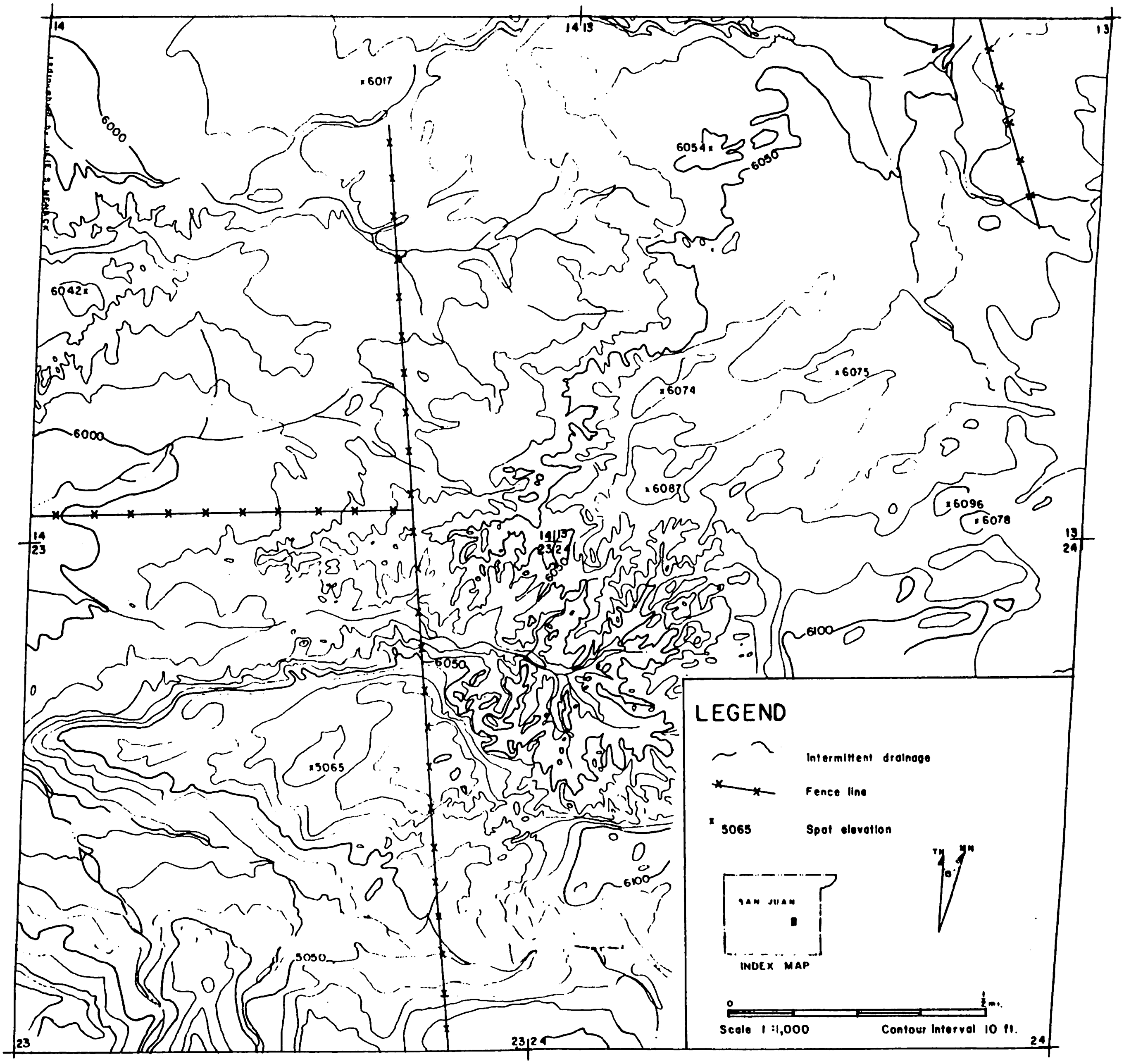


FIGURE 2.--Detail and topographic map of the immediate Fossil Forest area; note the prominent fenceline and well developed badlands. These badlands yield the fossils in the areas. Dune sands mantle the high surfaces.

formed by erosion. The Werlow-Fruitland-Turley association consists of deep, almost level soils of mixed origins. This association can be seen along drainages. Himes (1989) also reviewed the lack of plant cover in the Fossil Forest area. His results are interesting. He found that substantial amounts of key nutrients such as nitrogen, phosphorous, and potassium are present. However, soil pH is very high; the range at six sampling stations covering all soil types, was from 8.22-9.34. Himes concluded that high pH and low moisture are the primary factors responsible for poor vegetative cover in the Fossil Forest. To this we would add very high rates of erosion.

MODERN FLORA

Paleontological field studies frequently take place in remote areas not usually visited by other scientists, These areas provide opportunities for gathering additional data related to the modern environmental circumstances: soils, living plants and animals, etc. In 1987, 1988 and 1989, we undertook a study of the modern flora of the Fossil Forest area; this included the collection of as many extant plants as possible. The bulk of the work to date has been accomplished by our students Elvert Himes, David McKeever and Laura Howe. Howe will bring the final study to completion; she has received able assistance from Ken Heil, San Juan Community College. Table 1 represents a listing of extant plant taxa in the Fossil Forest and is the most complete listing available. More importantly, it based on collected material available for comparison with collections made elsewhere in the region.

PREVIOUS STUDIES

The Fossil Forest area has had a colorful history. This is discussed in another paper in this volume. For purposes of this paper, the most important work related to Fossil Forest geology concerns data in Bauer and Reeside (1920), especially those portions of their study that related directly to the Fossil Forest. Their work is discussed below.

During the course of a large-scale BLM-funded paleontological survey (Kues et al., 1977), the Fossil Forest was noted as a significant paleontological area and recommended "200+ days" of federally funded salvage. This study also suggested that the area be, "preserved indefinitely from significant land use, as such use would destroy or disturb many of the in situ relationships of the biota," (p.208).

Studies under my direction, as noted above, began in 1979 and a host of individuals have worked with us, and for a time we worked in cooperation with BLM staff. For almost a decade, work in the area has been carried out in part as a field school for secondary school teachers in the sciences (Chavez and Wolberg, 1988; Wolberg and Chavez, 1993). A number of papers have been presented and written dealing with various aspects of Fossil Forest paleontology, stratigraphy, fossil resins, clay and carbonate mineralogy and geochemistry. Studies continue in concert with specialists at other institutions. The reference section at the end of this report lists all the appropriate citations.

FOSSIL FOREST STRATIGRAPHY

Upper Cretaceous rocks of the San Juan Basin reflect a history of marine transgressions and regressions and were deposited near the shoreline of an epeiric seaway. This seaway was relatively shallow, and extended north-south from the Arctic to the present Gulf of Mexico, and eastward to the midcontinent; the seaway was about 1500 miles wide. The Cretaceous seaway effectively divided North America into island continents (Figure 3).

The Fossil Forest is dominated by a sequence of coals, mudstones, poorly fissile shales that are frequently carbonaceous, and sandstones. The sandstones frequently contain a basal clay-pebble conglomerate. All sandstones except the highest occurring sandstone unit, present in the area only locally as an erosional remnant have calcitic cement; the highest sandstone unit is characterized by siliceous cement. Sideritic concretions are common in the sandstones, generally at particular levels. Two major coal beds are exposed in the area and contain tonsteins. A single carbonaceous shale layer occurs throughout the area, not two carbonaceous shale layers as previously thought. Coal dominates the lower portion of a coarsening upward sequence. In general, beds dip 1-3 degrees to the NNE although locally dips as great as 12-18 degrees have been noted. Superficially the area is structurally simple but more detailed examination of exposures revealed substantial faulting and repetition of exposed section. These details and a failure to take into account the effects of even moderate dips might lead one to suggest for instance that two or more carbonaceous shales were present in the area (see Hunt, 1991). Our field group remeasured Bauer and Reeside (1920) sections 507, 508, 509 and 510. In addition, a section (A101) was measured and a reference section measured in the "Big Badlands" area to the south. The locations of these sections shown in Figure 4, and descriptions of the sections can be found in Wolberg and others (1988).

Figure 4 also the composite section and includes all rocks exposed in the Fossil Forest Study area. Two main coal zones are present, separated by about a maximum of 22 ft. The higher of these coal zones are exposed at sections 508, 509 and 510. Our continuation of Bauer and Reeside section 509, our section 509 1/2, has a relatively thick coal section beginning about 20 ft 5 in below the higher coal. We correlate this coal to the coal in Bauer and Reeside sections 511 and 521, placed by them about 25 ft below the coal at 508, 509 and 510. Bauer and Reeside (1920) note the presence of a thin (1 ft, 6 in) coal at their section 507, and correlate this with the coal in their sections 511 and 521, further to the south. We measured coal at 507 varying between 6 in and 2 ft, 6 in. However section 507 is actually downfaulted and is correlated to sections 508 and 509. The "coal" at 507 is the carbonaceous shale marker bed found

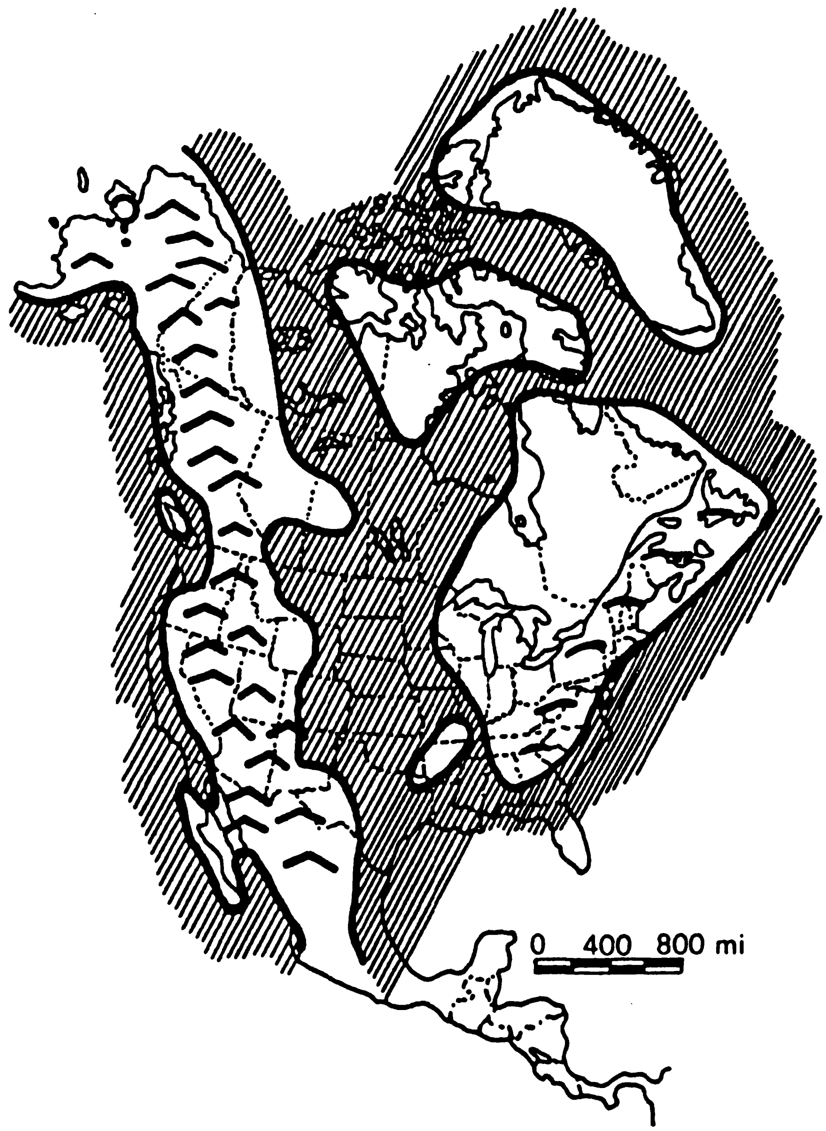


FIGURE 3.--North American paleogeography during Early Maastrichtian time. The Fossil Forest in northwestern New Mexico was situated just at the edge of the sea. The sea finally withdrew to the northeast. (After Williams and Stelck, 1975).

higher in the section.

In 1988, a 300+ ft core was drilled in cooperation with the USGS and BLM. The importance of this core is inestimable. The core was drilled in the NE1/4, SE1/4 Sec 24 T. 23 N., R. 12 W. and penetrates the Pictured Cliffs Sandstone. Wolberg and Bellis (1990) described the lithology of this core, and intensively sampled the core for clay mineralogy, whole rock geochemistry (trace elements), palynology and amino acid analysis. We have also included a graphic representation of this core at the end of this report.

AN UNUSUAL MINERAL

One aspect of our work depended on excellent cooperation from coworkers at Exxon Production Research Company and Texaco Oil Company. In addition, X-ray diffraction analyses have been conducted at the NMBM&MR X-ray Laboratory. Very significantly, our studies have disclosed the presence of the unusual magnesium carbonate mineral species, huntite, at eight sampling points in the core. This is the first documented pre-Holocene occurrence of the mineral and likely indicates a need to revise our interpretation of Fruitland paleoenvironments. We have since confirmed the presence of huntite in an exposure and have learned of its discovery in oil well drill cores east of the Fossil Forest. Thus, huntite has been found at two other sampling stations and strongly supports our conclusions as to its significance.

In our view, the Fossil Forest huntite was deposited in evaporitic sequences in shallow marine environments that periodically existed in the Fossil Forest. These environments were associated with warm, arid conditions that dominated between warm, humid periods associated with coal deposition or extensive rain forest development. It is interesting to speculate that the repeated huntite layers also indicate a climatic cyclicity, possibly taking place at regular intervals.

DISTRIBUTION OF FOSSIL TREES

The Fossil Forest takes its name from the presence of in situ fossilized stumps and some incomplete logs (Plate I, Figures b and c). Wolberg, Robison and Hunt mapped the distribution of approximately 40 of the best preserved stumps and 11 logs in the area known as the "main stump field," (portions of sections 14 and 23 parallel to the EW fenceline; this data was presented in Hunt (1984) and repeated in Hunt (1991), despite the availability of more complete data. It was our assumption at the time that a single forest floor was represented.

During the 1987 field season we became interested in the actual density of stump distribution and their stratigraphic distribution. A detailed, large scale mapping effort was undertaken to plot as many stumps as we could find. In some areas, although the actual stump no longer remains, fossilized root systems that radiate from where the stump should be can be

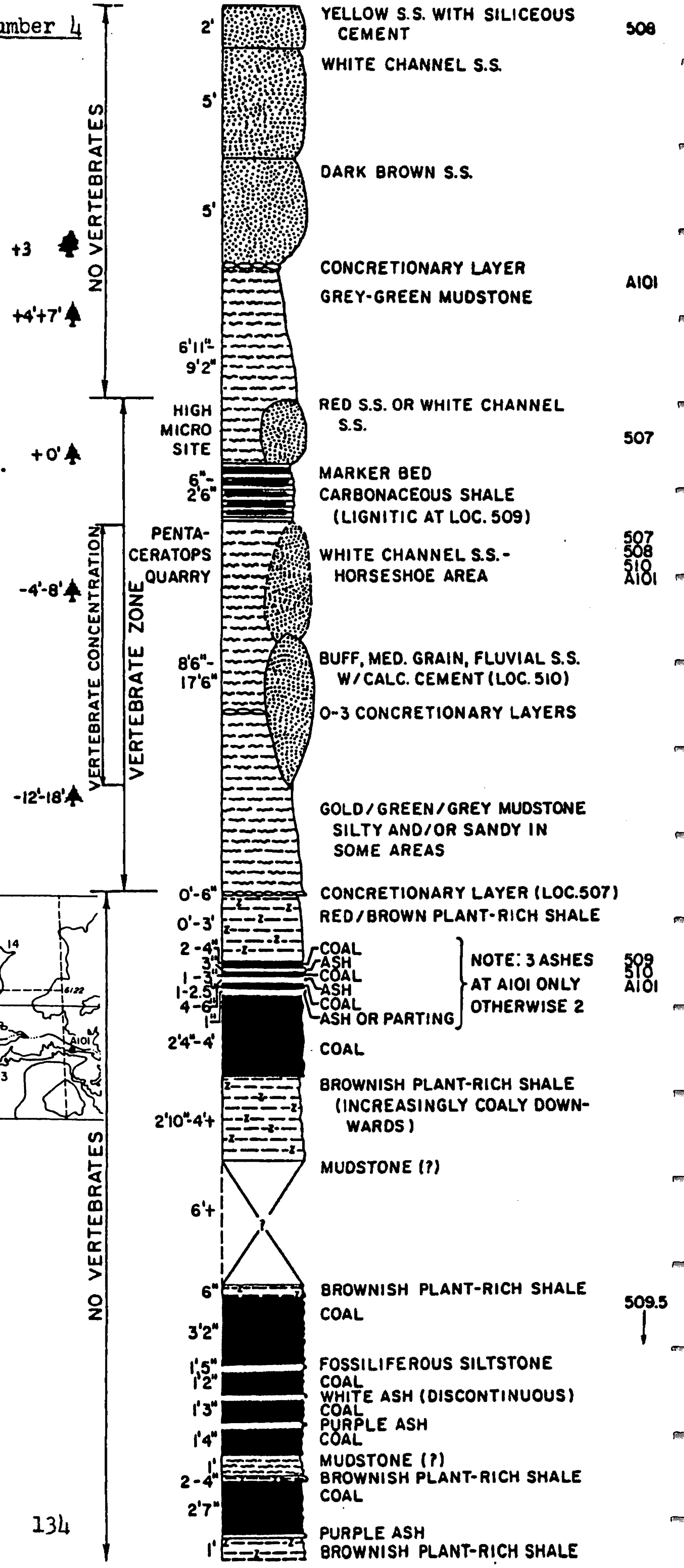
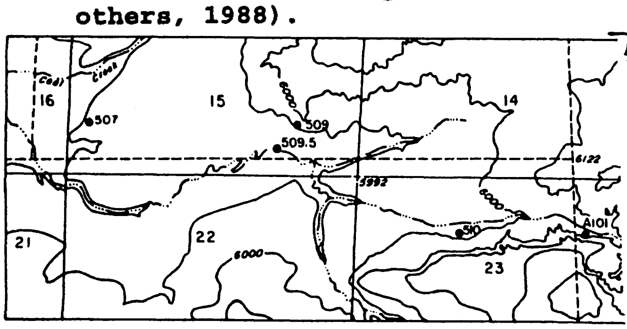


FIGURE 4.--Composite stratigraphic section for rocks exposed in the Fossil Forest. Five tree stump horizons are shown and these are separated by at least three fossil leaf horizons. The numbers on the right correspond to individual measured sections used to build up the composite section and include Bauer and Reeside (1920) remeasured sections. The Bauer and Reeside localities are shown in the map inset. The "High Micro Site "has produced dinosaur egg shell fragments and is at the same level as the infant hadrosaur locality. Vertebrate fossils occur in a relatively restricted stratigraphic zone. (After Wolberg and others, 1988).



discerned. The positions of several hundred stumps and more than forty logs were plotted using compass and pace or compass and tape. We know that in the "Main Stump Field Area" three forest levels are present: 1) the highest level is just above the carbonaceous shale; 2) an intermediate level is found 4-8 ft below the carbonaceous shale; 3) the third and lowest level occurs 12-18 ft below the carbonaceous shale.

Figure 4 shows the position of the various forest levels. Figure 5 shows the density and distribution of the our latest plot of stumps and logs in the Main Stump Field. Compass bearings of the orientations of the long axes of the logs are also indicated. Most of the logs are associated with the intermediate level of stumps, those 4-8 ft below the carbonaceous shale. The long axes of the majority of these logs trend NE-SW. Logs with NW-SE bearings show high angles (>60 degrees west of north). Those comparatively few logs associated with the lowest and highest levels show a preferential NE-SW orientation of their long axes as well, although some exceptions are noted.

In addition, we have documented the occurrence of fourth and fifth fossil forest levels in the badlands exposures to the east. The fourth level is about 7-10 ft above the carbonaceous shale and is represented by several in situ stumps and one or two logs. The fifth level is an additional 3-5 feet higher still and appears to be represented by isolated logs and in situ stumps. This highest level has been the level most subjected to erosion. It is important to note that some of the leaf localities discussed below obviously represent still additional forest levels. Almost all of the trees and logs are taxodiaceous. We have observed isolated pieces and possibly one in situ stump of palm wood. Elsewhere, we have noted the presence of Sequoia (Plate II, Figure b; Plate VI, Figure f). However, the stump field and logs are essentially monotypic and differ greatly from the much more varied flora known from leaf fossils found in the area. Preservation of the wood in the stumps and logs varies greatly. However, the best preserved wood is only moderately well-preserved. It is of some interest to note that tree rings are present in some but not all stumps, even those from the same stratigraphic level. Some stumps and logs evidence rotted cores, indicating different times of death from other trees in the area. Few, if any, logs can be associated with in situ stumps, indicating transport of virtually all logs, a conclusion reinforced by the preferential orientation of the log long axes.

FOSSIL LEAVES

Until the 1986 field season, productive fossil leaf sites were lacking in the area. Periodically, leaves were found as carbonaceous stains in various lithologies, but these were almost always poorly preserved or isolated occurrences. The first reasonably significant site was discovered in 1986 near the "toadstool" area just west of our permanent campsite. The leaves from this site occur as fair to poor carbonaceous,

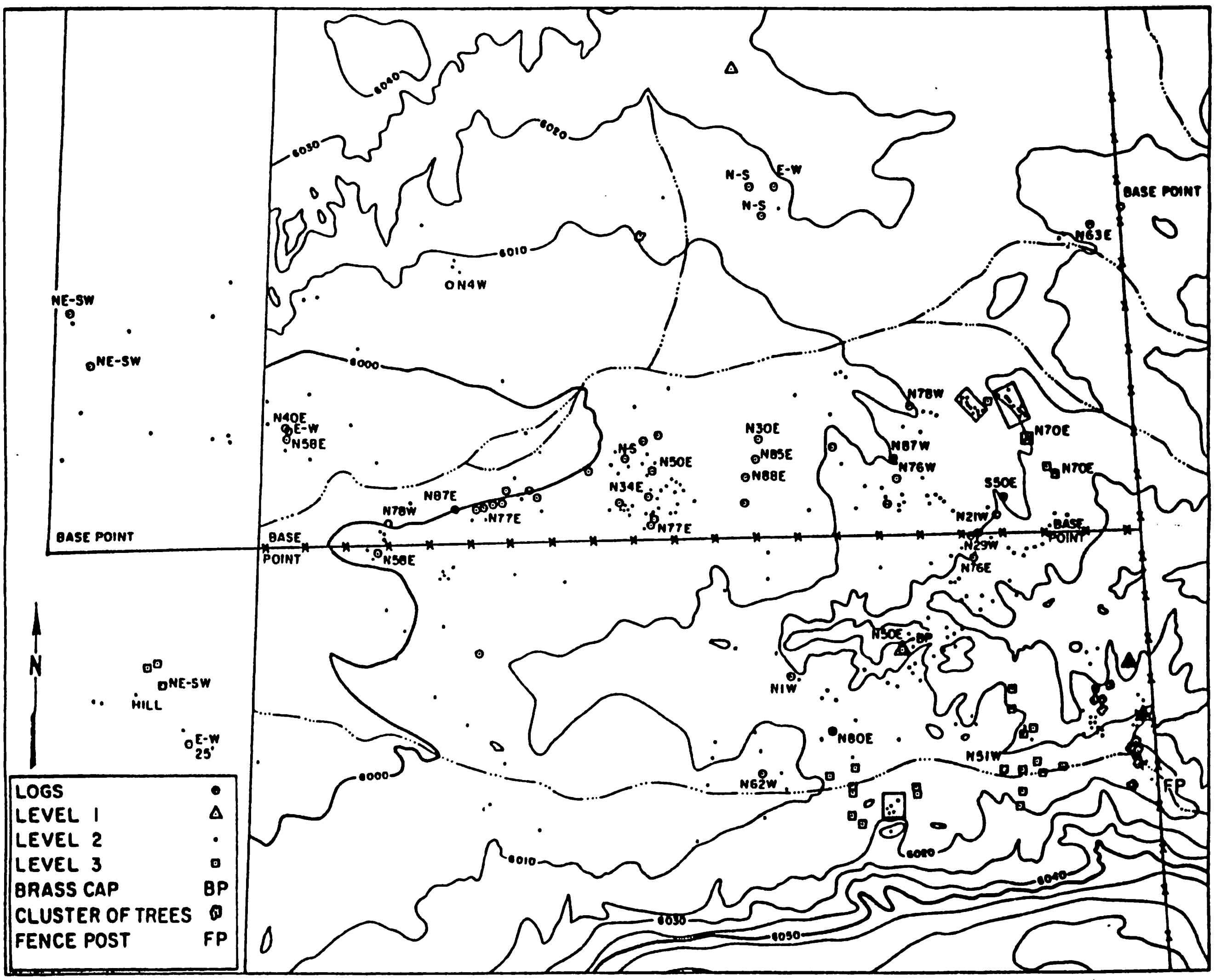


FIGURE 5.--Distribution of fossil tree stumps and logs in the "Main Stump Field" Fossil Forest. More than 400 trees have been plotted in this area and three forest levels are present. The fence lines date from the late 1930's after the passage of the Taylor Grazing Act; they were probably supposed be N-S and E-W but are just off true from an original base to the south, off the map. (After Wolberg and others, 1988).

occasionally limonitic, compressions and impressions in a fine- to medium-grained sandstone. Leaves are present in some abundance. In 1987, a second significant leaf locality was discovered in the drainage where stratigraphic section 509 1/2 was measured. The flora at this site is very abundant, preserved mainly as carbonaceous compressions, frequently with a good deal of morphological detail. Most of the leaves are angiosperm in origin. This is in contrast to the logs and stumps, which are gymnospermous. During the 1989 field season, a rather significant new leaf site was discovered at about the level of the highest forest preserved, and this was further delineated during the 1990 field season.

In all, leaves in abundance are now known from six sites; some leaves are shown on Plate II. these are documented in the inventory data sheets. However, significant occurrences are known from only the three sites noted above. Table 2 represents our current estimation of the diversity of the leaf flora in the Fossil Forest and represents a great deal of effort by Laura Howe and Dean Hollick. In 1989, excellent palm material was recovered (Plate II, Figure e).

INVERTEBRATES

Invertebrates known from the area include fossil mollusks (bivalves and gastropods) and, discovered during the 1987 field season, insects (Figure) known from caddice fly cases (Wolberg and others, 1988). The bivalves are presently being studied by J. Hartman and include several unionid taxa (Plate V, Figure e). At least one new unionid species is present; its distribution is now known to include the Fossil Forest area, and Upper Fruitland localities at Bisti. This taxon will be described by Hartman. Of some importance is the fact that Hartman (1981) has discovered that the molluscan fauna of the Pictured Cliffs, Fruitland and lower Kirtland Shale has paleoenvironmental value. Brackish forms dominate the Pictured Cliffs-Lower Fruitland sequence, but beginning in the Lower Fruitland, freshwater forms become progressively more important and are dominant by the Upper Fruitland. Recent geochemical and palynological work may require some modification of this view, however.

Several of the molluscan sites are characterized by relatively well preserved material present in abundance. These have been collected by Hartman or Wolberg. In all, a survey conducted in 1988 21 mollusc-producing sites.

DISTRIBUTION OF VERTEBRATE FOSSILS

Vertebrate fossils are best represented from only the approximately middle one-third of the stratigraphic section exposed in the Fossil Forest (Figure 5). The lower portion of the section is dominated by coals, and it has been our experience in New Mexico that coal swamps did not provide a favorable environment for preserving vertebrates. The upper part of the section is dominated by sandstones that differ in character from the sands in the middle of the section, and again, conditions do not seem to have been favorable for preserving vertebrates. Bone is not uncommon in the middle sands although the preponderance of vertebrate material consists of isolated elements. Articulated material occurs but generally consists of incomplete skeletons or portions of skeletons. Jaw elements are generally edentulous (Plate VI, Figures d and e) and well preserved hadrosaur jaws with intact tooth rows have been found. Long bones found in these sands are generally uncrushed, with and without a prominent patina and generally consists of original material with little evidence of permineralization Plate VI, Figures a and b). Unfortunately, the sands are very well indurated, making collection difficult.

Sporadically occurring mudstones have yielded the most complete fossil material to date, an incomplete Pentaceratops skeleton. The mudstone facies is comparatively easy to work although the fossil material tends to be crushed. At the Pentaceratops quarry site, sediments begin as a silty sand and sand that fines upwards into muds. Bone material, generally well preserved.

Unless treated, the bone does not hold up well once exposed. Bone quickly dehydrates upon exposure and exfoliation of the outer surface rapidly proceeds. An appropriate consolidant should be applied while excavating bone in the Fossil Forest.

Additional information has become available as well. The discovery of Carol's Quarry by Carol Horton has provided data not usually available. For example, this quarry has yielded portions of the skeleton of the second largest hadrosaur yet discovered in North America. It has also provided a log that contained well preserved bark as well as resin in the bark and from within the tree. Finally, this quarry has also yielded dinosaur skin (Plate V, Figures a and d). The size of this quarry has increased greatly during the past three field seasons, especially since the introduction of self-contained jack hammers (Plate IV). We have experimented with various quarrying techniques largely the result of having to deal with very indurated sandstones (for us more similar to reinforced concrete than rock) in which bones occur. In addition to the difficulty of working the material, we had to devise means of transporting sometimes massive blocks varying distances The badlands topography limited access to vehicles.

Mammal sites discovered to date all occur in a facies dominated by clay pebbles supported by a silty sand matrix. Mammals are largely known from isolated teeth, although edentulous jaws and at least one postcranial element have been discovered (Plate III, Figure f). The mammals from Quarry I are reported in Rigby and Wolberg (1987). Lower vertebrates are also known from the mammal sites and are reported in the table below. When they occur with mammals, the lower vertebrates are represented mainly by isolated teeth or postcranial elements. An incomplete and partially articulated new amiid has been found and described elsewhere Hall and Wolberg (1989). In 1988 a new survey of fossil producing sites was conducted. Our team located 157 bone-producing sites (Wolberg and Bellis, 1990.) Table 5 lists our current estimation of the diversity of the vertebrate fauna.

OTHER LATE CRETACEOUS LOCALITIES IN NEW MEXICO

New Mexico has a rich and colorful cultural past and present, abundant natural resources and a wealth of spectacular scenery, geology and paleontology. Late Cretaceous and Early Tertiary rocks are best documented in the San Juan Basin of northwest New Mexico and the Raton Basin of northeast New Mexico. Dinosaurs are longest studies and best known from the San Juan Basin. Evidence of dinosaurs in the Upper Cretaceous rocks of the Raton Basin seem to be restricted to footprints (C. Pilmore, pers. comm.). Renewed interest in the south-central part of the State at Elephant Butte Reservoir, near Truth or Consequences has revealed an Late Cretaceous record, with a surprisingly abundant dinosaur fauna and fossil forests known from in place tree stumps, logs and well preserved leaf horizons. In point of fact, a case can be made for the great importance to an understanding of the age and paleoenvironments of south-central New Mexico provided by studies of McRae Formation dinosaurs (Lozinsky and others, 1984; Wolberg, Lozinsky and Hunt, 1986; and Gillette, Wolberg and Hunt, 1986). Recently, work on the McRae Formation has been extended to include paleosol analyses, paleobotany and knew vertebrate discoveries under the direction of Gregory Mack, New Mexico State University. I have verified new occurrences of <u>T. rex</u> discovered by Mack as well as a very large ceratopsian that seems to have a solid frill. This may require reconsideration of the north-south faunal dichotomy for the Maastrichtian. The McRae discoveries can be interpreted as major breakthroughs, probably of equal significance to the San Juan Basin work done (by ourselves and others).

UNIQUE DISCOVERIES IN THE FOSSIL FOREST

Never before documented occurrences have resulted from our Fossil Forest studies and these have been cited above and are recapitulated here. For example, unusual as it may seem, the Fossil Forest is the first published occurrence of successive forest horizons in the Cretaceous of New Mexico. It is the only occurrence that includes distribution maps of the forests. In terms of animal fossils, the first Cretaceous insect from the region has been documented (Wolberg and others, 1988); marine fossils at two stratigraphic levels indicating that the area was inundated by possibly the latest transgressions yet identified in the San Juan Basin; new amiid fish described from an incomplete skeleton found in the Fossil Forest by Hall and Wolberg (1989). The first infant dinosaur known from the region, a hadrosaur juvenile jaw with teeth, was found in the Fossil Forest. The first detailed geochemical and biochemical studies of Cretaceous amber have been carried out in the region in the Fossil Forest. The first pre-Holocene occurrence of the unusual carbonate mineral huntite has been documented in the Fossil

Forest (Wolberg, 1989; Bellis and Wolberg, 1989). This last discovery indicates the presence of alternating arid and humid climates during Fruitland time.

THE FOSSIL FOREST CADDIS FLY

A number of tree stumps with rotted cores filled with penecontemporaneous matrix were identified in the Fossil Forest. We removed and broke down the filling of three of the stumps, washed and screened the material, leaving a residue that was examined under a binocular microscope. Fossil material was scarce, but significant. We recovered isolated garfish scales and several specimens identified as larval caddis fly cases (Plate V, Figures b and c). Caddis flies have an aquatic larval stage and are freshwater. This fact, along with the gar scales indicate that the area was submerged beneath fresh water for at least one period of time, long enough with water deep enough to fill the stumps with sediment. The environment had to be deep enough to allow gars to swim about and stable enough for caddis flies to survive and carry out their complex life cycle. This was the first record of Cretaceous insects in the Southwest (Wolberg and others, 1988).

FOSSIL FOREST FISHES AND OTHER LOWER VERTEBRATES

Fish are abundant in Fossil Forest deposits, although they are largely preserved as isolated vertebrae, scales, teeth, and tooth plates. A diverse fish fauna is present and includes freshwater and marine/brackish water forms. Selachicans are very abundant at certain localities as isolated teeth. It is likely that new selachian species await to be described.

Hall and Wolberg (1989) described a new. large amiid, Amia? chauloideia, based on incomplete but well preserved skeleton and cranial elements. This fossil was discovered in a greenish-gray mudstone that was lens-like, about 5 ft thick and no more that 75 ft in length. This deposit may be the fill in an ox-bow. We believe that this species is widely represented, but previously unrecognized in the Fruitland Formation.

Amphibians are present the fauna as isolated vertebrae, limb fragments and teeth. As yet, the Fossil Forest amphibians remain unstudied in detail. Lizards are also present as are crocodilians. There appears to be a fair diversity of the crocodilians, known from isolated pieces of bone, armor and teeth. The most common and widely distributed animal fossils present in the Fossil Forest are turtle shell fragments. Complete or even partially complete turtles are rare. Turtle shells are not resistant to erosion, but bits and pieces of turtle shell are--next to petrified wood, turtle shell is the most common fossil material seen in the area and elsewhere in the San Juan Basin. The turtle fauna, crudely identified by shell form and size, when discernible, and ornamentation, appears relatively diverse and in need of additional study.

FOSSIL FOREST MAMMALS

Cretaceous mammals are relatively rare everywhere; they are especially rare in the fossil record of the San Juan Basin. Significant collections of fossil mammals have been made in the Fossil Forest, however, and is exciting because it provides the best insights into Cretaceous mammal faunas in the Southwest yet found. The mammals have been studied in detail (Rigby and Wolberg, 1987; Wolberg, 1992). Other mammal localities have been discovered since the initial report was published. Fossil Forest mammals consist of three main groups of animals: multituberculates, marsupials and insectivores (Plate III, Figures f, i and j). They were all small, about mouse and squirrel-size. There was a certain adaptive advantage to being inconspicuous during the Cretaceous and no doubt, most of these animals were arboreal and nocturnal.

Fossil Forest mammal material occurs in a silty sandstone rich in clay pebble rip-up clasts together with isolated fish scales, fish teeth, dinosaur teeth (Plate III, Figures g and h), and other assorted fossil scraps and debris. The fossil material was probably a lag concentrate dumped by an event that tore up mud clasts from underlying beds and dropped the entire poorly sorted load as energy rapidly diminished. Because of the nature of the deposit, collection required quarrying blocks of matrix that had to be packaged in burlap sacks, each finally weighing 100 pounds or so, and transported back the lab some 250 miles for processing. There is no available water source for processing matrix in the Fossil Forest. We generally dug and transported 1-1.5 tons at a time. At the laboratory, the matrix was soaked in drums for 24-36 hours. A standard laboratory detergent was added to the water and rapidly break down the sediments to a sludge which was then poured through screens and further washed. Varying mesh-size screens produced residues that were dried and carefully examined. This technique served well for the production of many teeth, mostly isolated, however.

FOSSIL FOREST DINOSAURS

Dinosaur remains have an interesting distribution in the Fossil Forest; they do not occur uniformly through the rocks in the Fossil Forest section. The coals have yielded no animal fossils; the acid environment and slow depositional rates were not likely favorable to preservation of animal fossils. Most of the dinosaurs are associated with channel-form sandstones and siltstones above the coal deposits. Exceptions occur, and actually include a well preserved <u>Pentaceratops</u> specimen, found in a fine-grained mudstone. In general, the dinosaur material occurs as isolated skeletal elements, mostly as a lag deposit at the bottom of channels; streams and rivers are not good places to preserve whole animals. We have recovered an 6 ft long articulated segment of a hadrosaur tail, recovered a ceratopsian sacrum and discovered a series of articulated ceratopsian vertebrae, as well as isolated skeletal elements (Plate VI, Figure b) all from channel sands. Lastly, a major discovery, described below, occurred in a channel sandstone, but under very special circumstances.

The channel sandstone throughout the study area are difficult to work. They are very "hard" and do not fracture in a regular manner, frequently breaking across and not along bones. Quarrying activities requires mechanical equipment, hand-held air hammers or jack hammers.

Large dinosaur bones can form a lag concentrate on the surface as finer grained material is eroded and winnowed away. One such locality in the Fossil Forest was named "Ankylosaur Hill" for the concentration of ankylosaur armor plates that had accumulated. Unfortunately, no other bonely material of this animal was preserved.

One very important site was discovered by a crew member, Carroll Horton, when he came upon a series of rib ends just poking through the surface of a channel sandstone. Probing with hammer, chisel and awl showed that these ribs continued and that additional ribs were present as well (Plate IV). Carroll reported the discovery and activities at the site increased. It soon became apparent that a single, very large dinosaur, apparently still articulated was preserved at this locality. Additional ribs appeared as did a humerus, proximal ends of femurs, and a large log. The log, which eventually was identified as Sequoia was oriented with its long axis parallel to the axis of the channel, just as was the dinosaur. The log was important because a number of features were preserved. The log is massive and bark is preserved. A portion of the log is charred. A halo of branches and leaves is preserved in the sediment surrounding the log. Amber is present and directly associated with the exterior and the interior of the log, allowing for biochemical and chemical comparisons of resin exuded by the living tree and preserved within the living tree more than 73 million years ago. Finally, the dinosaur skeleton is associated with the tree and its branches (Plate VI, Figure c). The most reasonable hypothesis suggests that the redwood tree snagged the dinosaur carcass of a very large hadrosaur, and possibly kept it from being swept along with the current. Burial must have been rapid since the skeleton seems to be almost complete.

This quarry had other surprises: preserved dinosaur skin was recovered at a higher level in the channel sandstone (Hall, Wolberg and West, 1988). The skin is most similar to described hadrosaur skin (Plate V, Figures a and d). It is not associated with the skeleton and probably originated with a completely different hadrosaur and occurs as folded over sheet of shed skin. I believe it is shed skin because there is no indication of underlying tissue attached to the skin; this would be expected if the skin had been torn from a decaying carcass. This discovery was the first occurrence of dinosaur skin in the San Juan Basin.

Large carnivorous dinosaurs occur in the Fossil Forest. We have found large, serrated teeth identified as the tyrannosaurid Albertosaurus, as well as a tibia that is most likely associated with this genus. Teeth of small carnivorous dinosaurs also occur (Plate III, Figure g). At a number of localities, we have found concentrations of dinosaur coprolites, some of these large in size and containing substantial organic matter (Plate V, figure f).

THE FIRST BABY DINOSAURS, NESTS AND EGGS IN NEW MEXICO

There is always excitement associated with digging for fossils--one never knows what will turn up unexpectedly. As the data accumulated, it became apparent that the Fossil Forest lay very near or just at sealevel during the Late Cretaceous. The area was periodically inundated as shown by the presence of drowned forests, sharks, and marine invertebrates. We believed that dinosaurs nested inland and upland, away from coastal areas; we never expected to find nestlings, nests, or eggs. Of course, at a quarry site being excavated by Jim Baldwin of Silver City, New Mexico, and Mary Ann Pattison of Carrizozo, New Mexico, an infant hadrosaur lower jaw emerged just below an adult rib. This quarry too is located in a channel sandstone. Later work on an extension of this quarry yielded adult hadrosaur pelvic bones, limbs and isolated teeth.

The infant jaw is that of a nestling and consists of most of a dentary with teeth. The teeth are just about pristine with virtually no wear and are typically hadrosaurine, we assume <u>Edmontosaurus</u> or <u>Parasaurlophus</u> (Plate III, Figures b and c). The quarry site is located between the fourth and fifth forest levels. Based on palynological data (Jameossanaie and others, 1990), this locality is just higher than the Campanian-Maastrichtian boundary in the study area.

Almost due west of the infant locality, at about the same stratigraphic level, a microfossil site has yielded bone fragments of turtles, crocodile teeth (Plate III, Figure a), isolated hadrosaur teeth and dinosaur eggshell fragments. Once again, there is no doubt of the close proximity of the locality to the Cretaceous shoreline in the area.Still further to the west, a series of resistant structures have been excavated that we believe are empty dinosaur nests. These features are subcircular, about a meter across, buff colored and composed of a very silty sandstone. The structures are concave with margins composed of material that appears to have been scooped over the rim. Carbonized plant material occurs in layers in the feature. One of the excavated features contained a large coprolite. The features appear to be regularly and not randomly spaced; thin leaf accumulations are present between the features. No eggs or egg shell fragments have been found associated with these. These were the first dinosaur nests identified in the Southwest.

Away from the Fossil Forest, lower in the section and very near the Pictured Cliffs-Fruitland contact, Diane Bellis and I discovered intact dinosaur nests with eggs, quite by chance. We were actually sampling coaly beds for amber and bentonites; once again showing that in paleontology it is best to expected the unexpected. The eggs are generally elliptical, although some show deformation, five-seven inches in length (Plate III, Figure e). The surface of the eggs is not smooth but is rugose with isolated pimple-like ornamentation. Many nests occur in the area as do isolated logs and at least three levels of tree stumps.

These are the first dinosaur eggs and nests reported from the Southwest; the nests differ in size and shape from those in the Fossil Forest; they are smaller and more circular. We are uncertain of what taxon these eggs represent.

At about the same stratigraphic level, the first reported dinosaur footprints from the San Juan Basin are found (Wolberg, Hall and Bellis, 1988). The footprints are associated with near shore deposits; indeed the tracks trend towards the shoreline. The footprints are very large (Plate III, Figure d) and are of a hadrosaur.

TABLE 1.--MODERN FLORA OF THE FOSSIL FOREST

Cactaceae
- *Opuntia polyacantha* Haw.

Caprifoliaceae
- *Arenaria fendleri* Gray

Chenopodiaceae
- *Atriplex canescens* (Pursh.)
- *Atriplex confertifolia* (Torr. & Frem.)
- *Atriplex obovata*
- *Atriplex saccana*
- *Eurotia lanata* (Pursh.)
- *Kochia vestita* Wats
- *Salsola kali* L.
- *Sarcobatus vermiculatus* (Hook)
- *Suadea torreyana*

Compositae
- *Artemesia filifolia* Torr.
- *Artemisia tridentata* Nutt.
- *Chrysothamnus nasuseosus* Pursh,
- *Chrysothamnus viscidiflorus*
- *Gutierrezia sarothrae* (Pursh.)
- *Haplopappus tenuisectus* (Green)
- *Helianthus annus* L.
- *Lactuca pulchella* (Pursh.)
- *Platyschkuhria integrifolia* (Gray)
- *Stephanomeria pauciflora*
- *Townsendia incana* Hook
- *Xanthium strumarium* L.

Cruciferae
- *Arabis* sp.

Ephedraceae
- *Ephedra viridis* Coville

Gramineae
- *Agropyron smithii* Rydb.
- *Bouteloua gracilis* (HBK)
- *Bromus tectorum* L.
- *Hilaria jamesii* (Torr.)
- *Hordeum jubatum*
- *Muhlenbergia torreyi* (Kunth.)
- *Oryzopsis hymenoides* (Roem & Schult)
- *Sitanion hystrix* (Nutt.)
- *Sporobolus airoides* Torr.
- *Sporobolus giganteus* R. Br.

Hydrophyllaceae
- *Phacelia integrifolia* Torr.

Leguminosae
- *Astragalus ceramicus* Sheld.

- *Lupinus pusillus* Pursh.

Liliaceae
- *Allium macropetalum* Rydb.
- *Yucca glauca* Nutt.

Loasaceae
- *Mentzillia pumilia* L.

Malvaceae
- *Sphaeralcea parviflora* St. Hil.

Nyctaginaceae
- *Abronia fragans*

Ongraceae
- *Oenothera pumila* L.

Plantaginaceae
- *Plantago patagonica*

Polygonaceae
- *Eriogonum leptocladon* Torr.
- *Eriogonum rotundifolium* Benth.
- *Eriogonum salsuginosum* Hook
- *Rumex hymenosepalus* L.

Salicaceae
- *Populus fremonti* Wats.

Scrophulariaceae
- *Pentstemon angustufolius*

Solanaceae
- *Lycium pallidum* Miers

Tamaricaceae
- *Tamarix pendantra*

Umbelliferae
- *Cymopterus fendleri* Gray

TABLE 2.--FOSSIL PLANTS FOUND IN THE FOSSIL FOREST

- Filicophyta
  - Polypodiaceae
    - *Dryopteris cledophleboides* Knowlton
  - Equisetaceae
    - *Equisetum* sp.
- Coniferophyta
  - Araucariaceae
    - *Araucaria longifolia* (Lesquereux)
  - Taxodiaceae
    - *Taxodium*
    - *Sequoia* sp.
- Anthophyta
  - Monocotyledonae
    - Najadaceae
      - *Potamogeton* sp.
    - Nymphaceae
      - *Cabomba inermis* (Newberry)
    - Palmae
      - *Sabalites* sp.
      - sp. et gen. indet.
  - Dicotyledonae
    - Salicaceae
      - *Salix* sp.
      - *Populus* sp.
    - Fagaceae
      - *Dryophyllum subfalcatum* Lesquereux
    - Moraceae
      - *Ficus planticostata* Lesquereux
    - Polygonaceae
      - *Polygonum* sp.
      - *Rumex* sp.
    - Plantanaceae
      - *Plantanus raynoldsii*
    - Lauraceae
      - *Laurophyllum* sp.
    - Leguminosae
      - unidentified seed pod
    - Incertae sedis
      - Caprifoliaceae
        - *Viburnum antiquum* (Newberry)
    - Coniferales incertae sedis
        - *Podozamites sp.*

TABLE 3.--FOSSIL VERTEBRATES IDENTIFIED IN THE FOSSIL FOREST

Chondrichthyes
    Selachii
        Hybodontidae
            Lissodus sp.
    Batoidea
        Dasyatidae
            Myledaphus bipartitus
    Rajiformes
        Sclerorhynchidae
            Ischyrhiza avonicola
            Ptychotrygon sp.
Osteichthyes
    Amiiformes
        Amiidae
            New genus and species (Hall and Wolberg)
    Lepisosteiformes
        Lepisosteidae
            Lepisosteus sp.
    Elopiformes
        Phyllodontidae
            Paralbula casei
Amphibia
    Urodela
        Genus indet.
Reptilia
    Testudines
        Baenidae
            Baena sp.
        Dermatemydidae
            Adocus sp.
        Trionychidae
            Aspiderites sp.
            Trionyx sp.
Sauria
    Teiidae
        ?Chamops sp.
Crocodilia
    Goniopholidae
        Goniopholis sp.
    Crocodylidae
        Brachychampsa sp.
        Crocodylus sp.
Saurischia
    Theropoda
        Coeluridae
            Genus indet.
    Tyrannosauridae
        Albertosaurus sp.
    Sauropodomorpha
        Sauropoda
            Titanosauridae
                New genus and species

- Ornithischia
    - Ornithopoda
        - Hadrosauridae
            - Hadrosaurus navajovius
            - ?genus indet.
    - Ankylosauria
        - Ankylosauridae
            - genus indet.
    - Ceratopsia
        - Ceratopsidae
            - Pentaceratops cf. P. fenestratus
- Mammalia
    - Theria
        - Metatheria
            - Didelphidae
                - Didelphinae
                    - Alphadon halleyi
                    - A. parapraesaqus
                    - A. cf. A. wilsoni
                - Ectocentrocristinae
                    - Ectocentrocristus foxi
            - Pediomyidae
                - Pediomys fassetti
                - ?Pediomyidae indet.
                - Aquiladelphis paraminor
            - Stagodontidae
                - cf. Eodelphis
    - Eutheria
        - Insectivora
            - Leptictoidea
                - Leptictidae
                    - Gypsonictops clemensi
                    - G. cf. G. lewisi
            - Palaeoryctoidea
                - Palaeoryctidea
                    - Cimolestes lucasi
            - Erinaceoidea
                - Nyctitheriidae
                    - Paranyctoides cf. P. sternbergi

REFERENCES

Anderson, O. J., and Wolberg, D. L., 1987, The economics of coal production cycles in New Mexico: New Mexico Geology, v. 9, no., 3, pp. 45-49.

Baltensperger, A. A. and Maker, H. J., 1973, Soils of New Mexico: State University Agricultural Experiment Station, Research Report 285.

Bauer, C. M., 1916, Contributions to the geology and paleontology of San Juan County. 1. Stratigraphy of a part of the Chaco River valley: U. S. Geological Survey Professional Paper 98, pp. 271-278.

Bauer, C. M. and Reeside, J. B., 1920, Coal in the middle and eastern parts of San Juan County, New Mexico: U.S. Geological Survey, Bulletin 716, pp.155-237.

Bellis, D. and Wolberg, D. L., 1989, An unusual occurrence of the mineral Huntite from the Late Cretaceous, coal-bearing, Fruitland Formation, San Juan Basin, New Mexico, Geological Society of America, Annual Meetings, Combined Cordilleran-Rocky Mountain Section Spokane, Washington, Abstracts With Programs, V. 21, p. 173.

-----., and Wolberg, D. L., 1989, Geochemical signatures in a Late Cretaceous stratigraphic sequence from the San Juan Basin, New Mexico, (Abstract), Geological Society of America, Annual Meetings, Combined Cordilleran-Rocky Mountain Section, Spokane, Washington, Abstracts With Programs, V. 21. p. 104.

Chavez, W. X., and Wolberg, D. L., 1988, An innovative geological education program for secondary school science teachers. 100th Annual Meetings, Geological Society of America, Denver. Abstracts with Program, V. 20, p. 78.

Fassett, J.E. and Hinds, J.S., 1971, Geology and fuel resources of the Fruitland Formation and the Kirtland Shale of the San Juan Basin, New Mexico and Colorado: U. S. Geological Survey, Professional Paper 676, 76 p.

Flores, R. M. and Erpenbeck, M. F., 1982, Stratigraphic framework and coal correlation of the Upper Cretaceous Fruitland Formation, Bisti--Ah-shi-sle-pah area, San Juan Basin, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map, MF-1390.

Gabin, V. L. and Lesperance, L. E., 1977. New Mexico Climatological Data: W. K. Summers and Associates, Socorro, New Mexico, 367 p.

Gilmore, C. W., 1935, On the Reptilia of the Kirtland Formation of New Mexico, with descriptions of new species of fossil turtles: Proceedings of the United States National Museum, V. 83, No. 2978, pp. 159-188.

Gillette, D., Wolberg, D. L., and Hunt, A. P., 1986, Tyrannosaurus rex from Elephant Butte Reservoir, New Mexico Geological Society Guidebook 37th Field Conference, p.235-238.

Hall, J. P. and Wolberg, D. L., 1989, A new Cretaceous amiid from the Fruitland Formation, San Juan Basin, New Mexico: Journal of Paleontology, V. 63, no. 1, pp. 108-115.

-----., Wolberg, D. L., and West, S., 1988, Dinosaur-skin impressions from the Fruitland Formation (Campanian-Maastrichtian) of the Fossil Forest, San Juan Basin, San Juan County, New Mexico; in Wolberg, D. L., (ed.), Contributions to Late Cretaceous Paleontology and Stratigraphy: New Mexico Bureau of Mines and Mineral Resources, Bulletin 122, pp. 7-21.

Hartman, J.H., 1981, Mollusca from the Upper Cretaceous Fruitland and Kirtland Formations western San Juan Basin, New Mexico: American Association of Petroleum Geologists, Bulletin, V. 92, no. 3, p. 560.

Himes, E., 1989, A soil analysis of the Fossil Forest. Report to D. L. Wolberg, 15 p.

Hunt, C.B., 1956, Cenozoic geology of the Colorado Plateau: U. S. Geological Survey, Professional Paper 279, 99 p.

Hunt, A. P., 1984, Stratigraphy, sedimentology, taphonomy and magnetostratigraphy of the Fossil Forest area, San Juan County, New Mexico: Unpublished MS thesis, New Mexico Institute of Mining and Technology, 338p.

-----., 1991, Integrated vertebrate, invertebrate and plant taphonomy of the Fossil Forest area (Fruitland and Kirtland formations: Late Cretaceous), San Juan County, New Mexico, USA, Palaeogeography, Palaeoclimatology, Palaeoecology, 88:85-107.

Keetch, C. W., 1977, Soil survey of San Juan County: U. S. Department of Agriculture.

Kues, B. S., Froelich, J. W., Schiebout, J. A., and Lucas, S. G., 1977, Paleontological survey, resource assessment, and mitigation plan for the Bisti-Star Lake area, northwestern New Mexico: U.S. Bureau of Land Management, Albuquerque District Office, 398 p.

Lozinsky, R. P., Wolberg, D. L., Hunt, A. P., and Lucas, S. G., 1984. Late Cretaceous dinosaurs from the McRae Formation, south-central New Mexico: New Mexico Geology, 6:72-77.

Maker, H. J. and Keetch, C. W., 1973, Soil associations and land classification for irrigation, San Juan County: New Mexico State University Agricultural Experiment Station, Research Report 257.

O'Sullivan, R. B., Mytton, J. W., Strobell, J. D., Scott, G. R. and Erpenbeck, M. F., 1986, Preliminary geologic map of the Tanner Lake Quadrangle, San Juan County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies, Map MF-1864, 1:24,000.

Reeside, J. B., Jr., 1924, Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin Colorado and New Mexico: U. S. Geological Survey, Professional Paper 134, 70 p.

Rigby, J. K. and Wolberg, D. L., 1987, The therian mammalian fauna (Campanian) of Quarry 1, Fossil Forest study area, San Juan Basin, New Mexico; in Fassett, J. E. and Rigby, J. K., Jr., (eds.), The Cretaceous-Tertiary boundary in the San Juan and Raton basins, New Mexico and Colorado: Geological Survey of America, Special Paper 209, pp. 51-80.

Shaler, M. K., 1906, A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geological Survey, Bulletin 316, pp. 376-426.

Smith, L. N., 1983, Quaternary history and fluvial evolution of some tributary drainage basins north of the Chaco River; in Wells, S. G., Love, D. W. and Gardner, T. W., (eds.), Chaco Canyon country: American Geomorphological 1983 Field Group Field Trip Guidebook, pp.149-158.

Sternberg, C. H., 1932, Hunting dinosaurs in the bad lands of the Red Deer River Alberta Canada: privately published, 261p.

Storrs, L. S., 1902, The Rocky Mountain coal fields: U. S. Geological Survey, Twenty-second Annual Report, pp. 421-472.

Strobell, J. D. Jr., O'Sullivan, R. B., Mytton, J. W., and Erpenbeck, M. F., 1985, Preliminary geologic map of the Pretty Rock Quadrangle, San Juan County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies Map, MF-1788, 1:24,000.

Wells, S. G., 1983, Regional badland development and a model of late Quaternary evolution of badland watersheds, San Juan Basin, New Mexico; in Wells, S. G., Love, D. W., and Gardner, T. W., (eds.), Chaco Canyon country: American Geomorphical Field Group 1983 Field Trip Guidebook, pp. 121-132.

Wolberg, D. L., 1989, The mineral huntite, an unusual occurrence from the Fossil Forest, Late Cretaceous, Fruitland Formation, San Juan Basin, New Mexico, New Mexico Geological Society, Annual Meeting, Abstracts With Program.

-----., and Chavez, W. X., 1993, Teaching paleontology to science teachers; a report from the San Juan Basin of New Mexico, Geological Society of America Abstracts with Programs, 25:231.

-----., and Rigby, J. K., Jr., 1981, Paleontology of the "Fossil Forest"; an interesting late Cretaceous fossil assemblage, San Juan Basin, New Mexico (abstract): American Association of Petroleum Geologists Bulletin, v. 65, p.582.

-----., Bellis, D., Austin, G. S., Domski, P., Stratigraphy and biogeochemistry of the Fossil Forest sedimentary sequence, Late Cretaceous, San Juan Basin, New Mexico; implications for depositional environments, Geological Society of America, Annual Meetings, Combined Cordilleran/Rocky Mountain Section, Spokane, Washington, Abstracts With Programs, 21:64.

-----., Hall, J. P. and Bellis, D., 1988, First record of dinosaur footprints from the Fruitland Formation, San Juan Basin, San Juan County, New Mexico; in Wolberg, D. L., (ed.), Contributions to Late Cretaceous paleontology and stratigraphy of New Mexico, Part III: New Mexico Bureau of Mines and Mineral Resources, Bulletin 122, pp. 33-34.

-----., Hall, J. P., Bellis, D., Chavez, W. X., Anderson, O., Moro, R. and Gil, A., 1988, Regional historic, stratigraphic, and paleontologic framework of the Late

Cretaceous (Campanian-Maastrichtian) Fossil Forest locality near Split Lip Flats, San Juan Basin, San Juan County, New Mexico; in Wolberg, D. L. (ed.), Contributions to Late Cretaceous paleontology and stratigraphy of New Mexico, Part III: New Mexico Bureau of Mines and Mineral Resources Bulletin 122, 60 p.

-----., Hunt, A. P., Rigby, J. K., Jr., and Menack, J., 1981, Geology and stratigraphy of a late Cretaceous "Fossil Forest" near Split Lip Flats, San Juan Basin, New Mexico (abstract): American Association of Petroleum Geologists Bulletin, v. 65, p. 574.

-----., Lozinsky, R., and Hunt, A. P., 1986, Late Cretaceous stratigraphy and paleontology of the McRae Formation, Sierra County, New Mexico: New Mexico Geological Society Guidebook 37th Field Conference, p.227-234.

-----., West, S., Hall, J. P., and Zidek, J., 1988, Probable caddisfly (Trichoptera: Insecta) larval cases from the Fruitland Formation (Campanian-Maastrichtian) of the Fossil Forest, San Juan Basin, San Juan County, New Mexico; in Wolberg, D.L., (ed.), Contributions to Late Cretaceous paleontology and stratigraphy of New Mexico, Part III: New Mexico Bureau of Mines and Mineral Resources, Bulletin 122, pp. 29-31.

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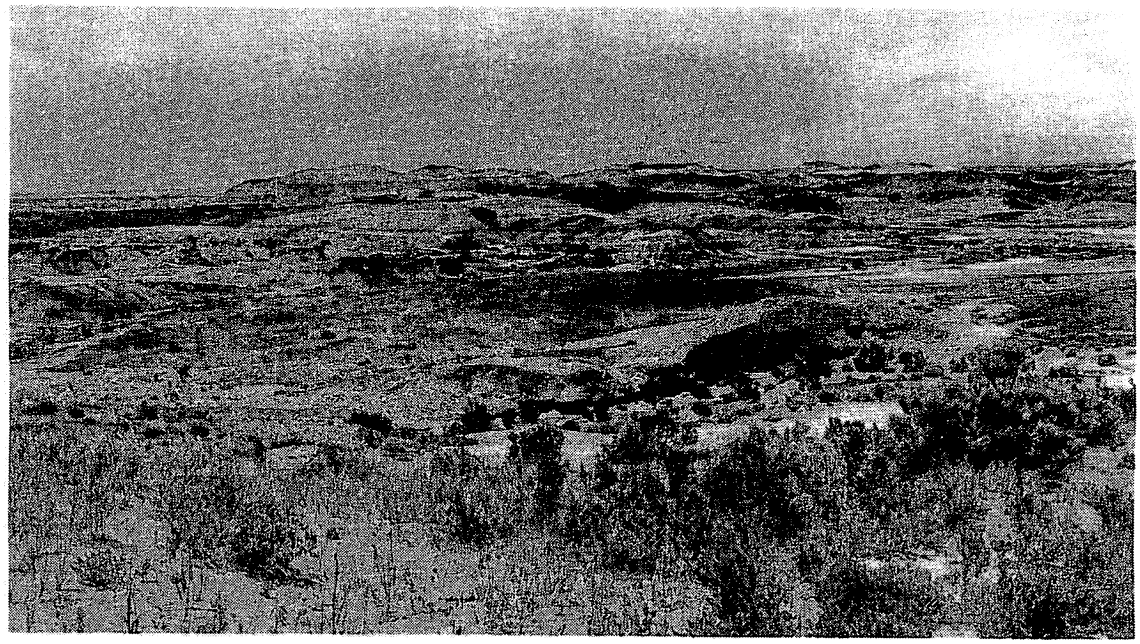
PLATE I.--

Figure a. The Fossil Forest Study Area. A view looking just East of North, east of the north-south fence line, from a poorly stabilized sand dune. A coal bed that has been faulted up, is seen in the wash in the foreground. The expanse badlands consisting of interbedded siltstones, sandstones and mudstones, are well developed. The rim of outcrops at the horizon is approximately a mile from the dune.

Figure b. Fossil log; this log originally extended intact to the petrified wood rubble in the foreground. Logs weather relatively rapidly once exposed. Note that the log has been flattened. Many logs have orientations that have a NW-SE orientation. This logs is withing the area known as the "Main Stump Field."

Figure c. Fossil tree stump preserved in the Fossil Forest. This is one of more than 400 stumps that we have mapped. Note that the tree is in place. The roots extend downward through a mudstone and suiltstone. Also note the large amount of petrified wood debris associated with the stump. The dark, thin band behind the people is the carbonaceous shale marker bed that can be traced throughout the area.



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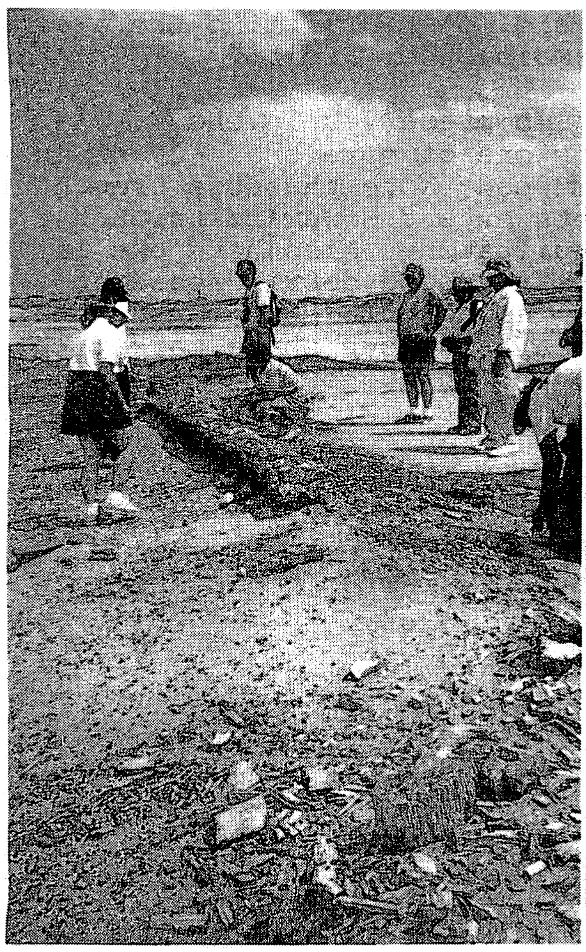

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Plate I

PLATE II.-- FOSSIL PLANTS FROM THE FOSSIL FOREST STUDY AREA

Figure a. Ferns from the plant rich-she parting at the lowest coal.

Figure b. Sequoia cone; one of several cones discovered in the Fossil Forest. Perhaps three different gymnosperms are represented.

Figure c. Block with willow, (Salix), leaves and plant debris. Scale in millimeters.

Figure d. "Ficus" leaf. Scale in millimeters.

Figure e. Large palm (Sabalites) fronds (two overlapping fronds are show) being uncovered in a silty mudstone.

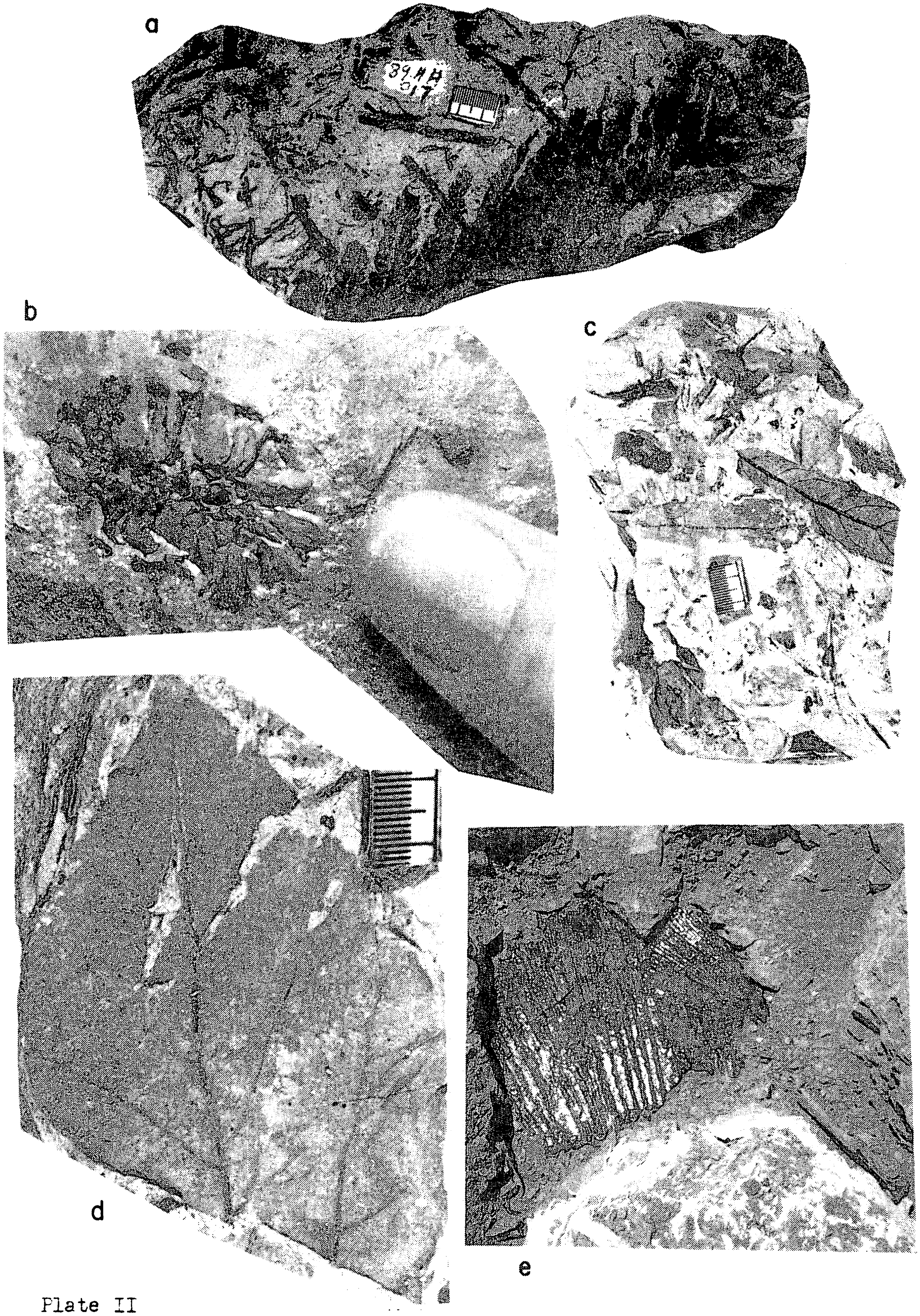

Plate II

PLATE III.--

Figure a. Single, almost complete crocodilian tooth.

Figure b. Almost complete infant hadrosaur jaw with teeth; external view.

Figure c. Dorsal view of infant jaw. Millimeter scale. The crocodile tooth (a) and the infant jaw are shown at the same scale.

Figure d. Very large hadrosaur footprint, located near the Bisti Badlands; the print is almost a meter in diameter. This is the first dinosaur footprint reported from New Mexico.

Figure e. First dinosaur eggs discovered in the Southwest. A series of nests were discovered, most with eggs. These eggs are small and resemble reported ceratopsian eggs.

Figure f. Incomplete multituberculate femur from the Fossil Forest Study Area. The scale shown is 5 mm between the bars. This is the first Cretaceous mammalian postcranial bone reported in the Southwest.

Figure g. Dromaeosaur tooth, most resembling Troodon; note the prominent serations. The scale represents 5 mm between the bars.

Figure h. Ceratopsian tooth; scale represents 10 mm between the bars.

Figure i. Lateral view of a marsupial left molar. Note the prominent cusps and roots.

Figure j. Lateral view of multituberculate tooth, a "blade," thought to be a premolar. The tooth has prominent serations. The scale is in millimeters and both (i) and (j) are at the same scale.

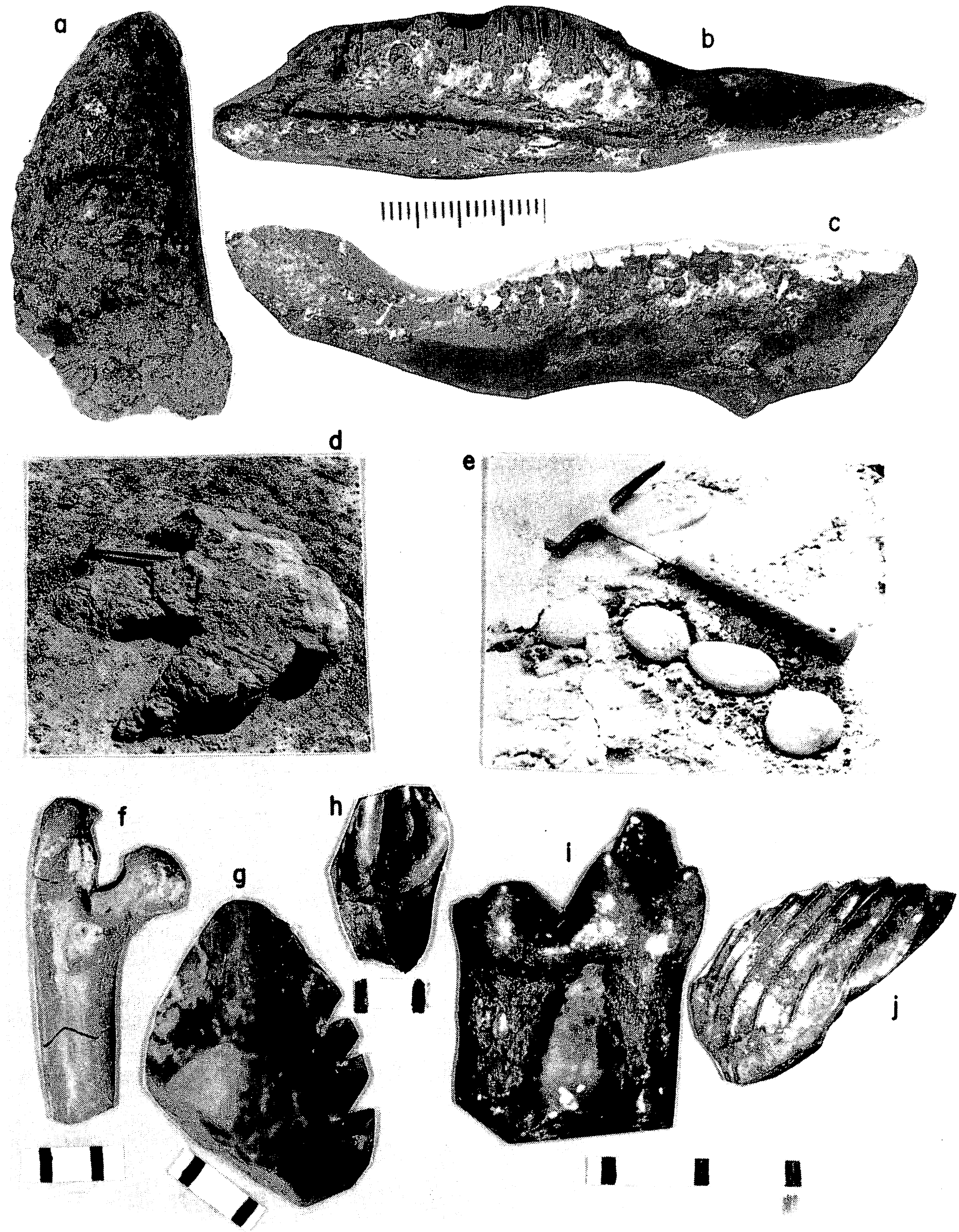

Plate III

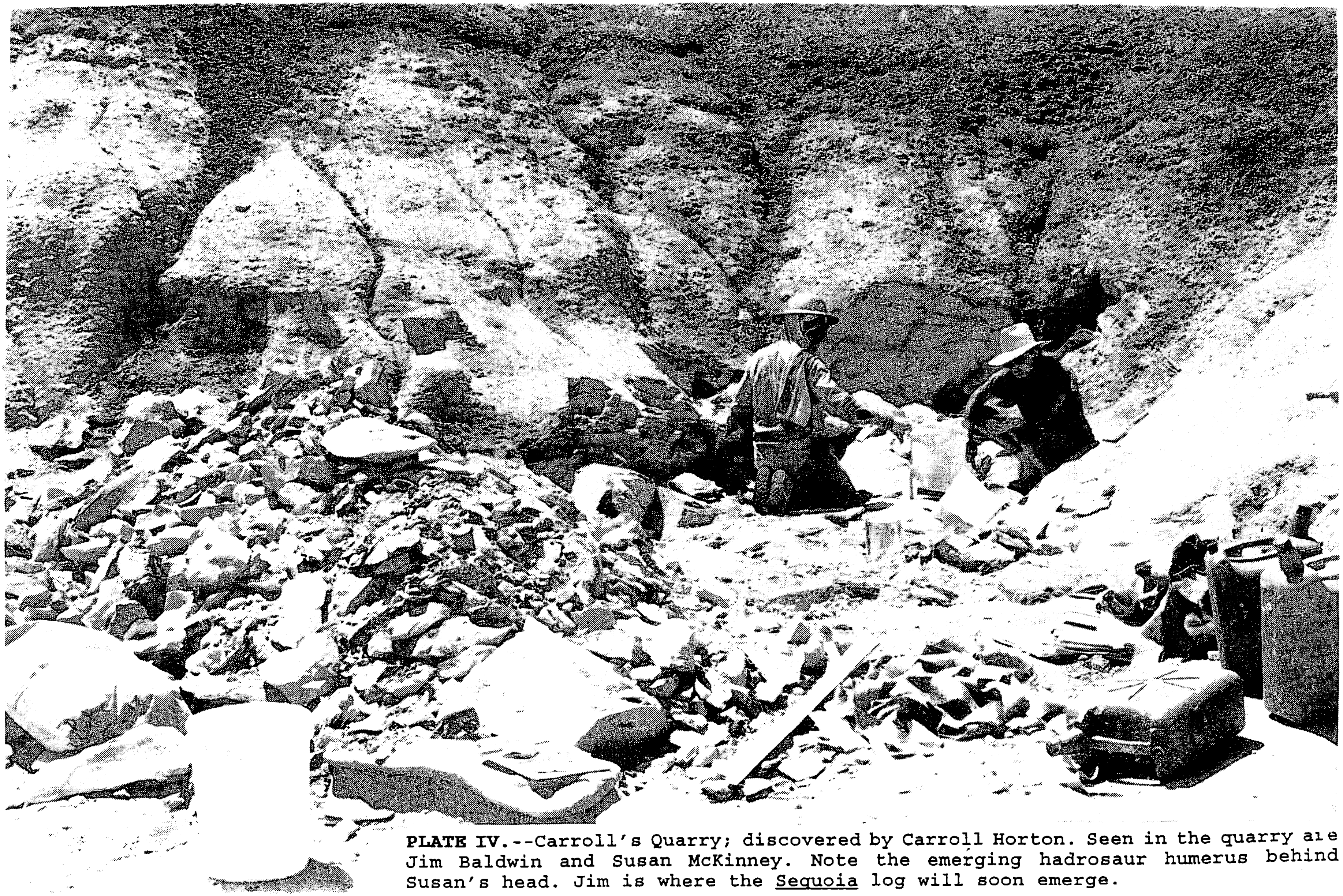

PLATE IV.--Carroll's Quarry; discovered by Carroll Horton. Seen in the quarry are Jim Baldwin and Susan McKinney. Note the emerging hadrosaur humerus behind Susan's head. Jim is where the <u>Sequoia</u> log will soon emerge.

PLATE V.--

Figures
a, d. Slightly polished composite photomicrograph (x6) of dinosaur (a). The skin was found at Carroll's Quarry, above the very large hadrosaur skeleton. There are several layers of skin folded over each other. Note the prominent squamation preserved in section on top. It is likely that organic material is preserved. One of the actual specimens is shown in Figure d (x.8), drawn by Vivian Olsen. This is the first dinosaur skin reported from the Southwest.

Figures
b, c. Lateral and dorsal views of a complete larval case of a caddisfly (Trichoptera) from the Fossil Forest (x8). Caddisflies have an aquatic larval stage. This specimen was recovered from fill material found in a rotted our fossil stump. This is the first insect material recovered from the Cretaceous in the Southwest.

Figure e. Clam bed in Fossil Forest; the clams are freshater unionids. Several taxa are present. Most of the shells have both valves present, most still closed. Relatively thick clam beds occur at several sites in the Fossil Forest. At some of these, vertebrate remains such as isolated garfish scales, bone fragments and teeth also occur.

Figure f. Dinosaur coprolite. Coprolites, although uncommon in the Fossil Forest, are not rare. These frequently contain organic material. Probable crocodilian and shark coprolites also occur.

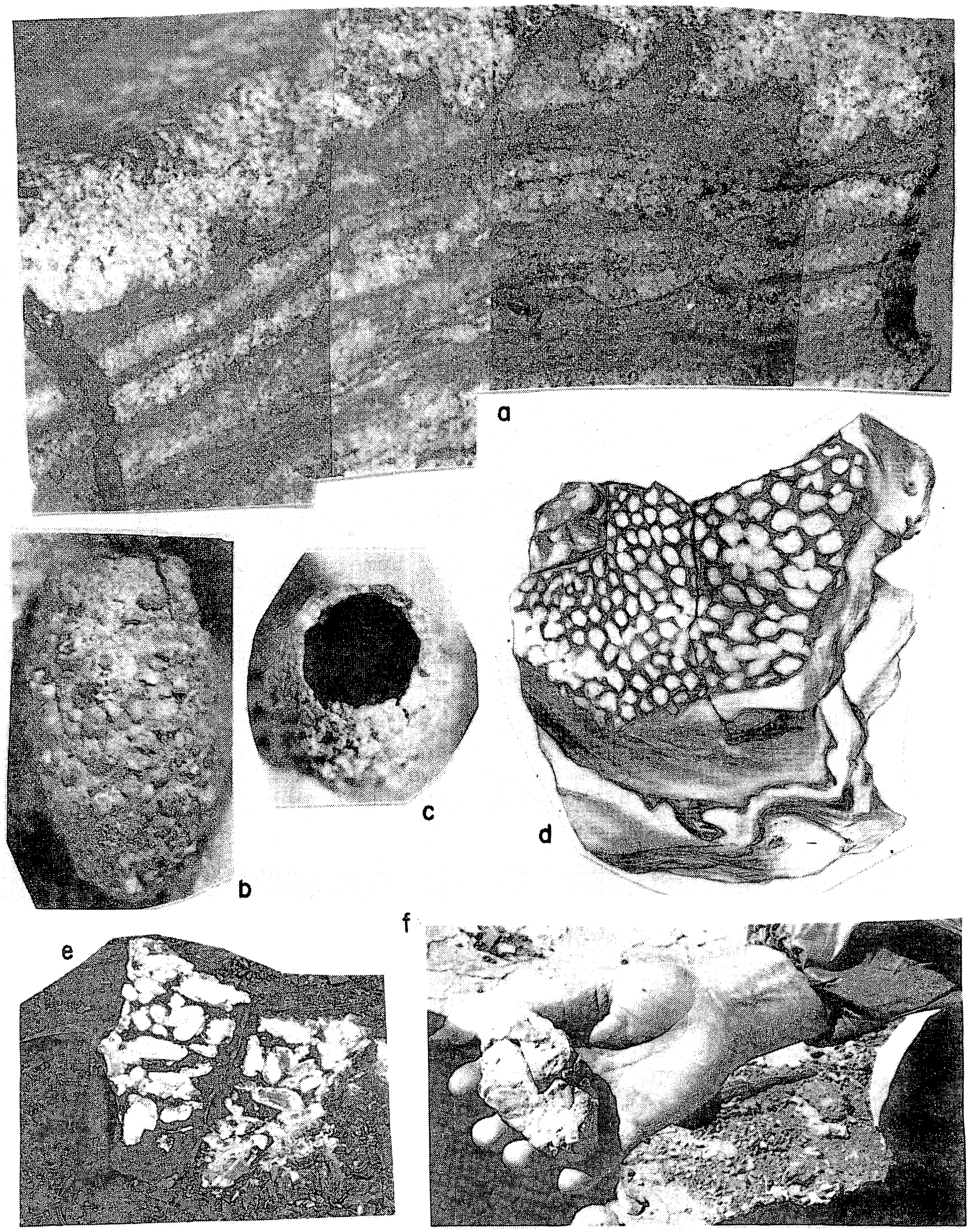

Plate V

PLATE VI.--

Figure a. Hadrosaur humerus from the Fossil Forest; the hammer handle is about 12 in. in length. The matrix in which the fossil was found is extremely hard and concrete-like.

Figure b. Amy Allison, from San Antonio, Texas, one of our science teacher-graduate students, is preparing a hadrosaur fibula. She is using a high speed Dremel tool to remove matrix from the surface of the specimen/ If required, Glyptol diluted in acetone is applied as a consolidating agent.

Figure c. Elvert Himes, from Farmington, New Mexico, another of our science teacher-graduate students applying plaster bandages to a very large hadrosaur humerus in Carroll's Quarry. Note the wood bracing also used to support the specimen. The specimen, when transported, weighed about 300 pounds; it had to be carried almost one-half mile, the closest we could get the trucks.

Figures d,e. external (d) and internal (e) views of a ceratopsian lower jaw (x.25). Note that although well preserved the jaw lacks teeth.

Figure f. Plant fossil, Sequoia, preserved in Carroll's Quarry, as a halo around the log. The specimen is shown at actual size. Most of the quarry consists of an indurated siltsone. However, the matrix around the tree is a relatively fine siltstone, at times a mudstone.

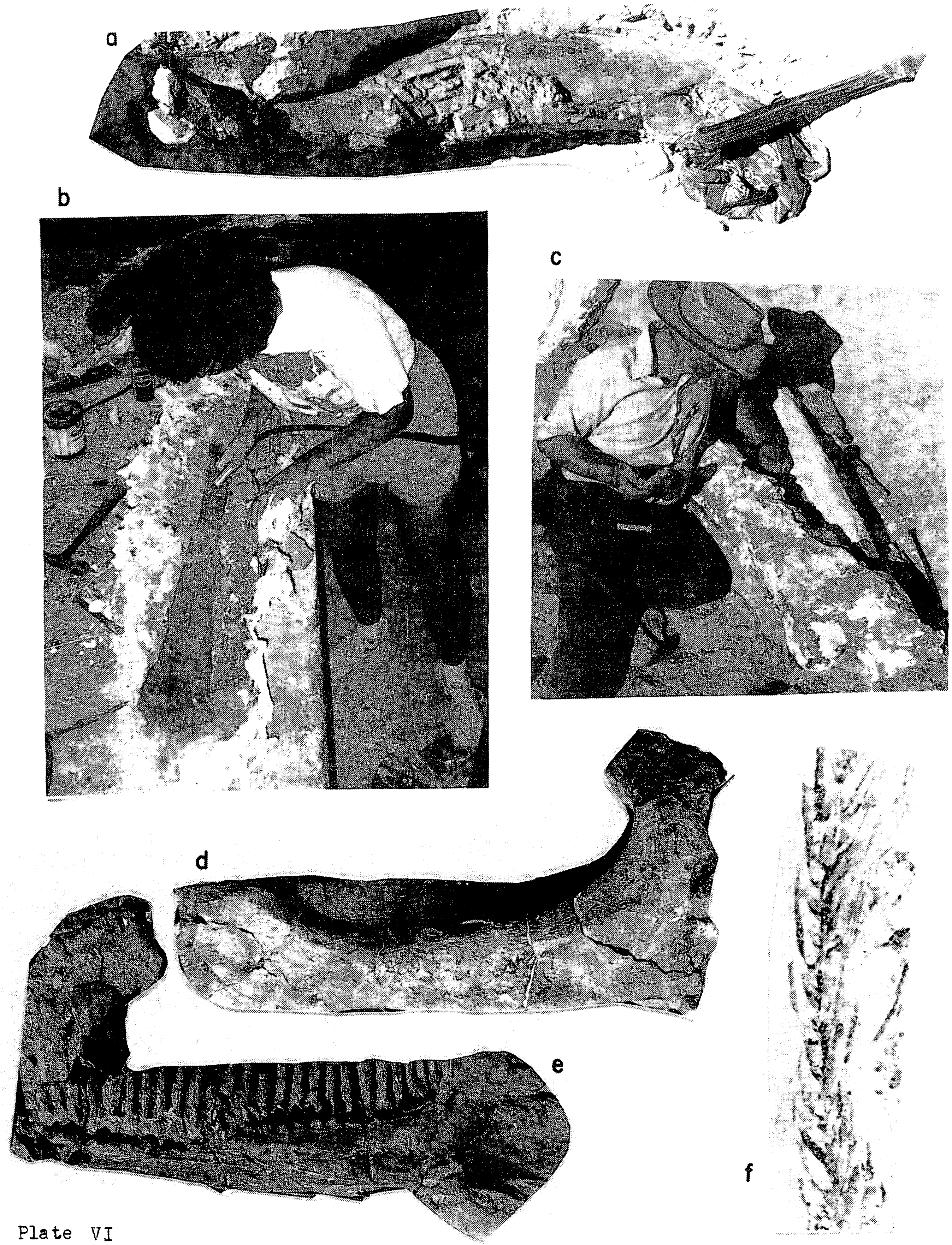

Plate VI

THE PALEONTOLOGIST AS DETECTIVE AND HISTORIAN; AN EXAMPLE FROM THE SAN JUAN BASIN OF NEW MEXICO

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INTRODUCTION

Paleontology is concerned with the collection and study of fossils. However, there is often a historical dimension to fossil collecting that is neglected entirely or briefly glossed over. In places where fossil collecting has been going on for a long period of time, although not necessarily continuously, the historic background to that collecting can be of great interest and importance in unraveling the story of collecting in the area. Who collected what, where and when and what became of the material are important questions. The presence of a series of quarries that predated our own work in the Fossil Forest Study Area of northwestern New Mexico prompted the historical excursion that follows and we were finally able to understand their context and also provide locality data for fossils, including type specimens, in museums for decades.

The Fossil Forest Study Area is located south of Farmington, New Mexico, the major population and commercial center in northwestern New Mexico, and north of Chaco Canyon, a major, world class archeological center (Figure 1). Access to the region is via NM 370 on the west or NM 44 on the east. County Road 7500 crosses an area known as Split Lip Flats, a colorful and at time appropriate name with some age. The Fossil Forest study area is located in portions of secs 13, 14, 22, 23, 24 and 26 T23N R12W (Figure 2) and is included on the U. S. Geological Survey 1:24,000 Pretty Rock Quadrangle topographic map. The NE 1/4, sec. 14 and the N 1/2 sec 13 consist of private land. The s 1/2 sec 13 is State of New Mexico land. The area has been designated a Research Natural Area by the U. S. Bureau of Land Management (Wilderness Act of 1984); access and collecting for any reason is restricted. In theory, the area is patrolled by BLM personnel. A substantial portion of the 2770 acres included within the Fossil Forest Study area has little or no geologic interest but were included as a buffer around fossil-containing areas.

The area takes its name from the presence of numerous in situ fossil tree stumps that occur at five stratigraphic levels in the exposed strata. The badlands exposed in the Fossil Forest consist largely of Fruitland Formation coals, shales, mudstones and sandstones that represent the upperpart of the Fruitland.

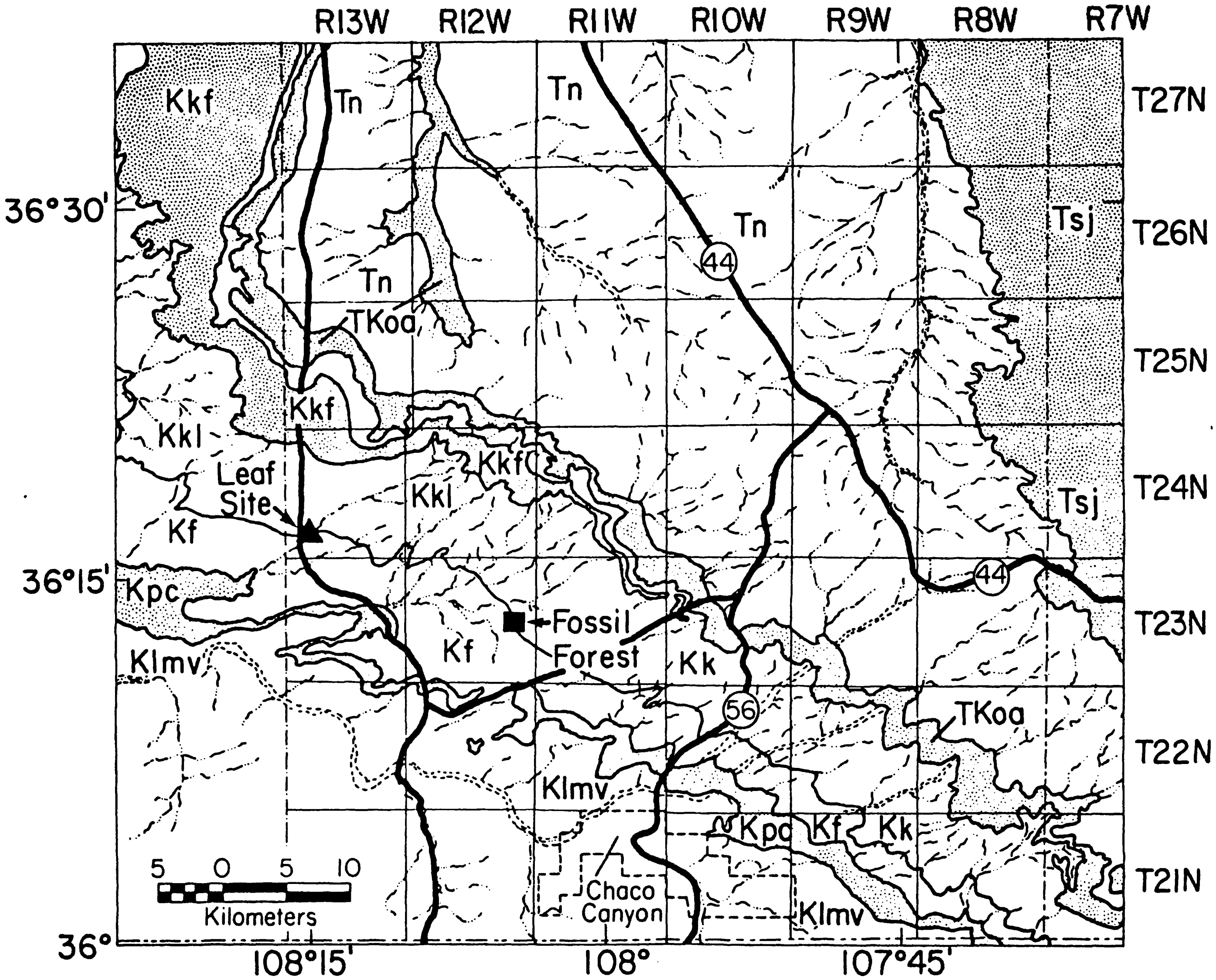

FIGURE 1.--Index and geologic map of the Fossil Forest Study Area in relation to major landmarks. The fossil leaf locality of Robison, Wolberg and Hunt (1982) in the Bisti Badlands is also shown. Abbreviations of rock units from highest to lowest are: Tsj, San Jose Formation (Eocene); Tn, Nacimiento (Paleocene); TKoa, Ojo Alamo (variously Cretaceous or Paleocene); KkF, Farmington Sandstone Member of the Kirtland Shale; Kkl, lower shale member of the Kirtland Shale; Kk, undifferentiated Kirtland Shale; Kf, Fruitland Formation; Kpc, Pictured Cliffs Sandstone; Klmv, undifferentiated Lewis Shale and Mesaverde Group. (After Wolberg and others, 1988) .

Isolated and thin remnants of the overlying Kirtland Shale occur in the study area. Fossil leaf, invertebrate and vertebrate localities are restricted to the middle portions of the stratigraphic sequence in the Fossil Forest, above the highest coal and below the highest sandstone sequence.

The Fossil Forest lies at an altitude of between 5980 ft and 6100 ft and is drained by Coal Creek and its tributaries, eventually joining the De-na-zin drainage to the southwest. De-na-zin is a name derived from the Navajo term, deli naazini, referring to Navajo pictoglyphs found about 2 mi east of Tanner Lake (York, 1984). Historically, De-na-zin Wash was known to local residents and paleontologists as Coal Creek. A northeastern tributary of Coal Creek, was previously known as Barrel Springs Arroyo, a name that fell out of favor during the late 1920's except among paleontologists. The name De-na-zin replaced Coal Creek for the main Chaco tributary, and Coal Creek replaced Barrel Springs and is now used as the name of the main De-na-zin tributary.

HISTORY OF THE REGION

In 1868, General William Tecumseh Sherman visited the Bosque Redondo in eastern New Mexico, bear Fort Sumner, where Mescalero Apaches and Navajos, traditional rivals had been sequestered since 1864 Their internment at Bosque Redondo followed the devastating campaign against them and the Apaches led by Kit Carson. Some 8,000 Navajos were at the camp, approximately three-quarters of the Navajo population at the time. Sherman visited Bosque as part of a Indian peace commission authorized by Congress. Even the battle tested Sherman was appalled by the conditions of the Indians. A treaty of peace was signed by the Indians and the commissioners and the Navajos were allowed to return to their homelands (Josephy, 1991).

At some time shortly after the return, probably in the early 1870's, a Navajo band was camped on Split Lip Flats at the confluence of Coal Creek and De-na-zin Wash, near the Fossil Forest. They were attacked and many were massacred by a large force of Indians, possibly including Utes, Apaches, Jemez and Taos (Carroll, 1983). York (1984) spoke to two residents of Lake Valley, south of Coal Creek, who were relatives of survivors of the raid. These people told York that the Navajos had established a settlement at the Coal Creek-De-na-zin confluence and that the raiders were Beehai (Jicarilla Apaches). The raiders killed all the men and scalped many of them. Women and children were taken as captives, as well as horses and sheep. Incredibly, some of the captives were sold as slaves.

At some time around 1878, the De-na-zin (Tiz-na-tzin) Trading Post was built on Coal Creek (Carroll, 1983). The trading post, "was first operated by Old Man Swires, of whom practically nothing is known," (McNitt, 1962, p.339). By 1895, this trading post was incorporated into a chain of eight trading

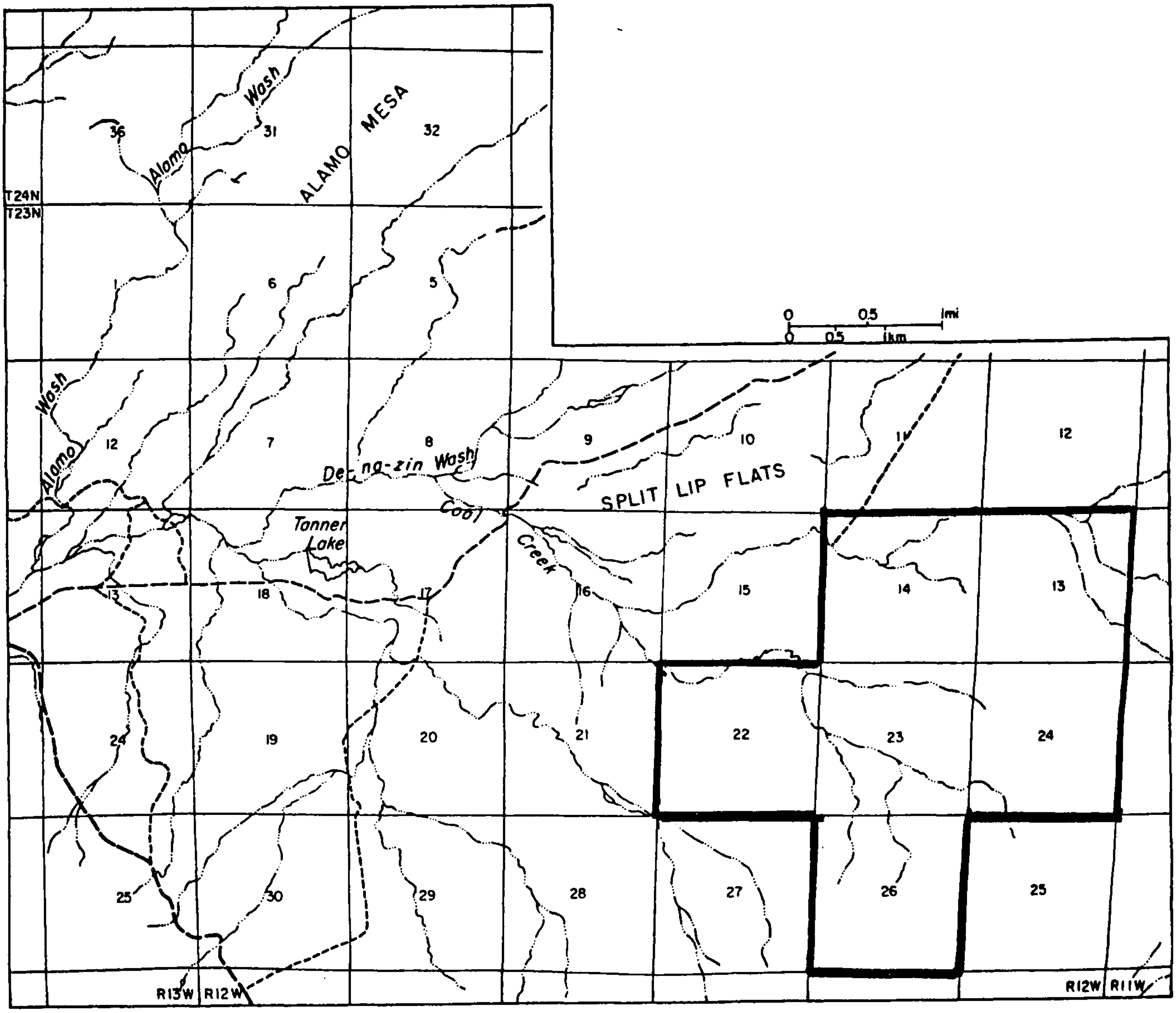

FIGURE 2.--Detailed location map of the Fossil Forest Study Area, outlined in heavy black.

posts (Figure 3) operated by the Hyde Exploring Expedition, a project that developed between Richard Wetherill and Talbot and Frederick Hyde, and which financed archeological collection at Grand Gulch, Utah and Pueblo Bonito, in Chaco Canyon (Brugge, 1980). The Hydes inherited their wealth from their grandfather, Benjamin Babbitt and the Babbitt Soap Company (York, 1984).

York (1984) places the De-na-zin Trading Post on De-na-zin Wash, proper, six miles west of Tanner Lake. Shortly after its incorporation into the Hyde trading post network, the store was abandoned before being rebuilt and operated for a time by Harvey Shawver, who had also rebuilt the Tsaya Trading Post, described below. After Shawver, the store was finally operated by Bert McJunkins (McNitt, 1962). Thus, by 1920, the De-na-zin Trading Post had changed hands several times and was finally deserted and in ruins (Brugge, 1980; Bauer and Reeside, 1920).

Of some interest is the fact that a coal mine was developed at the De-na-Zin Trading Post, exploiting the surface and shallow coals present. Shaler (1906) called these coals Mesaverde, and this view is supported by Bauer and Reeside (1920, Plate XXXI). Shaler notes that the coal workings had been opened in 1901 and that a slope had been driven about 25 feet before being subsequently abandoned. The surface workings were apparently still ongoing as of 1906. There is a problem, however, if York's (1984) siting of the De-na-zin Trading Post is accurate; this area is mapped as Lewis Shale overlain by Pictured Cliffs Sandstone (O'Sullivan et al, 1986). Yet, we know that coal was mined at the trading post; Shaler (1906) describes a measured section, and Bauer and Reeside (1920) show the by then abandoned ruins at the site to lie within their Mesaverde outcrop belt and also describe a measured section of Mesaverde coal at the Tiznatzin mine, which must have been abandoned at the time. Bauer (1916) does show the area as lying on the Lewis-Mesaverde contact, as does Reeside (1924). The upper 30 ft of sand described by Shaler (1906) must then represent the Cliff House Sandstone and the most parsimonious explanation is that O'Sullivan, et al (1986) simply mapped the area incorrectly. The coal mined at the trading post must have been Menefee coal, using current terminology.

By 1898, Wetherill had established a trading post at Pueblo Bonito (Figure 3). Pueblo Bonito and the store assume some importance, as will be discussed below, because it was also the site of Putnam and the reference point for citations of fossil and other occurrences in the area (Foster, 1913). Putnam was actually the name of the U. S. Post Office established at Pueblo Bonito, and was named for Dr. Frederick W. Putnam, an archeologist from the American Museum of Natural History (Brugge, 1980). The Pueblo Bonito or Putnam Trading Post functioned sporadically until the late 1950's or 1960's (York, 1984). However, Brugge (1980) notes that by 1915, the trading post at Putnam was closed. The name Putnam appears on Schrader's (1905) map and Shaler's (1906) map, not Pueblo Bonito. The name, "Pueblo Bonito (Putnam)" appears on Bauer and Reeside's (1920) map. Pierce (1965) notes that Putnam was a U. S. Post Office during the 1901-1911 period.

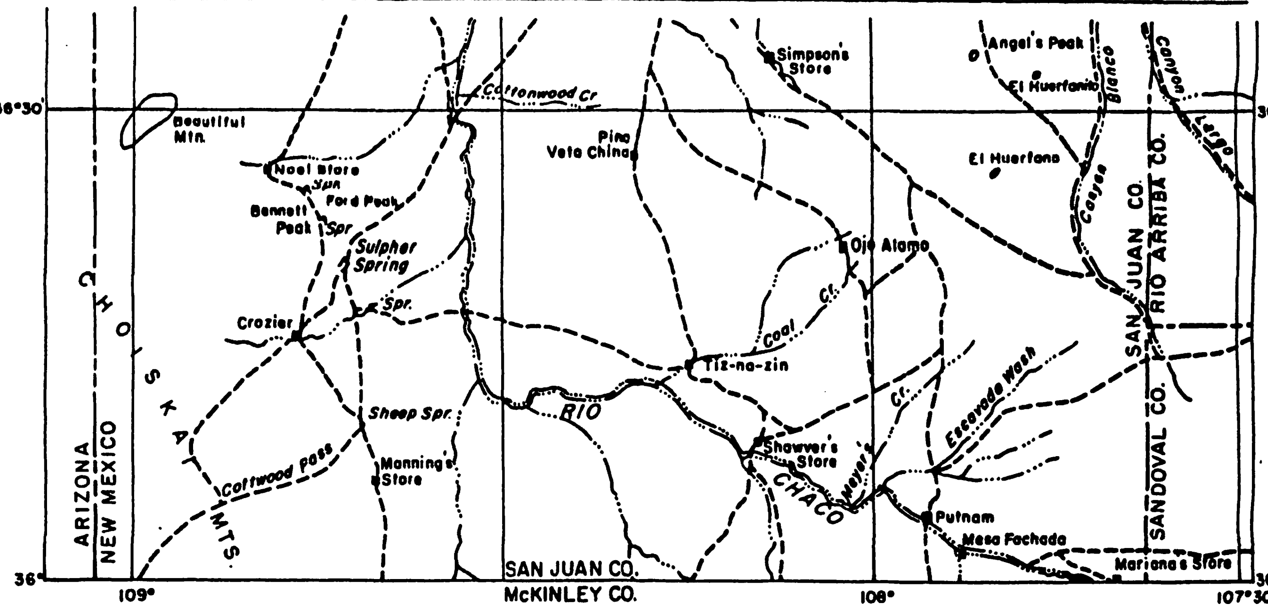

FIGURE 3.--Location map of trading posts and roads/trails existing at about 1900 (after Shaler, 1906).

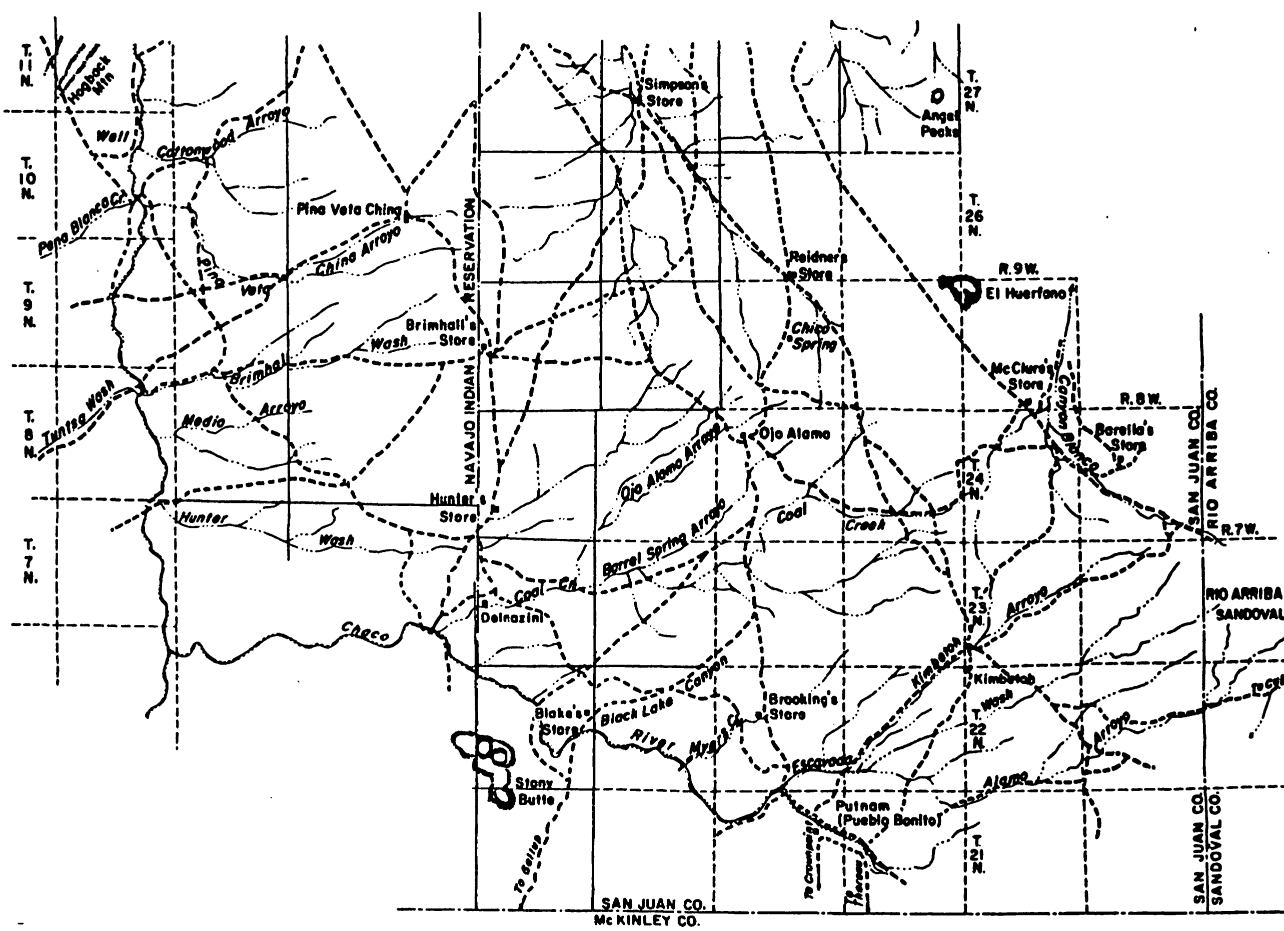

FIGURE 4.--Location map of trading posts and roads/trail existing just after World War I (after Bauer and Reeside, 1920).

The Bisti Trading Post was sited on the north side of Hunter Wash, just east of a Navajo missionary center built rather late in the history of the trading store. Once on the main N-S unpaved county road, the area is now east of paved NM 371. The date of the establishment of the trading post is uncertain but has been suggested to be about 1900-1901 (McNitt, 1962; York, 1984) and by a man named Hunter (Figure 4). This early date for establishment of the trading post is probably in error. In point of fact, a man named D. H. Hunter operated a trading post west of Shiprock in 1918 (Brugge, 1980), while Billy Hunter built and operated a trading post at Beclabito, near the Carrizo Mountains at about the same time (McNitt, 1962). Apparently, the Hunter who built and first operated the trading post at Bisti also ran cattle in the area (York, 1984).

Importantly, however, Hunter's Store does not appear on Schrader's (1905) or Shaler's (1906) maps of the area, and it is very probable that the trading post at Bisti had not yet been established. Hunter's Store first appears on Bauer's (1916) map, and is shown again on maps by Bauer and Reeside (1920) and Reeside (1924). Hunter's Store had a long list of owners until it was destroyed by fire in 1971; the ruins of the store were finally bulldozed in 1981. At one time, the store was part of the network of twenty trading posts owned or operated by the Foutz family as part of the Progressive Mercantile Company (McNitt, 1962). The store was also owned by the Ashcroft family of Kirtland and Tsaysa (York, 1984), a name that also emerges when considering the history of the Fossil Forest. The present trading post at Tsaysa is still operated by the Ashcroft family.

The Ojo Alamo Trading Post was located on a major N-S wagon road at the head of Alamo Wash opened in the 1890's, and by 1900 was incorporated into the chain of Hyde Exploring Expedition stores. A brother of Richard Wetherill, John, operated the store with his wife Louise but probably had abandoned it by 1906. The store was then reopened by 1909 by Joe Hatch and O. S. Thurston (Brugge, 1980). The store was deserted by 1921, a fact noted by Sternberg (1932), who collected in the area that year and only found an empty building.

Brugge (1980) and York (1984) note that Royal Davis operated the Ojo Alamo store as late as 1917. However, they probably confused the Ojo Alamo store with the Davis Store to the northwest of Ojo Alamo. The site of the Davis Store does not appear on any map until Reeside (1924). Brugge and York were dependent on Bauer and Reeside's map of 1920. Sternberg (1932) makes a clear distinction between the old abandoned Ojo Alamo store and the Royal Davis Store, which he knew about and visited in 1921.

Tsaya Trading Post, named for Tsaya Canyon on current maps, has an interesting and important history as well. Originally, Tsaya Canyon was named Black Lake Canyon and takes its current name from the Navajo, Tsaya-chas-kesi, or, "Dark under the rock," which according to McNitt (1962) refers to a shaded spring near the old Tsaya Trading Post. However, as will be developed below, the Navajo term may actually refer to an unusual geologic deposit of uncertain composition and origin noted by Foster (1913), Bauer and Reeside (1920) and York (1984). This material has long been used for ritualistic and possibly medicinal purposes by the Navajo people.

The old Tsaya Trading Post situated at the southwestern mouth of Black Lake Canyon, and northeast of the Chaco, was among the oldest of the regions trading posts. The clearest clue to its origin can actually be found in an inscription carved in a cliff wall immediately north of Pueblo Bonito, an early form of advertisement, which indicates that the store was operated in 1887 by H. L. Haines. In 1895, Richard Wetherill led a family named Palmer to Pueblo Bonito, and the old Tsaya Trading Post was on their route; they found the store abandoned (Brugge, 1980) and in ruins, and what became of Haines is unknown.

In 1906, Harvey Shawver rebuilt the trading post and eventually took George Blake on as a partner. In 1910, Shawver sold his interest to George's brother, Albert (McNitt, 1962). The old Tsaya store operated until 1961 (York, 1984). Interestingly, Sternberg (1932) notes hiring a Navajo field assistant at Pueblo Bonito in 1921 named, "Ned Shouver."

Shaler's map (1906) shows Shawver's Store, and by 1916, Bauer's map shows Blake's Store. In 1918, Roy Burnham purchased the store from the Blake brothers, in turn selling it to his brother-in-law, Corliss Stolworthy, in 1927 when he opened the Burnham Trading Post on Brimhall Wash, about 15 mi northwest of Hunter Wash (McNitt, 1962). By 1929, Stolworthy was in partnership at Tsaya with R.L. "Chunky" Tanner (York, 1984), who later constructed Tanner Lake in the Split Lip Flats area. In 1939, Karl Ashcroft purchased the Tsaya Trading Post and ranched between there and De-na-zin (York, 1984). Ashcroft also ranched within the Fossil Forest area, as described below. The new Tsaya Trading Post was established in 1961 at a site southwest of the old store and south of Chaco Wash, on New Mexico Highway 371; this continues to operate to the present. Kaye Ashcroft still greets customers and his son shares in the operation of the store.

Tanner Lake (secs 17 and 18, T23N, R12W) and numerous associated ranch buildings and structures were constructed by R. L. Tanner, his family and hired workers during the 1935-1937 time period. The Tanners operated a ranch and trading post, the Tanner Lake Trading Post (York, 1984). One impressive series of masonry and adobe structures still present as a linear set of foundation ruins can be found in the NE1/4, SW1/4 sec 17, T23N R12W. These ruins consist of a series of 8 adjoining room-like structures that York (1984) suggests were used for storage of grain, feed and agricultural equipment and which were built for these purposes by the Tanners. These sorts of uses were certainly in effect as late as 1976 when the preparers of the EMRIA report on Bisti West (EMRIA, 1976) interviewed the then current Navajo lease holder of the ranch. York discounts the suggestion that this structure was built and used by a unit of Afro-American cavalry troops late in the 19th or early in the 20th century.

However, the structure appears much too substantial to be the remains of storage bins or tool sheds and at the very least, a great deal of effort went into their construction, much more than would be justified for such casual use as storage. The enclosures appear to be about the correct size for use as stables, or sleeping quarters for people. The uniformity of each enclosure would be in keeping with a military architectural plan. Finally, the Afro-American cavalry origin of the structure seems to be widely enough known to merit further attention. It is possible that records remain in Department of the Army archives and would be worthwhile reviewing.

The Tanners closed the trading post and sold the ranch to a Navajo man, Eli Smith, by 1960. Smith in turn sold the property to the Navajo Tribe in 1962; the Tribe periodically leased the ranch to Navajo ranchers as the Eli Smith Tribal Ranch (York, 1984). Access to the property has been restricted during the last several years by locked gates.

Several other trading posts existed in the region that are of importance in interpreting the history of early paleontological expeditions in this part of the San Juan Basin. For example, Brookings Store existed on Meyer's Creek (Ah-sli-sla-pah Wash) and was centrally located on a main N-S route between Pueblo Bonito and Ojo Alamo. This route also connected with a major E-W route in Black Lake Canyon. Brookings Store is shown on a map drawn in 1912 by S. F. Stacher, Superintendent of the Pueblo Bonito Indian Agency, but is not shown on Shaler's map of 1906, thus giving a likely date range for its establishment. The store appears on Bauer and Reeside's map (1920) and it appears on Reeside's 1924 map as well. Given the history of the region, it is likely that someone named Meyers operated a store at the site before Brookings, but we can find no additional information about Meyers or Brookings.

Kimbetoh was a major center of trading, Navajo and government operations quite early; by 1902, the Kimbetoh store was part of the network operated by the Hyde Expedition (Brugge, 1980). Sinclair and Granger (1914) show the Kimbetoh Store was operated by someone named Winters. Sternberg (1932) reports that he purchased supplies from the store, and that in 1921, it was operated by a Mr. Tyler. However, Sternberg may have actually be referring to John C. Tyler, a U. S. Government livestock superintendent in the region at the time (Brugge, 1980); Kimbetoh functioned as a regional livestock center.

In terms of paleontology, it is clear that the historic trading posts of the region were situated at or near most of the major fossil localities or sites that have assumed importance in the paleontological literature. The trading posts provided appropriate jumping off stations or base camps for the geologic and paleontologic exploration parties late in the last and early in the present century.

THE RECENT HISTORY OF THE FOSSIL FOREST

A great deal of federal funding and time, both contracted and BLM staff time, has been expended on the prehistoric archeology of the Fossil Forest. The results of these studies are probably available in the reports and maps documenting the prehistoric archeology of the Fossil Forest. We have not been able to obtain copies of any Fossil Forest archeology reports, but have seen copies of some of the BLM archeology site distribution maps. Artifacts of some age perhaps, on the order of thousands of years, although still Holocene and certainly postglacial, have been documented within the badlands exposures of the Fossil Forest. It is likely to us that none of the material that occurs in badlands context can to be shown to be in situ or associated with a camping, tool-making, killing or habitation site. This is simply a reflection of the intensity of erosion in the region and the fact that stone material, artifact or natural, can be transported during storm events. The same can be said for almost all of the other documented archeological materials found within the badlands exposures. The badlands are as their name infers, not attractive for habitation. Almost all of the archeological materials seen in the Fossil Forest have been transported varying distances. Again, this is not unusual given the rapidity and intensity of erosion. Historic sites in the Fossil Forest are better documented.

York (1984) documents a Navajo campsite in the SE1/4, NE1/4, NW1/4 sec 14, T23N R12W periodically used by Mr. Many Horses and his family around 1900. Mr. Many Horses lived between 1847-1922. McNitt (1962) notes that Ganado Mucho ("Many Herds"), sub-chief of all western Navajos and head of the Big Water Clan, had a son, Many Horses, who saved Lorenzo Hubbell's life. Whether this is the same Many Horses who camped in the Fossil Forest is unknown. York's record does, however, provide important documentation of historic Navajo occupation of the area, certainly an actual occupation that predates any known non-Indian occupation. The Bureau of Indian Affairs documents various allotments in the immediate Fossil Forest area; these were recorded by York (1984). In T23N R12W, allotments were made for the following: secs 10, 11, 14 and 15. These allotments were approved in 1908 and all have been subsequently relinquished.

York (1984) has reconstructed the land holdings in the region of the Fossil Forest from BIA and BLM data. The following is extrapolated from his findings (Figure 5). By 1939, as noted above, Karl Ashcroft was ranching in the Fossil Forest area while also operating the Old Tsaya Trading Post. Ashcroft holdings included all or portions of secs 15, 22, and 23 in the immediate Fossil Forest area. Frank Wood's ranch included most of sec 14 and the eastern 1/2 sec 15. "Tabby" Brimhall's Black Lake Ranch included parts of secs 14 and 23 and all of 24. To the east, the Tanner holdings extended into sec 17. By 1958, the land holdings had been consolidated (Figure 6). Karl Ashcroft died in 1953 or 1954 and his son, Kaye Ashcroft now ranched on most of secs 14, 15, 22 and 23. The Wood Ranch occupied the northern 1/4 of secs 13, 14 and 15 and was operated by Frank Wood's son, Dewey (York, 1984). The Wood Ranch headquarters is located on New Mexico Highway Department maps in the NW 1/4 sec 36 T24N R12W. Brimhall sold the Black Lake Ranch to M. Elkins and it now occupied most of sec 13 and all of 24. Brugge (1980) notes that Mark Elkins attended a stockman's meeting in Gallup on March 25, 1926 and that Elkins was a rancher from the public

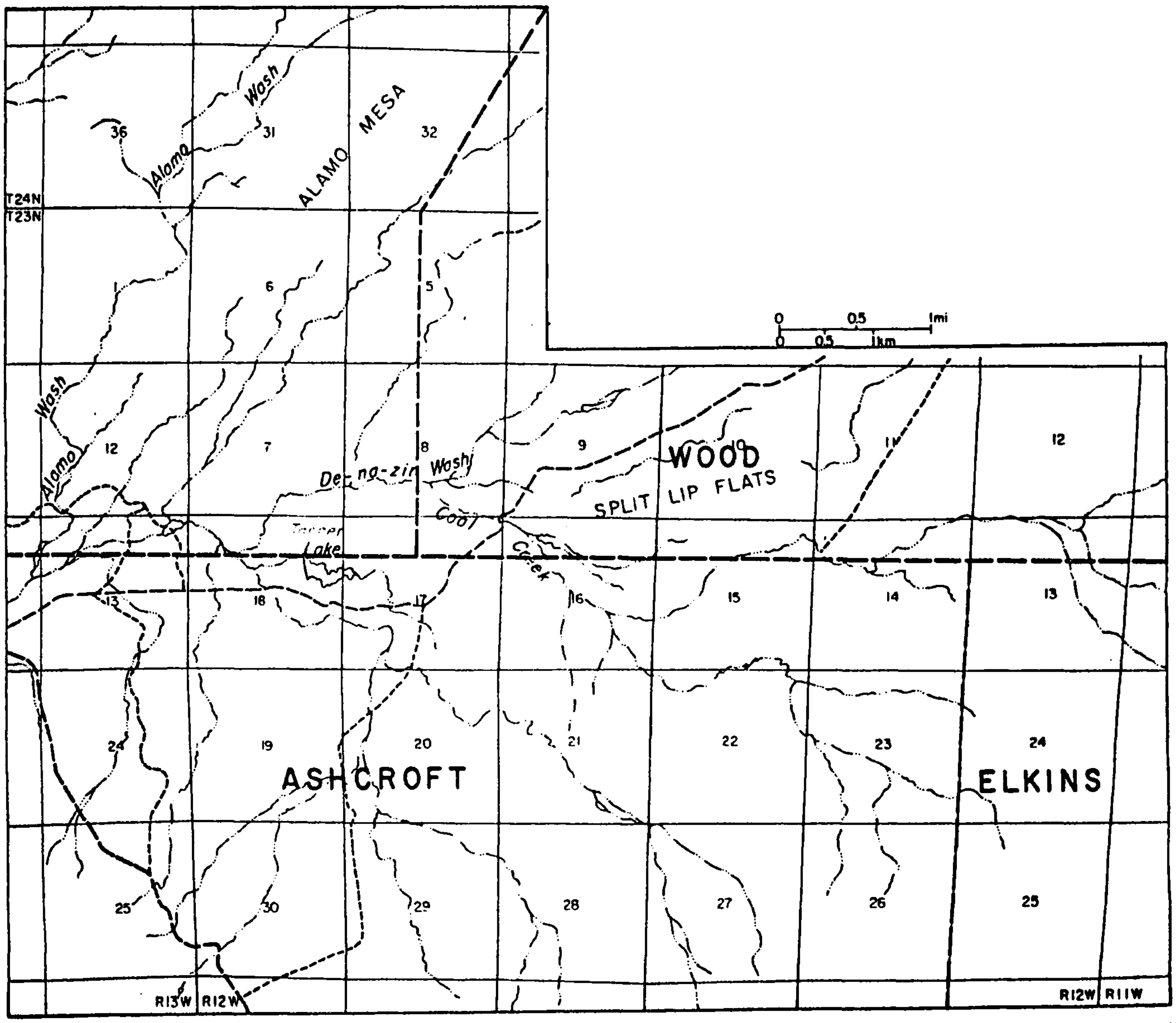

FIGURE 5.--Land ownership in the Fossil Forest area at about 1940 (after York, 1984).

domain east of the Navajo Reservation. Mark Elkins eventually retired and moved to Utah (E. Elkins, pers. comm.).

THE FENCELINES

Two prominent fencelines, trending just off N-S and E-W, are present in the Fossil Forest; we are now in a position to determine their origin. The N-S fenceline is slightly west of north in the Fossil Forest area and originates from a section corner at the junction of secs 35 and 36 T23N R12W and secs 1 and 2 T22N R12W on the Tsaya Canyon (Black Lake Canyon) road. It is likely that when this fenceline was surveyed an effort was made to run the line N-S; it actually runs less than 3 degrees west of north. This fenceline separates "Tabby" Brimhall's Black Lake Ranch from Karl Ashcroft's ranch circa 1940. York (1984) notes that the Taylor Grazing Act was implemented in the area in 1939, and following that implementation, ranchers built fences. The E-W fenceline was surveyed perpendicular to the N-S line, but actually trends slightly south of north because of the offset of the N-S line. This line separates the 1940 Ashcroft Ranch from the Wood Ranch to the northeast and the Tanner Ranch to the northwest. The fenceline are thus of relatively recent origin, certainly not older than 1939 (York suggests that they were built during World War II), and with the consolidation of the ranch holdings in the 1950's, the old fencelines became superfluous and more trouble to tear down or replace than to leave standing. It is possible that the N-S line was still used to separate the Ashcroft and Elkins holdings, however. Finally, all of the Fossil Forest holdings were incorporated into the Paragon Ranch (Wood, Black Lake and Ashcroft), owned by Public Service Company of New Mexico, or the Eli Smith Ranch (Tanner Ranch).

PREVIOUS STUDIES

Storrs (1902) described the Rocky Mountain coal fields including coal producing areas of the time throughout New Mexico. His Plate XXIX, a map of the coal fields in Utah, Colorado and New Mexico , is significant for what it does not show: no documented coal resources in the central portions of the San Juan Basin. This region, including the Fossil Forest area was still poorly known.

Schrader (1905) shows Coal Creek on his map, but is certainly referring to De-na-zin Wash. The crudeness of Schrader's map is in sharp contrast to Shaler's (1906) map, covering much the same area, but with a wealth of detail. The Laramie Formation constituted Shaler's coal-bearing Cretaceous rock unit and this was overlain by Puerco and Wasatch Tertiary-age rocks. Shaler shows the Tiz-Natzin store and its coal mine, and his Coal Creek is De-na-zin, but of particular interest are his descriptions of outcrops at localities 69, 70 and 71. Shaler's Laramie included a basal sandstone, followed by coal-bearing strata that alternate with sandstones and shales. This is roughly the Pictured Cliffs-Fruitland-Kirtland sequence of

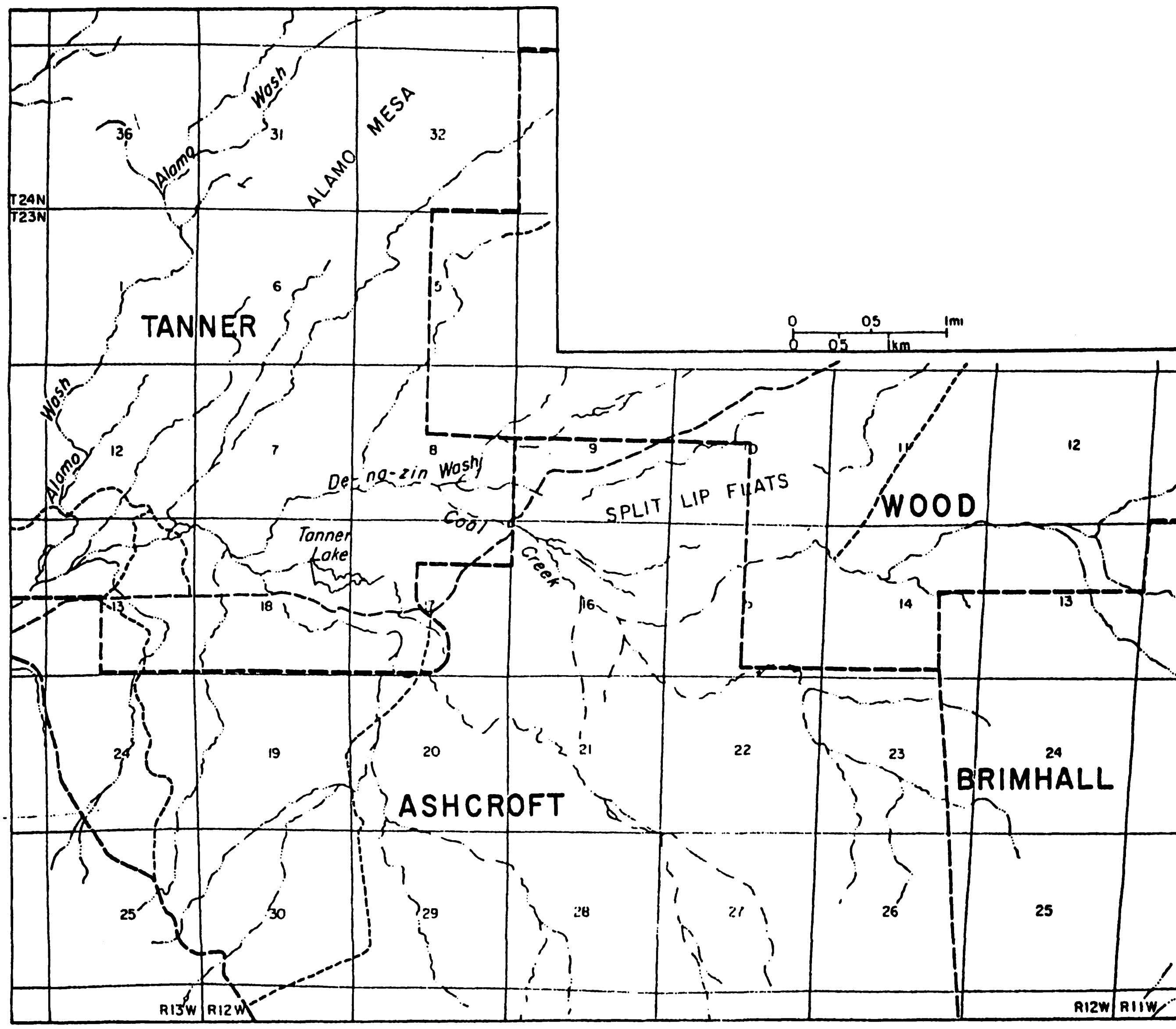

FIGURE 6.--Land ownership in the Fossil Forest area at about 1958 (after York, 1984)

current terminology. Closing the discussion of locality 68, Shaler notes that northeast of Shawver's Store (Tsaya or Black Lake trading post), Laramie coals appear at a number of places between the Chaco and Coal Creek (De-na-zin Wash). Shaler describes locality 69 as being 5 miles northeast of Shawver's store and, "... about 3 miles north of the wagon road leading northeastward from Shawver's store," (p.404). The wagon road referred to was the road in Black Lake Canyon that further east connected to a N-S wagon road connecting Putnam (Pueblo Bonito) and the Ojo Alamo Store, operated at the time that Shaler wrote (but soon to be abandoned) by John Wetherill.

Using Bauer and Reeside's Plates XXXIII and XXXIV, it is evident that the old Black Lake road was situated about a mile south of its present location in the area of secs 10 and 11, T22N R12W. A trail still exists in this position on current topographic maps of the area although the modern Tsaya Canyon road crosses through secs 2 and 3. Tracking approximately north from this point, Shaler would have seen coal approximately 2.5-3 miles from his turnoff somewhere in secs 34 or 35 T23N R12W, where thin coals are conspicuously exposed. This is the area of the "Big Badlands" just south of the Fossil Forest.

Shaler's locality 70 is, "two miles north of locality No. 69 and stratigraphically above the coal bed just described." Approximately two miles north would have placed Shaler in sec 23 T23N R12W, in the Fossil Forest study area proper. Here too coals are present and formed the basis of Bauer and Reeside's (1920) coal sections at localities 511 and 510. Shaler's locality 71 is approximately one mile further north of locality 70, "and on a branch of Coal Creek." This locality must represent the coal seen in sec 15, very near the sec 14 line, T23N R12W and in the vicinity of Bauer and Reeside's (1920) localities 508 or 509. These localities are on the modern Coal Creek. The evidence indicates that Shaler was probably the first geologist to visit the Fossil Forest area.

THE SEEP LOCALITIES

Foster (1913) described a still poorly understood carbonaceous deposit found, "...about fifteen miles northwest of Putnam," (p.361), "...on a broad, flat wash having a drainage towards the northwest and into Chaco Canyon. This was between Coal Creek and Chaco Canyon," (p.362). Foster was actually referring to two separate localities, "...each distant from each other about four miles," (p.361). The deposit noted by Foster is at times caramel-like, or gelatinous, or grease-like and dries to a black powder. This material has not been sampled for analytical chemistry since Foster described it and the nature of the tests performed for Foster are inconclusive. Bauer and Reeside (1920) place the deposit in the vicinity of Black Lake and intermittent lakes or ponds in Black Lake Canyon. They suggest that the material, "...is a peat and may represent a period when these lakes were permanent throughout the year," (p.230).

However, it is our view that Foster (1913) was actually referring to at least two deposits, one in the Black Lake area and a second about 4 mi north of Black Lake. Foster notes that S. J. Holsinger actually visited the deposits. Brugge (1980) notes that J. S. Holsinger was a Special Agent of the U. S. General Land Office sent to New Mexico in 1901 to investigate the need for preservation of the archeology of the Chaco Canyon area. As part of his report to the Land Office, Holsinger proposed that the land included in T20-21N, R11-13W, and T22-24N R11-13W be made a new national park. In his report, he noted that the Navajos would not tamper with archeological materials or fossil remains.

In sec 9 T23N R12W, York (1984) documents a seep locality where a black, greasy fluid periodically naturally occurs and is known to the Navajos as "leejin." It is gathered by the Navajos for special ceremonial purposes. This locality is approximately 5 mi north of Black Lake. In his correspondence with Holsinger, Foster cites Holsinger's description of vertebrate fossils 8-10 miles north of the deposit but does not distinguish which deposit. Holsinger could have been referring to almost any of the badlands areas between the Fossil Forest and Hunter Wash. The area of one of the deposits is described as having extensive deposits of clinker; the Big Badlands to the south of the Fossil Forest have such deposits. Thus, although we cannot positively place Holsinger in the Fossil Forest proper, he was certainly familiar with the area, "between the Chaco and Coal Creek" and given his sensitivity to archeological and paleontological materials, it is very likely that he traversed the Fossil Forest study area.

Foster notes that he obtained the black material from a Mr. Barringer, who in turn obtained the samples from a Mr. McCullough, "who made the expedition to secure the samples," (p.362). McCullough obviously new the region well and where to go to obtain the samples. Very importantly, in his correspondence with Barringer, McCullough notes that, "...there are many petrified trees lying on the surface," (Foster, 1913, p.362), and that, "fossil remains (heavy bones, etc.) are abundant in the near neighborhood in the shales," (Foster, 1913, p. 363). This information suggests that McCullough very likely traversed the Fossil Forest area.

We are still uncertain of the nature of the black material noted. In 1988, Wolberg and Diane Bellis did locate one seep and obtained samples for analysis. At the known localities, the substance seems to lie beneath surficial deposits but above bedrock. It does not appear to be associated directly with coal deposits. The samples transported to the Chemistry Laboratory at the NMBM&MR, for some reason as yet undetermined, quickly oxidized. We question the results of the preliminary analyses and will have to obtain other samples. The Canyon occupied by Black Lake is, in our view, probably a structural feature. This view is shared by others (K. Fragelius, pers. comm.).

THE BAUER AND REESIDE PERIOD

By 1916, Bauer had named the Fruitland Formation and the

Kirtland Shale, after settlements of the same names in the vicinity of exposures along the San Juan River. The Fruitland Formation overlies the Pictured Cliffs Sandstone and includes a sequence of interbedded coals, mudstones, poorly fissile shales and sandstones. The Fruitland Formation contains the preponderance of New Mexico's coal reserves, and these are concentrated in the lower part of the formation. The Pictured Cliffs Sandstone represents the last regression of the epeiric seaway from the region, and is actually the last of several regressive-transgressive episodes that characterize Upper Cretaceous sedimentation in the San Juan Basin

The Kirtland Shale overlying the Fruitland Formation has been divided into three generally recognized members: an unnamed lower shale member, the Farmington Sandstone and an unnamed upper shale member. Various boundaries have been proposed to separate the Fruitland and Kirtland, and none are satisfactory (see Fassett and Hinds, 1971; Hunt, 1984). Eventually, it is likely that the Fruitland/Kirtland will be recognized as a single unit, perhaps of formational status, with member divisions. Bauer and Reeside (1920), as part of their study of coal in the middle and eastern parts of the San Juan Basin, provide the first clearly documented report dealing with the Fossil Forest. They note the lack of adequate land surveys in the area included in T21N-T24N, R12W (among others), at the time of their field studies in the area. It is likely that they had access to Shaler's report, unpublished field notes and were thus encouraged to expand on Shaler's coal studies in the Fossil Forest. They could not locate any marked corners and details on official plats were grossly in error. They had to relocate points in the Fossil Forest area with local surveyors and Bureau of Indian Affairs personnel.

This lack of geographic certainty regarding the area is very evident in both earlier and later efforts in the region. Bauer and Reeside do not give any indication that fences existed in the area and as discussed above, it is likely that no fences existed until passage of the Taylor Grazing Act. The fences must have been set in place just before or during World War II. Bauer and Reeside (1920, Plate XXXIII) must have entered the Fossil Forest from the northwest and Split Lip Flats. Their coal sections are sequentially numbered NW-SE. There is a problem in matching their maps of adjoining areas (Plates XXXI and XXXIII); wagon roads shown on Plate XXXI terminate abruptly at the eastern edge and do not continue on Plate XXXIII. Reeside (1924) published a geologic map of part of the San Juan Basin which shows a road from Hunter's Store, south past the De-na-zin store (then abandoned), before turning east and traversing the northern part of T23N R12W through secs 18, 8, 9, 10, and 11 where it joins the Split Lip Flats road, finally terminating at the road juncture to the Ojo Alamo Store. Bauer and Reeside (1920, Plate XXXI) show this road terminating within sec 18, at the edge of the plate and is not continued within sec 18 on Plate XXXIII. A second road, south of the first road noted above is shown on Reeside's (1924) map and traverses T23N R12W in a SW-NE direction. It crosses secs 31, 30, 20, 16, 15, 11 where it merges with the northern road. Bauer and Reeside (1920, Plate XXXI) show this road terminating in sec 31, again at the edge of the plate, and not continuing on to Plate XXXIII. Interestingly, the Pretty Rock 1:24,000 topographic map, and the Alamo Mesa East quadrangle to the north of Pretty Rock show a trail extending northwestward from secs 11, 2 and 1 and then north to the old Ojo Alamo Store.

There can be little doubt that this is basically the route of the old road shown on Reeside's 1924 map. Thus a rather significant road or wagon trail traversed the Fossil Forest study area; the modern Split Lip Flats road has shifted to the north and west. It is likely that Bauer and Reeside entered the area from this old road, an interpretation in keeping with their numbering of localities. They must have worked south and east through the area, intending to tie up with the Black Lake Canyon road to the south. Their numbering of coal sections indicates that they then worked towards the head of Meyer's Creek (Ah-sli-sla-pah Wash), following the then south fork of the Black Lake Canyon road which intersected a N-S trending road connecting the Ojo Alamo Trading Post and Pueblo Bonito via Brookings Store on Meyer's Creek. They were working downsection, although their description of coal exposures is organized upsection. It should also be stressed that they were less interested in discussing the fine details of the rocks they encountered than in providing a good appraisal of the coal resources over a very large area, of which the Fossil Forest, described by them as part of the area, "between Black Lake Canyon and Splitlip Flat," (Bauer and Reeside, 1920, p.230) was but a minor component.

It seems certain that Bauer and Reeside actually entered and were familiar with the main part of the Fossil Forest RNA, in contrast to the earlier views of Hunt (1984) and restated in Rigby and Wolberg (1987). In actuality, the Fossil Forest occupied a central location between other areas of interest to them and they couldn't help but traverse the Fossil Forest with some frequency.

During the 1987 field season, we remeasured Bauer and Reeside sections 507, 508, 509 and 510. Additionally, we measured a section, A101, and a reference section for the "Big Badlands" area to the south. Sufficient detail is present on Bauer and Reeside's Plate XXXIII and their section descriptions to reasonably relocate their sections on the modern USGS topographic map of the Pretty Rock Quadrangle. The results of this remeasurement are discussed in a paper elsewhere in this volume. Bauer and Reeside make no mention of the tree stumps in the area; in fact they do not mention fossils at all. Again, their main purpose was to map coals. The content and style of most USGS coal studies of the period generally restricted the inclusion of non-pertinent data, so the lack of paleontological content is really not so unusual. Although I am not aware of any direct evidence to support the notion, it is possible that Bauer and Reeside may have intended to hold information of any significant fossil finds in the Fossil Forest area in confidence, intending to direct USGS or Smithsonian paleontologists to the area to collect material. The time period during which they worked in the San Juan Basin was a period of intense paleontological collecting by a variety of people, and some competition between institutions may have resulted.

ENTER STERNBERG

Of some interest is the fact that Charles H. Sternberg (1850-1943), certainly the best known commercial collector of fossils, describes meeting J. B. Reeside in 1921, possibly at the site of the Ojo Alamo Trading Post, and receiving from him information about, "...the type localities from which he had secured many fine turtles of the Cretaceous and Tertiary," (Sternberg, 1930, p. 207). Thus, despite the lack of paleontological data in Bauer and Reeside (1920), Reeside was certainly accumulating information and specimens as evidenced in much of the relevant literature of the period.

Sternberg's writing style is very straight-forward, but frequently disjointed in the sense that nonsequitors frequently occur. This style and the shifting of place names in current usage pose difficulties in trying to follow his collecting activities in New Mexico. Several passages are very suggestive of the Fossil Forest area, but almost always also contain a contradictory element as well. Very early in the NMBM&MR efforts in the Fossil Forest, these suggestive passages colored our interpretations of Sternberg's activities, and these views were forcefully stated in Hunt (1984) and Rigby and Wolberg (1987), although our views evolved (Wolberg and others, 1988).

As an example of Sternberg's style, in a passage discussing the Kirtland shales (p. 210), he notes: "In one place I counted more than thirty large tree trunks to the acre." But then he says: "There are many different levels through the one hundred and more feet of this formation exposed on Meyers Creek." Is he really saying that the thirty tree trunks/acre are on Meyers Creek, or are they somewhere else and he is actually confusing two separate localities? It is likely that he has confused different localities.

Later, (pp. 210-211) in discussing how this tree-laden terrain bode well for the discovery of vertebrates, he says: "Although it took many weary miles of travel, my best specimen, a Pentaceratops skull seven and one-half feet long, and the complete skeleton of a duckbilled dinosaur, were discovered in this formation. This is the only formation where the stumps of trees attached to their own roots stood erect among all the evidences of their past history around them." Were these specimens recovered from an area with in situ stumps? Time probably clouded the clarity of what he did and saw in New Mexico must have entered his mind by 1932 because he places the coal-bearing Fruitland Formation above, not beneath the Kirtland Shale.

In July, 1921, "acting on information received from Mr. Reeside," (p.214) Sternberg was at Kimbeto and by July 26, 1921, was exploring the head of Escavada Wash. Then he was back at Kimbeto by July 28, 1921 having been forced to return because of poor weather. He then decided to explore the Kimbeto area and found the 7.5 foot long Pentaceratops skull. This seems to have been the same skull noted above. Significantly, he does not mention in situ stumps. The Kimbeto skull is the skull that Sternberg sold to Wiman in Upsala, Sweden, and which was described as Pentaceratops fenestratus (Wiman, 1930), and which came from a locality 1 mile south of the Kimbeto Wash store, on the south branch of Meyers Creek (Wiman, 1930, p. 216).

A second skull, collected in 1922, was sold to the American Museum of Natural History and was described as Pentaceratops sternbergi by Osborn (1923). The locality for this skull was recorded as: "... nine miles northeast of Tsaya, New Mexico, in the Cretaceous formation described in 1916 by Bauer as the Fruitland Beds," (Osborn, 1923, p.1). Rowe, et al (1981) document two other Pentaceratops skulls collected in 1922 and 1923 from near Tsaya. George Sternberg collected a portion of a P. sternbergi skull from the SW1/4 T24N R13W in 1929 (Gilmore, 1935).

In 1923, Sternberg collected fossil material described as Parasaurolophus cyrtocristatus by Ostrom (1961, 1963), a crested hadrosaur. Ostrom (1961, p. 575; 1965, p. 146) identified the locality as:

"Fruitland formation (Maastrichtian?) near Coal Creek, eight miles southeast of Tsaya, McKinley County, New Mexico. (This locality is not to be confused with a "Coal Creek" ten miles north of Tsaya in San Juan County.)"

There is a problem with this locality data. The region so designated by Ostrom has no Coal Creek and the rock outcrops are simply wrong. Most importantly, Sternberg makes no mention of working the area. Available records at the Field Museum, Chicago, include a transcribed "box list" and correspondence from and to Sternberg. Specimen N0. 49 was listed as being found at a locality in, "San Juan Co., New Mexico, Coal Creek, 8 miles S. E. of Tsaya." A quarry diagram accompanied the list and marginal notations include the following: " Sternberg's scrawl is practically illegible." Thus, the specimen was found in San Juan County, not McKinley County (the change in counties is only needed if the direction from Tsaya is read as southeast) and a direction northeast, rather than southeast of Tsaya was intended by Sternberg. Sternberg's difficult handwriting could easily account for mistaking SE for NE. This would put the locality in the proper geographic and geologic surrounding for the Fossil Forest and consistent with other documented fossil occurrences noted by Sternberg, in the Coal Creek (De-na-zin) area, eight or nine miles northeast of Tsaya.

Lull and Wright (1942) list a Kritosaurus? ischium and metapodial in the American Museum of Natural History collections as originating from a Sternberg locality 9 miles northeast of Tsaya. They also list a U. S. National Museum trachodont locality noted by Gilmore (1916) as 30 miles south of Farmington and 4 miles east of the Navajo Reservation line. This locality would also be about 8 or 9 miles northeast of Tsaya. It is important to note that the Reservation boundary noted by Gilmore has since been adjusted westward. This fact has not generally considered when trying to reconstruct locality information.

Sternberg initially seems to have relied heavily on the locality data given him by Reeside and Bauer's (1916) paper. He spent a great deal of time and effort on the trails between Hunter Wash, Tsaya, Ojo Alamo and Kimbetoh, using the then wagon roads as his main routes. As he tells us in himself, he explored every wash and outcrop.

It seems clear to me that there can be little doubt that this wonderfully energetic collector traversed the Fossil Forest area. He really could not avoid the Fossil Forest; as discussed above a rather significant wagon road crossed the area. It is likely that his son George literally followed in many of his father's footsteps a few years later. Yet, it is not possible to ascribe any particular specimen as having originated in the Fossil Forest, or any of the Fossil Forest quarries that predate our activities there to the collecting activities of the Sternbergs. At best, the localities eight or nine miles northeast of Tsaya are certainly suggestive and in any case would place Sternberg very close to the Fossil Forest.

It seems reasonable to suppose that the locality 8 or 9 miles northeast of Tsaya is a real locality designation, just as much so as Sternberg's localities in and around Hunter Wash, Kimbetoh or Ojo Alamo. The designations are real reference points. Of course, references to distances at this early date must be considered approximations--modern topographic maps did not exist, landmarks were designations of places, not mileage markers; roads were more track and trail than maintained roadways, horse-drawn wagons did not have odometers (a fact forgotten by Hunt, 1991).

During various field seasons we have found evidence of quarrying tools and assorted detritus at various collecting and camping sites. At one site, obviously and old quarry, we found the broken head of an old Marsh pick. At another site, also adjacent to a fossil locality, we found a broken hand-wrought chisel and soldered cans and at a third, the remnants of a campsite and pieces of a broken wagon. As it develops, the wagon material was along the old wagon trail that traverses the area and should be dismissed. In my view the several quarrying sites can be classed into three age groups based on the amount of erosion that has occurred and obscured the sites; the techniques used to develop the site and remove fossil material; and the extent to which plaster or burlap detritus still exists. Not surprisingly, old, intermediate-age and relatively recent quarrying sites emerge from this analysis after factoring in such components as rock type involved or the location of the quarrying site.

It seems probable that the oldest quarries, involving at least three and possibly five quarrying sites, still evident, date from the period of intensive coal resource studies and the activities of the earliest collectors in the area of the Fossil Forest, 1915-1930. C. H. Sternberg and possibly his son George are the likeliest candidates for these activities. U. S. Geological Survey parties under Shaler, Bauer or Reeside would have left more of a documented imprint in terms of locality data attached to specimens that would most likely have been included in Gilmore's papers. It is also possible that the Sternberg sold Fossil Forest material elsewhere, other than directly to museums.

We know that some interesting New Mexico turtles were sold by Sternberg to Ward's Natural Science Company. These could have easily come from the Fossil Forest. Henry August Ward (1834-1906) had a insatiable urge for travel and adventure. He collected, bought, traded and sold just about anything having to do with natural history. Ward's Natural Science Establishment had its formal beginnings in 1862, at about the time that American colleges and universities wanted "collections" of all sorts. Rocks, minerals and fossils always formed a major part of Ward's interests and Sternberg frequently dealt with Ward's company.

THE STOVALL PERIOD

A second group of perhaps two or three quarrying sites seems to postdate the earlier group but predate the most recent, non-NMBM&MR quarrying activities. Two of these sites still retain some traces of rotted burlap and plaster and some camping debris. The most likely group responsible for these quarries is the 1940-41 collecting expeditions of J. W. Stovall, University of Oklahoma. Two of Stovall's field assistants on his New Mexico collecting trips were Wann Langston and D. E. Savage. Langston (pers. comm. 1988) relates that he believes he did not accompany Stovall into the Fossil Forest area and that it probably was D. E. Savage, although Langston recalls the Wood Ranch. One of the Stovall localities, on file at the Oklahoma State Museum in Norman, Oklahoma, is described as being about 5 miles south of the Wood Ranch headquarters (Kenneth Carpenter, pers. comm.).

As described above, the Wood Ranch property included part of the Fossil Forest. The ranch headquarters were located in the SE 1/4 NW1/4 sec 36 T24N R12W, about 4 mi (in a straight line) almost due North from the corner between secs 13, 14, 23 and 24 T23N R12W as documented on the Bisti Trading Post Quadrangle (not to be confused with the U. S. Geological Survey Bisti topographic quadrangle) published by the New Mexico State Highway Department Planning Division. This map, Quadrangle 14, includes an inventory of roads completed in 1955, a time when the Wood holdings were still in operation. The material collected seems to have included at least ceratopsian remains (Kenneth Carpenter, pers. comm.) but may well have included additional vertebrate material. This ceratopsian material is different from the ceratopsian collection made in the vicinity of Ojo Alamo by the Stovall group. It appears that the entire collection still resides in the Stovall Museum in Norman, Oaklahoma.

THE "UNKNOWN" COLLECTORS

The third group of quarrying sites includes at least four quarries that are of much more recent origin or they are older quarries that have been reworked at a later date. At these sites, the cuts are still relatively fresh; evidence of rock debris thrown from the quarries still remains on the slopes and weathered burlap and plaster are relatively abundant. Uncollected bone fragments may be present in some abundance. These quarry sites are most interesting, and until our recent work, represented the largest quarries in the Fossil Forest. Many cubic yards of rock have been moved, largely in well-indurated sandstones. The time and resources committed to these efforts were substantive to say the least. At the most, these quarries probably date from the early to mid-1970's. No institution to our knowledge has let it be known that it holds documented collections from this group of quarries. We are certain that such collection exist, however.

During the course of a large-scale BLM funded paleontological survey (Kues et al., 1977), the Fossil Forest was noted as a significant paleontological area and recommended "200+ days" of federally funded salvage. This study also suggested that the area be, "preserved indefinitely from significant land use, as such use would destroy or disturb many of the in situ relationships of the biota," (p.208). Some collections may have been made by this group (Hunt, 1991).

Studies under my direction, as noted above, began in 1979 and continue to the present. During this span of time, a host of individuals have worked with us, and for the last five field seasons, work in the area has been carried out in part as a field school for secondary school teachers in the sciences. A number of papers have been presented and written dealing with various aspects of Fossil Forest paleontology, stratigraphy, fossil resins, clay and carbonate mineralogy and geochemistry. Studies continue in concert with specialists at other institutions.

REFERENCES

Bauer, C. M., 1916, Contributions to the geology and paleontology of San Juan County. 1. Stratigraphy of a part of the Chaco River valley: U. S. Geological Survey Professional Paper 98, pp. 271-278.

----. and Reeside, J. B., 1920, Coal in the middle and eastern parts of San Juan County, New Mexico: U.S. Geological Survey, Bulletin 716, pp.155-237.

Brugge, D. M., 1980, A history of the Chaco Navajos: Reports of the Chaco Center, Number 4, 542 p.

Carroll, C. H., 1983, Ute Mountain land exchange ethnographic study: Public Service Company of New Mexico, 100 p. EMRIA Energy Mineral Rehabilitation Inventory and Analysis, 1976, Resource and potential reclamation evaluation, Bisti West Study Site, Bisti Coal Field; Report 5-1976: U. S. Department of the Interior, 108 p. and 6 appendices.

Foster, W., 1913, A remarkable carbonaceous deposit near Putnam, New Mexico: Economic Geology, v. 8, pp. 360-368.

Gilmore, C. W., 1935, On the Reptilia of the Kirtland Formation of New Mexico, with descriptions of new species of fossil turtles: Proceedings of the United States National Museum, V.

83, No. 2978, pp. 159-188.
Hunt, C.B., 1956, Cenozoic geology of the Colorado Plateau: U. S. Geological Survey, Professional Paper 279, 99 p.
Hunt, A. P., 1984, Stratigraphy, sedimentology, taphonomy and magnetostratigraphy of the Fossil Forest area, San Juan County, New Mexico: Unpublished MS thesis, New Mexico Institute of Mining and Technology, 338p.
----., 1991. Integrated vertebrate, invertebrate and plant taphonomy of the Fossil Forest area (Fruitland and Kirtland formations: Late Cretaceous), San Juan County, New Mexico, USA. Palaeogeography, Palaeclimatology, Palaeoecology:85-107.
Josephy, A. M., Jr. 1991. The Civil War in the American West. Alfred A. Knopf., N.Y. 448 p.
Kues, B. S., Froelich, J. W., Schiebout, J. A., and Lucas, S. G., 1977, Paleontological survey, resource assessment, and mitigation plan for the Bisti-Star Lake area, northwestern New Mexico: U.S. Bureau of Land Management, Albuquerque District Office, 398 p.
McNitt, F., 1962, The Indian traders: University of Oklahoma Press, Norman, 393 p.
Osborn, H. F., 1923, A new genus and species of Ceratopsia from New Mexico: American Museum Novitates, No. 93, 3p.
Ostrom, J. H., 1961, A new species of hadrosaurian dinosaur from the Cretaceous of New Mexico: Journal of Paleontology, V. 35, No. 3, pp.575-577.
Ostrom, J. H., 1963, Parasaurolophus cyrtocristatus, a crested hadrosaurian dinosaur from New Mexico: Fieldiana, Geology, V. 14, No. 8, pp. 143-168.
O'Sullivan, R. B., Mytton, J. W., Strobell, J. D., Scott, G. R. and Erpenbeck, M. F., 1986, Preliminary geologic map of the Tanner Lake Quadrangle, San Juan County, New Mexico: U. S. Geological Survey, Miscellaneous Field Studies, Map MF-1864, 1:24,000.
Pierce, T. M., 1965, New Mexico Place Names: University of New Mexico Press, Albuquerque, 187 p.
Reeside, J. B., Jr., 1924, Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin Colorado and New Mexico: U. S. Geological Survey, Professional Paper 134, 70 p.
Rowe, T., Colbert, E. H., and Nations, J. D., 1981, The occurrence of Pentaceratops (Ornithischia: Ceratopsia) with a description of its frill, in Lucas, S. G., Rigby, J. K., Jr. and Kues, B. S.(eds.), Advances in San Juan Basin paleontology: University of New Mexico Press, pp. 29-48.
Shaler, M. K., 1906, A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geological Survey, Bulletin 316, pp. 376-426.
Sinclair, W. J., and Granger, W., 1914, Paleocene deposits of the San Juan Basin: Bulletin American Museum of Natural History, V. XXXIII, Article XXII, pp. 297-316.
Sternberg, C. H., 1932, Hunting dinosaurs in the bad lands of the Red Deer River Alberta Canada: privately published, 261p.
Storrs, L. S., 1902, The Rocky Mountain coal fields: U. S. Geological Survey, Twenty-second Annual Report, pp. 421-472.

Wiman, C., 1930, Uber Ceratopsia aus der oberen Kreide in New Mexico: Nova Acta Refiae Societatis Scientarium Upsaliensis, Ser. IV, V. 7, No. 2, pp.1-19.

Wolberg, D. L., Hall, J. P., Bellis, D., Chavez, W. X., Anderson, O., Moro, R. and Gil, A., 1988, Regional historic, stratigraphic, and paleontologic framework of the Late Cretaceous (Campanian-Maastrichtian) Fossil Forest locality near Split Lip Flats, San Juan Basin, San Juan County, New Mexico; in Wolberg, D. L. (ed.), Contributions to Late Cretaceous paleontology and stratigraphy of New Mexico, Part III: New Mexico Bureau of Mines and Mineral Resources Bulletin 122, pp. 1-21.

York, F. F., 1984, Historic cultural resources in the Arch joint venture project area along the De-na-zin Wash: University of New Mexico, Office of Contract Archeology, Project No. 185-147A, 113 p.

HOW TO TELL A BIRD FROM A DINOSAUR

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How many times have you heard that if *Archaeopteryx* (the oldest bird) had not been found with associated feathers, no one would have thought that it was a bird. Indeed, two of the seven known *Archaeopteryx* specimens did pass as a small dinosaur, *Compsognathus* for long periods of time, and the earliest described specimen as a pterosaur for over one hundred years. Recently there has been an influx of very dinosaur looking animals like *Mononychus* being passed as early birds. It would seem that birds and dinosaurs are much alike. Maybe the only way to tell them apart is feathers, but even that may fail, as many now equip their favorite dinosaur with any amount of plumage, and often with such colors as might put the birds of paradise to shame.

It is easy to see why the bird-dinosaur link is an attractive idea. If birds are little more than feathered dinosaurs, then we can use living birds to extract information on the behavior and physiology of dead dinosaurs. In fact much of the modern dinosaur revolution including hot-blooded dinosaurs is based on their presumed relationship with birds. If birds have some more distant origin, most of these ideas are no better than speculation. If we work on dinosaurs, we would also be tempted to throw in with that crowd. Instead, we still think of *Tyrannosaurus* as a dinosaur and a parrot as something else.

This leaves the question of why there is confusion of the two. Is it sloppy paleontology or are they so much alike that we really can't tell which is which? As is so often the case, both factors may be at work. For a long time the only truly bipedal animals known besides man were birds, and many features of birds are related to this bipedal form of locomotion. It tends to make birds look very different from their closest living nonavaian relative the crocodilians. When it became possible to really know what dinosaurs looked like (the middle of the last century) most people were suprised to learn that many of them were bipedal. This led to an immediate suggestion that they might provide a suitable progenitor for birds. This idea held in spite of the fact that it was widely recognized that most dinosaurs were too specialized to be suitable bird ancestors.

At the begining of the twentieth century more primitive and older archosaurs (ruling reptiles) were found in South Africa, that were bipedal but lacked the embarrassing specializations of the dinosaurs. A rather loose taxonomic umbrella was found for these animals (Pseudosuchia) and they pushed the dinosaurs out of the bird origins business for about seventy years. Since then the re-establishment of a dinosaur ancestry for birds has taken on all the intensity of obscure nobility trying to establish rights to a vacated throne. Any and all possible evidences have been tried including the suggestion, that if people can't tell them apart they must be the same thing.

But is it true? Are they so similar? If not, how are they different. Can we be taught how to tell a dinosaur from a bird? Of course, we can! Let us take for example two fairly recent mistakes. One is the confusion of the bird *Archaepteryx* with the dinosaur, *Compsognathus*, and the other is the confusion of the dinosaur, *Mononychus* with a bird. We will try not to be too influenced by size. In general birds are small and dinosaurs are tremendously big. *Compsognathus* is supposed to be one of the exceptions, a bird-sized dinosaur. Perhaps it is, although its lack of a clearly ossified wrist and the unfused condition of its skull are often signs of juvenility. It certainly wouldn't surprise us very much if someone found a *Compsognathus* the size of a cow, and that would still leave it a small dinosaur.

Because the most obvious similarities between birds and dinosaurs result from their shared bipedal locomotion, that should be a good region to establish differences. Most of these result from a different evolutionary history for their activity patterns. As far as we can tell dinosaurs are and always were fundamentally terrestrial. They have improved their locomotion by bringing the hind legs underneath the body in a vertical rather than a sprawling stance. The weight of the body is suspended like a teeter-totter, the middle of the roof of the acetabulum pivoting on the head of the femur. The body is compacted and the forelimbs reduced (much shorter than the hindlimbs). A greatly elongated tail serves as the counterbalance. The scapula and the coracoid lie on the side of the ribcage so that the glenoid (articulation for the arm) opens backwards and the arms cannot be greatly spread. Such a positioning of the glenoid prevents the use of the arm as a wing and for most climbing. The overall posture of dinosaurs makes climbing almost impossible as it holds the body far away from the tree trunk. It is no accident that people who want a dinosaur origin of birds still try to cling to the nearly completely discredited running model for the origin of bird flight. In general the body of the dinosaur is laterally flattened including the long vertical hypapophyses on the caudal vertebrae and the long vertical pubis. Such a shape contributes practically no aerodynamic lift and contrasts with the horizontally flattened body form of *Archaepteryx* and other birds. In all of these respects *Compsognathus* is a perfect dinosaur and *Archaeopteryx* a perfect bird. In details of the skeletal structure we see that *Compsognathus* has very reduced and shortened forelimbs and the manus has only two functional fingers compared to the three in *Archaeopteryx*. The head also has a bone behind the orbit forming the middle bar of the diapsid (two holed) skull. This is lacking in birds including *Archaepteryx*. The inner dorsal margin of the tooth bearing bone of the lower jaw is much lower than the outer in *Compsognathus* indicating that like in other dinosaurs the adults had well-developed interdental plates. *Archaeopteryx*, like the other toothed birds, has the two margins at about the same level with tooth septa like we have, although some workers have confused the tooth septa with the condition in dinosaurs. In other words, almost any structure tells us that *Compsognathus* is a dinosaur and we can only speculate why it has been confused with anything else, especially because there is only the one *Compsognathus* skeleton from Solnhofen and seven birds. A betting person would surely guess *Archaeopteryx* before *Compsognathus*.

The describers of *Mononychus* not only considered it a bird, but thought it closer to modern birds than *Archaeopteryx*. This is not very surprising when we consider that another cladogram put *Tyrannosaurus* in the same position. Clearly almost any outcome is possible in that sort of an analysis. For example, we could use the same features used by Norell et al. (1993) to describe *Mononychus* as a bird to identify it as a flightless pterosaur (ossified, large and longitudinally rectangular sternum; undivided femoral trochanteric crest; fibula does not reach the tarsus) and place it in a cladogram between *Pterodactylus* and *Pteranodon*. Such a suggestion would be ridiculous but could be done using almost the same data that supports an argument of avian affinities, and may in any case, be no worse than calling it a bird. All of the problems with comparing *Compsognathus* with birds hold for *Mononychus*. If we compare it with an undoubted bird of more modern affinities (*Ichthyornis*), we see that it: lacks or has few teeth, has a small head, long neck, no furcula; the scapula and coracoid are lateral to the ribcage; reduced forelimbs; no free carpals; enlarged metacarpal I; unusually short ribs (shorter than the hypapophyses on the caudal vertebrae), elongated and vertical hypapophyses on the caudal vertebrae; a long tail; preacetabular ilium short and pointed; postacetabular ilium elongate; ischium slender and almost vertical; astragalus enlarged to the point that the calcaneum is reduced to a nub or lost; no antitrochanter on the pelvis. The condition of the ischium is unique as illustrated and is not comparable to known dinosaurs or birds. The authors claimed an antitrochanter, but their figure would not seem to allow one. In birds more advanced than *Archaeopteryx*, the hind leg can be held horizontally so that it extends forward around the rib cage and is held permanently in roughly this position so that running is accomplished almost entirely by moving the shin bone (tibia) and the foot. The femora splay outward to get around the ribcage and this forces the articulation for the femur out of the acetabulum forming the antitrochanter. Dinosaurs (including *Mononychus*, as figured) do not extend their femora forward in that way and hence have not developed the avian structure which is also not present in *Archaeopteryx*. Other than the ischium and the antitrochanter all of the features that we have listed can be found in one particular group of dinosaurs, the ornithominids (bird-mimic dinosaurs).

The answer seems clear, *Mononychus* is a dinosaur in the ordinary sense and *Archaeopteryx* is a bird. However, the ornithomomids as their name suggests do resemble birds in some respects, and *Mononychus* is unusually birdlike. Can we find additional relatives for it? We think so, and interestingly they were also originally mistaken for birds. Around the beginning of this century there was a count in Transylvania not much less interesting than Dracula himself. This Count Nopsca was an early champion of the running origin of bird flight and he also collected dinosaurs including an ornithomimid that was described as a Cretaceous bird, *Elopteryx*, based on a femur like that described for *Mononychus*. Two later birds were described from distal tibiae in this same material that also have the unusual enlargement of the astragalus found in *Mononychus*. The latter two specimens were described as giant owls indicating how far this whole thing can go astray. We suspect that the Transylvanian Ornithomimid and that from the Gobi are much the same, and both indicate the many pitfalls of telling birds from dinosaurs.

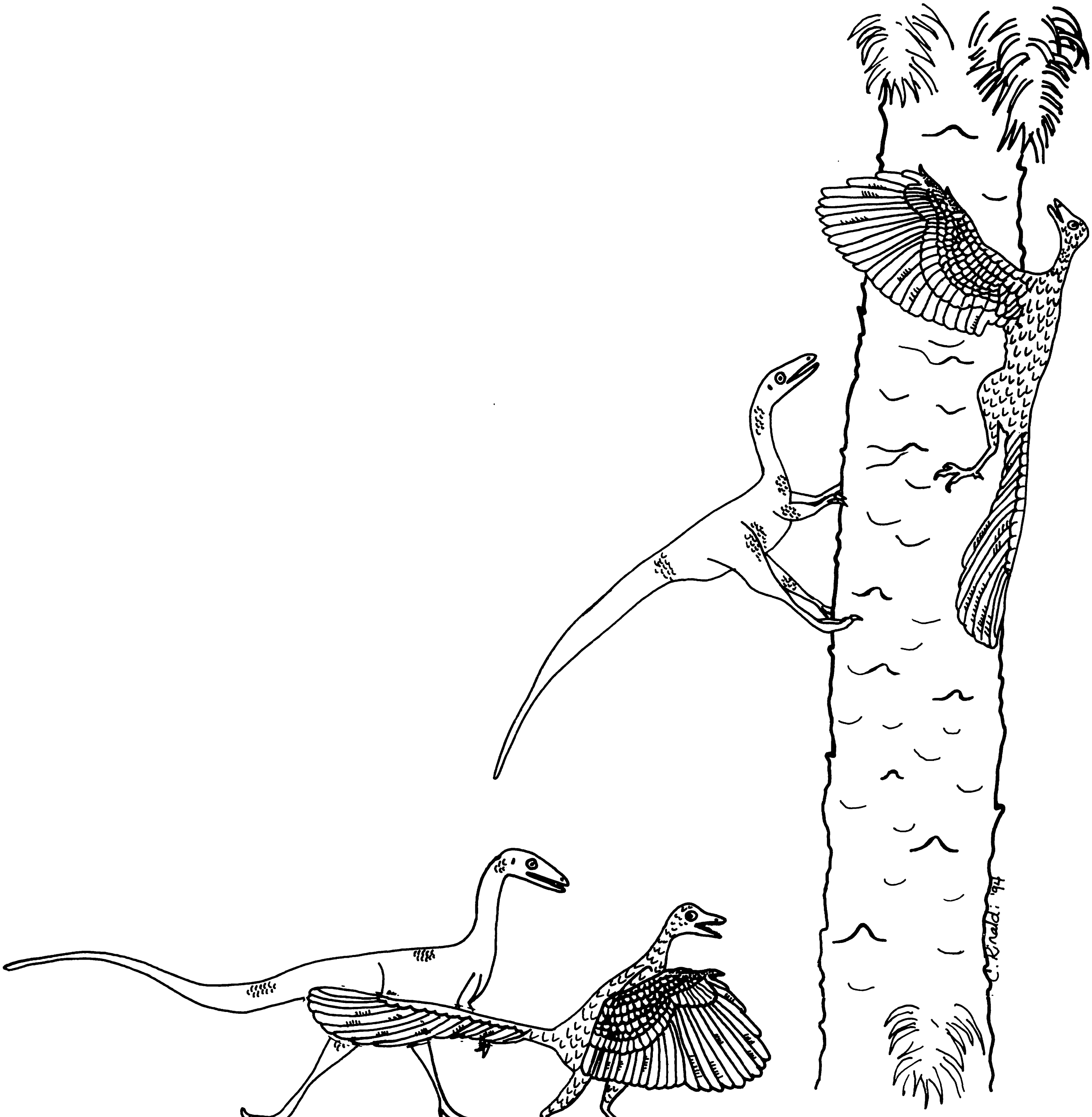

Figure 1. On the ground *Archaeopteryx* would have been dinner for a passing *Compsognathus,* but climbing trees was a different matter.

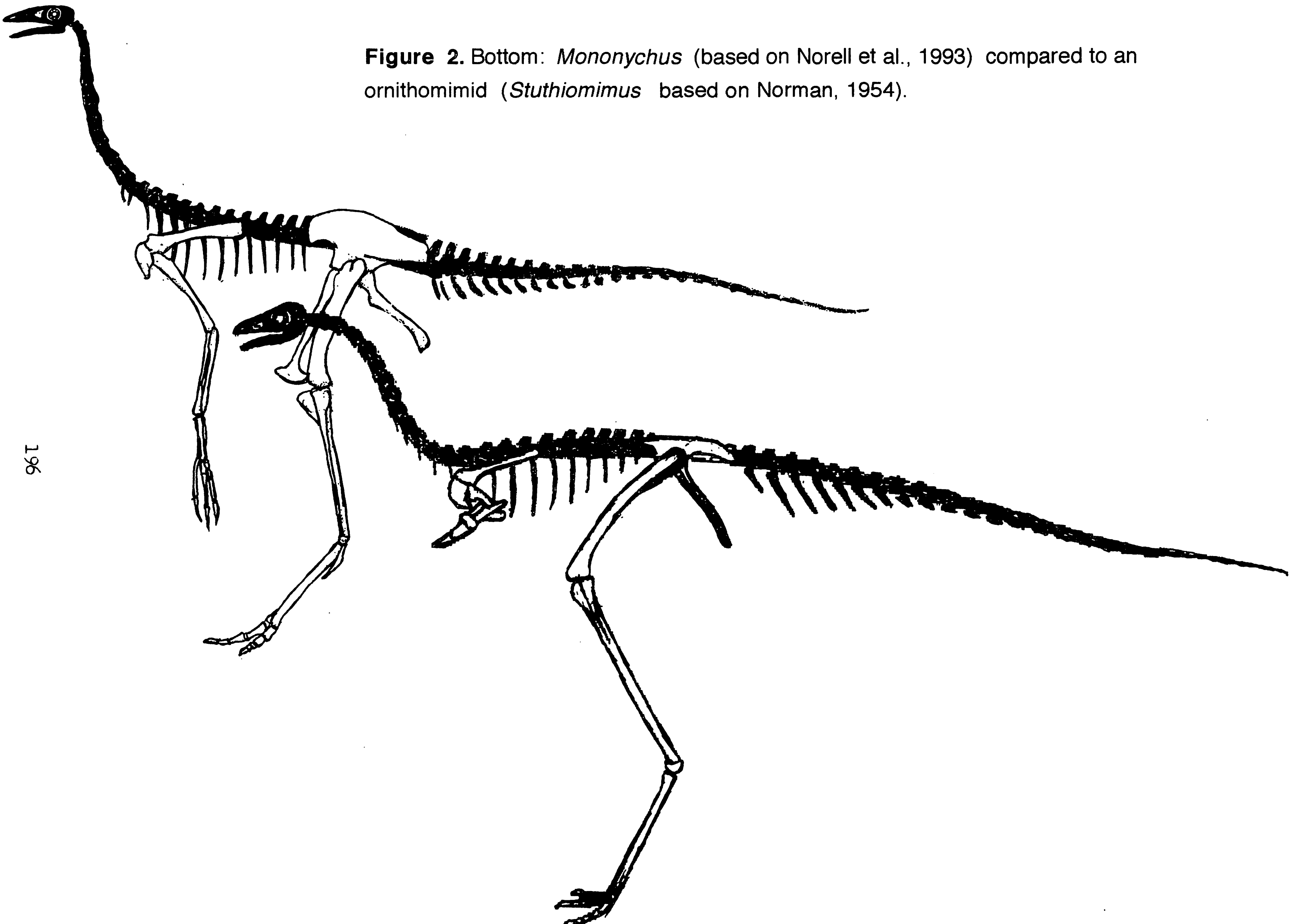

Figure 2. Bottom: *Mononychus* (based on Norell et al., 1993) compared to an ornithomimid (*Stuthiomimus* based on Norman, 1954).

An Overview of Dinosaur Tracking

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Introduction

Dinosaur tracks are remarkably abundant in many areas, and provide rich sources of scientific information on dinosaur behavior, locomotion, foot anatomy, ecology, chronology, and geographic distributions. Yet for many years many dinosaur tracks were largely neglected by most paleontologists, who often seemed to view them as incidental curiosities. Fortunately, this attitude changed dramatically in recent years. The widespread revival of interest in dinosaurs has been paralleled by a renewed interest in dinosaur tracks. Today countless amateur and professional "trackers" are actively studying tracksites all around the world. New sites are being discovered at a rapid rate, and track studies are becoming more detailed and systematic as the scientific importance of tracks becomes more widely recognized.

Uncovering, documenting, and interpreting dinosaur tracks involves tools and techniques different from those applied to body fossils, but the basic principles can be learned and applied by anyone. Moreover, a number of excellent dinosaur track exhibits are now available to the public. Standing amid the footprints of these fantastic prehistoric beasts can be an exhilarating experience. Some trackways are so fresh-looking that it is not hard to imagine the trackmakers having strode by only moments before. Unless the fantasy of cloning dinosaurs becomes a reality, this is probably the closest we can come to standing beside a living, breathing dinosaur.

Basic Terms and Definitions

Fossilized dinosaur tracks are forms of **trace fossils**, also known as **ichnites** or **ichnofossils**. Unlike body fossils, which are the remains of dead bodies, trace fossils record the active movements and behaviors of ancient organisms. Besides footprints, trace fossils include fossilized burrows, dens, feeding tunnels, eggs, nests, stomach contents, coprolites (excrement), tooth and claw marks, and any other product or trace formed while an ancient organism was still alive. The study of trace fossils is known as **ichnology**. Some workers restrict the term to mean the study of *fossil* traces. Others include both modern and ancient traces, using the term **paleoichnology** to specify the study of ancient traces. At any rate, the study of modern traces often helps in interpreting ancient traces.

The terms **track, print, footprint** and **footmark** are often used interchangeably, although the first two include footprints as well as marks from other body parts, such as a tail, snout, or belly. A series of two or more consecutive tracks by the same animal is known as a **trackway** or **trail.**

A Brief History of Dinosaur Tracking

Native Americans probably knew of dinosaur tracks before the first European settlers. Ancient petroglyphs occur alongside several western tracksites. In fact, one site is known by an Indian name that translates, "location with bird tracks." The first authenticated dinosaur track discovery occurred in 1802 when a farm boy in South Hadley, Massachusetts, ploughed up a slab of reddish rock bearing several small three-toed footprints. The find was proudly displayed above a door in the Moody farmhouse, and a local doctor declared the prints to be those of Noah's raven. The confusion of dinosaur tracks with bird tracks was understandable. Dinosaurs were not yet known, and bipedal dinosaur tracks (especially small ones) bear a very close resemblance to bird tracks. The similarity is more than coincidental, since birds and dinosaurs are now considered close relatives.

By the late 1830's an intensive study of the fossil tracks of the Connecticut Valley was undertaken by professor Edward Hitchcock, president of Amherst College. Hitchcock systematically excavated, described, and classified thousands of tracks in remarkable detail, culminating in a monumental volume (Hitchcock, 1858), which is still a classic reference work in the field. Although Hitchcock believed many of the trackways were made by ancient birds, other trails puzzled him. Noting the occasional appearance of narrow, lizard-like tail marks, Hitchcock speculated that some of the trackways may have been made by large bird-like creatures with long, reptile-like tails. Without realizing it, he had just described dinosaurs.

By the time of Hitchcock's death, dinosaurs were better understood. However, most paleontologists soon became preoccupied with bones, and largely neglected dinosaur tracks for the next several decades. A notable exception was Richard S. Lull, who expanded and updated Hitchcock's work on the early Jurassic tracks of New England (Lull, 1915, 1953). Another exception was Roland T. Bird, who did extensive work on Cretaceous tracks near Glen Rose, Texas (Bird, 1941, 1953).

The neglect of dinosaur tracks came to an abrupt end in the early 1980's, when a veritable explosion of interest and research on dinosaur tracks occurred. In 1986 the First International Symposium on Dinosaur Tracks and Traces was held in Albuquerque, New Mexico, bringing together dinosaur trackers from all over the globe. The papers presented at the symposium were subsequently published in a book entitled ***Dinosaur Tracks and Traces*** (Lockley and Gillette, Ed. 1989). Subsequently two other books devoted to dinosaur tracks were published: ***Dinosaur Tracks***, by Tony Thulborn (1990), and ***Tracking Dinosaurs***, by Martin Lockley (1991). Each has a slightly different focus, but combined they provide a good review of modern dinosaur tracking.

Information from Dinosaur Tracks

Some of the most direct information available from dinosaur tracks concerns locomotion. Trackways can indicate whether a dinosaur was walking, trotting, running, or wading. They also show whether the animal was traveling in a **bipedal** (two-legged) or **quadrupedal** (four-legged) manner, or altering its gait between these modes. One can also calculate approximately how fast the trackmaker was moving. Additionally, tracks tells us how a trackmaker carried its tail, whether it walked with a narrow or sprawling gait, and in some cases, what posture the animal assumed while resting.

Inspection of individual prints provides data on the size and shape of the trackmaker's feet, and the number the toes. Clear prints can even reveal details of the soft anatomy of the foot, including the pattern of pads and muscles on the feet, and the flexibility of the digits. These track features, combined with trackway patterns, reveal important clues about the identity of the trackmaker.

Tracks also provide clues about the social behaviors of dinosaurs, and the environment in which they lived. Some sites contain dozens of parallel trails heading in the same direction, indicating a herding or migratory behavior. Often such trails seem to indicate the position of an ancient shoreline. Other sites indicate several herbivores clustered around apparent tree impressions, suggesting a feeding group. One interesting site has been interpreted by some as recording an ancient chase scene. Another site appears to record a dinosaur "stampede" (Thulborn, 1990).

Tracks also complement body fossils in providing information about geographic distributions of dinosaur groups, as well as their chronologic ranges. Knowledge of ancient ecology and population biology can also be expanded by studying tracks. For example, researchers may tabulate the ration of carnivore to herbivore tracks in a region, or the proportions of large to small trackmakers.

Where Dinosaur Tracks are Found

Rock strata from the Mesozoic era (Triassic, Jurassic, and Cretaceous periods) contain literally billions of dinosaur tracks, and actually outnumber bones by orders of magnitude. After all, a dinosaur could leave only one skeleton, but could make countless tracks during its lifetime.

Dinosaur tracks have been found in over 1000 locations throughout the world, on every continent except Antarctica. In the U.S., they are especially abundant in southern and western states, including Texas, Colorado, Utah, Arizona, New Mexico, as well as some eastern states, especially Connecticut, Massachusetts, and New Jersey. Most tracksites are found in quarries, mines, riverbeds, desserts, and mountain terraces--wherever Mesozoic strata are likely to be exposed. Paleontologist Martin Lockley notes that in the western U.S. alone new sites are being reported at the rate of about 50 per year (Lockley, 1991). Of course, the original settings in which the tracks were made were considerably different from the modern ones. Most tracks were made in the kinds of places one commonly sees tracks today: near shorelines and tidal flats, where large expanses of moist sediment are found.

How Dinosaur Tracks are Formed

Unlike body fossils, which often are best preserved when they are buried rapidly, tracks are more likely to be well preserved when they are buried in a relatively slow, calm manner. For this reason, tracks and bones are seldom found in close association.

There are two main ways in which tracks can be formed and preserved. The classic scenario is as follows. First, a trackmaker walks along a moist but firm, fine-grained sediment. Then the tracks remain exposed for a short while, allowing them to become drier and harder (and thus able to resist damage during subsequent burial). A short time later the prints are gently buried with additional sediment, preferably of a contrasting type (which would allow the layers to separate when later reexposed). While buried for millions of years, the original sediment lithofies (turns into rock). Finally the tracks are reexposed in modern times by erosion or other forces. Finally, the tracks must be found and studied before they are destroyed by weathering, quarry workers, or other dangers. Tracks formed under less ideal conditions would be less indistinct, if preserved at all.

Recent research suggests another mechanism of print formation, which involves a dinosaur walking on a very soft surface. In such a case, the animal's feet may push into firmer layers below the surface. The soupy surface material may then rush back over the upper depressions, simultaneously covering the prints made in the lower layers. The subsurface prints are known as **underprints**, undertracks, or ghost tracks. Because they are buried as soon as they are made, any erosion or other destructive forces at the surface would pose no threat to them, increasing their chances of being preserved.

Variables Affecting Track Appearance

Besides the variables of initial formation, tracks are often affected by a number of other factors that can alter or distort their shapes and sizes. Trackers should be aware of these factors in order to avoid misinterpretations and misindentifications.

Often major differences in track shape or features can result from variations in the consistency of the substrate. The best tracks are made on sediment that is neither too firm nor too soft. When a track is made on very soft substrate, some sediment may slump back into the print. This phenomenon, called **mud-collapse** or mud back-flow, often distorts and reduces track features. Digit marks may become mere slits. Soft sediment can also result in undertracks, as described earlier. On the other hand, if the substrate is very firm, portions of the foot may record only lightly, if at all.

Another common factor affecting track appearance is erosion and weathering, which can occur in both ancient and modern times. Erosion can distort or blur track features or even obliterate them. It can also create depressions of its own, which are sometimes mistaken for fossil tracks.

Track features may also be obscured by **infillings,** which occur when an overlying layer is largely scoured away, but remains trapped in some of the track depressions. Well-infilled tracks may exhibit little or no topographic relief. On some sites entire trackways of infilled tracks were missed for decades. Only when the substrate was thoroughly washed were the infillings revealed by virtue of their contrasting color and texture from the surrounding substrate (Kuban, 1989b).

In other cases a series of thin laminations may completely cover a track bed, but still reflect the contours of tracks below. These upper layer depressions are known as **overtracks.** Like undertracks, they may be mistaken for "true tracks" on the original surface. Edward Hitchcock wired together a kind of stone book made from a stacked sequence of thin track plates--all from the same footstep. The "pages" toward the front and back of the book (representing overtracks and undertracks) are less distinct than those in the middle, but it is difficult to determine exactly which plate was the original track layer. One can be more confident that a print was made on the original track surface if it overlaps with lithofied mud cracks, ripple marks, or rain drops. In one special case one can be *sure* a track was made on the original surface: when it shows scale impressions from the dinosaur's foot. Unfortunately, only a few tracks with clear scale impressions are known.

Tracks are usually thought of as an indented impressions. However, they can also consist of natural casts from overlying or infilling material--showing the opposite relief of an indented track. Irregular foot movements such as slips and slides can also create unusual shapes, especially when combined with other variables. Indeed, most tracks are a product of foot shape and movement, combined with at least some of the other factors noted above. Sorting out these variables is part of the challenge of tracking. Many dinosaur tracks have been misidentified or misinterpreted based on

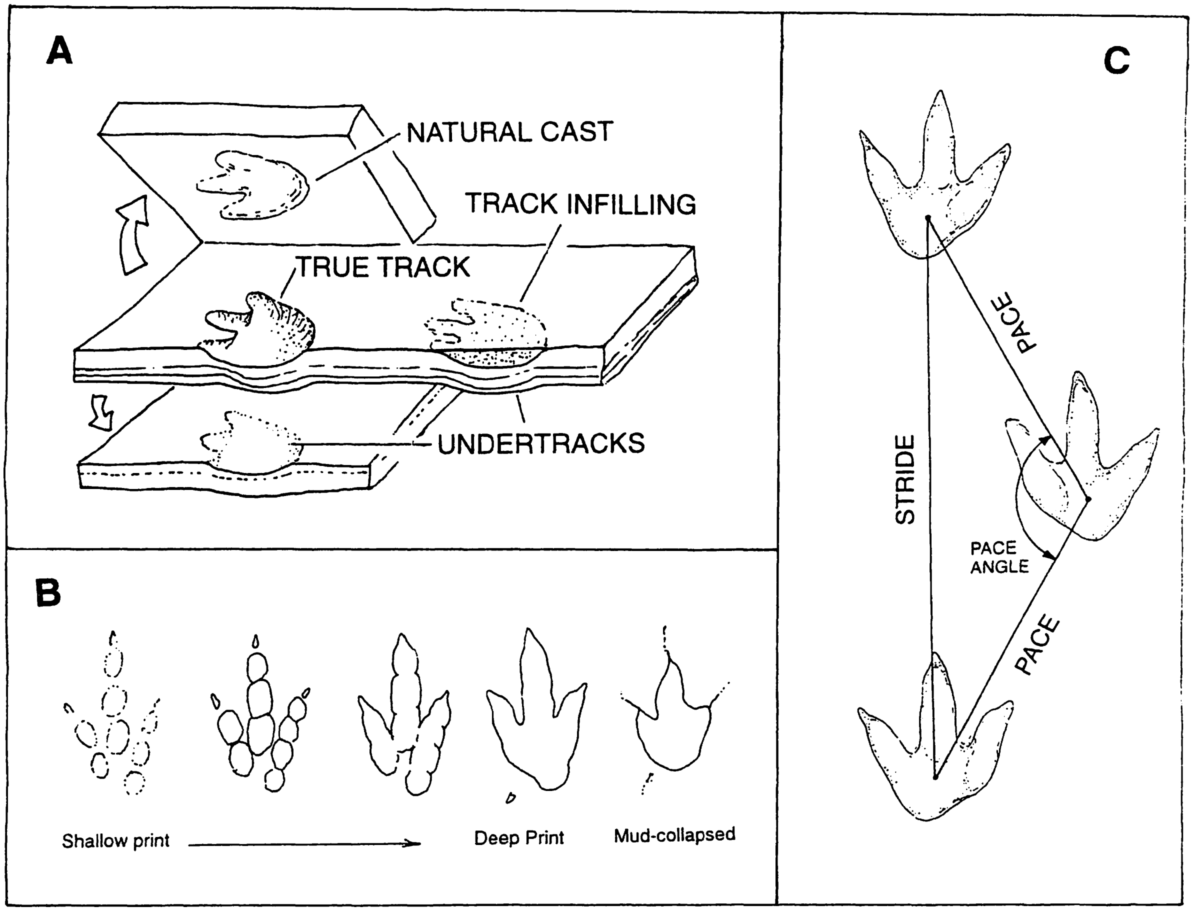

Figure 1.

A. Track Formation and Preservation.
Stylized diagram showing a true track, natural cast, undertracks, and track infilling as they might appear in rock strata. Adapted from Lockley (1991).

B. Variation in track appearance due to sediment consistency.
All tracks were made by a single dinosaur stepping on substrates of different consistencies, becoming progressively soft from left to right. Notice the absence of distinct pads in the deeper prints, and the appearance of a hallux mark only in the right-most prints. The print at the far right suffers from mud-collapse, which results when very soft mud slumps back into a track depression, distorting its shape and reducing its size. Adapted from Thulborn (1990).

C. Basic Trackway Measurements.
Pace angles (also called step angles or pace angulations) may be calculated using trigonometry once pace and stride measurements have been made. On a quadrupedal trackway, these measurments should be made on both the rear and front prints.

poorly preserved specimens, or a failure to recognize one or more variables affecting print appearance.

Major Types of Dinosaur Tracks

It is often difficult or impossible to identify the particular genus or species of dinosaur that made a given trackway. However, one can usually determine at least the general *group* of dinosaurs to which the trackmaker belonged, since foot structures vary considerably among different dinosaur groups. In many cases the locomotor styles of different groups varied as well.

Paleontologists divide dinosaurs into two main groups based largely on hip structure: the Ornithischians and Saurischians. However, when dealing with tracks, it is more convenient to first determine whether a trackmaker is bipedal or quadrupedal (Ornithischians and Saurischians both included bipedal and quadrupedal members).

Bipedal trackways are the most common. They contain left-right sequences of similarly shaped prints, each containing three major digit marks. They are commonly called "three-toed tracks" or **tridactyl** tracks. Most bipedal dinosaurs actually possessed four digits on each foot, but one digit (the hallux) was small and held in an elevated position at the inside rear of the foot. When recorded at all, hallux marks are usually small and shallow.

Dinosaurs that made bipedal tracks fall into two major groups: **theropods** (bipedal meat-eating dinosaurs) and **ornithopods** (bipedal plant-eating dinosaurs). Theropod tracks typically exhibit relatively long and narrow digit impressions, terminated with sharp, slender claw marks. The posterior ends are typically somewhat V-shaped. Among theropods, a somewhat arbitrary division is made between small, gracile forms called **coelurosaurs**, and large, robust forms known as **carnosaurs**. Coelurosaur tracks often exhibit digits held closely together, and distinct toe pads. The shapes and positions of the pads are useful in identifying particular ichnogenera. The digit marks of carnosaur tracks are often more widely splayed and robust, with less distinct pads.

Ornithopod tracks are normally wider than theropod tracks, with well rounded posteriors and relatively short, blunt digit marks reflecting hoof-like claws. However, the distinction between ornithopod tracks and theropod tracks is less clear-cut in some small and poorly preserved tracks. Even experienced trackers debate whether small tracks represent ornithopods or theropods, and whether they represent small species or merely juveniles of larger species. Also, carnosaur tracks can be mistaken for large ornithopod tracks when their digits are partially mud-collapsed, causing them to appear shorter and blunter, and thus more ornithopod-like.

Both theropods and ornithopods habitually walked in a **digitigrade** (toe-walking) manner. Until recently it was assumed that they *always* did so. However, my research in the Paluxy Riverbed of Texas during the early 1980's (and later in collaboration with Ron Hastings), showed that some bipedal dinosaurs at least occasionally walked in a **plantigrade** or plantigrade-like manner, impressing their soles and heels as they walked--thus making elongate tracks. Why they sometimes did this is uncertain. One idea relates to a lowered or 'crouching' body position--perhaps during a foraging or stalking behavior--which would force the metatarsus into a more horizontal position. Incidentally, when the digit impressions of metatarsal tracks are subdued by erosion, mud collapse, or a combination of factors, they often resemble giant human tracks, for which they were mistaken by many locals and strict creationists. The latter often cited such tracks (along with erosional markings and some loose carvings also promoted as "man tracks") in attempts to demonstrate dinosaur and human cohabitation, and thus refute evolution. However, most "man track" advocates backpedaled from their claims after detailed explanations of the metatarsal tracks and related phenomena were published. (For further discussion on this topic see "Elongate Dinosaur Tracks," elsewhere in this volume).

Quadruped dinosaur tracks are far less common than bipedal tracks. Most quadruped dinosaurs probably preferred dry or wooded habitats, where their prints would not be preserved. Quadruped tracks generally show rear and front prints of different sizes and shapes, with the rear prints larger than the front prints. Both the front and back feet of quadruped dinosaurs can have as many as four or five digits. The most spectacular quadruped tracks were made by sauropod dinosaurs--commonly called "brontosaurs." Some sauropod prints are over a meter long and as deep as bathtubs. Until recently only a handful of sauropod tracksites were known, but today several dozen locations are known worldwide. Some of the best are found in the Paluxy Riverbed of Glen Rose, Texas. Roland Bird and his crew cut out a large set of these tracks, which are on display at the American Museum in New York. Other tracks are still visible in the riverbed when the water level is low (typically July through

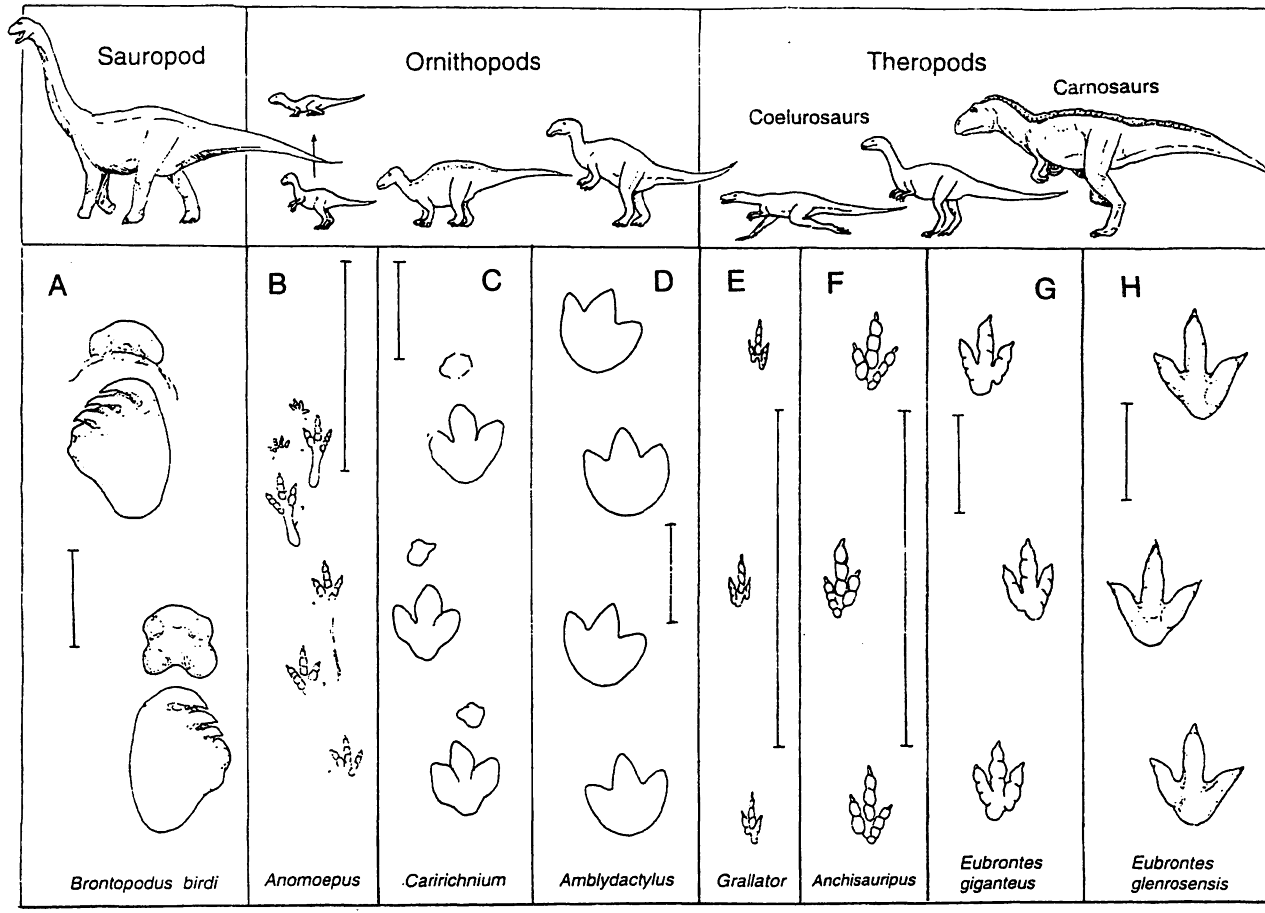

Figure 2. Common Dinosaur Tracks and Trackmaker Groups.

Scale bars indicate 50 cm. Unless otherwise specified, names refer to ichnotaxa (track names), not animal species.

A. *Brontopodus birdi.* Sauropod tracks from the lower Cretaceous, Glen Rose, Texas, often attributed to *Pleurocoelus.* Note partially overlapped front track at the top.

B. *Anomoepus.* Small ornithopod prints from the lower Jurassic of Massachusetts, showing squatting trace and tail impression. Lower Jurassic, Mass.

C. *Carirchnum.* Tracks of an iquanodont or other large ornithopod walking in a quadrupedal manner. Lower Cretaceous, Colorado.

D. *Amblydactylus.* Tracks made by a large ornithopod, either a hadrosaur or an iquanodont. From the lower Cretaceous of British Columbia.

E. *Grallator.* Footprints attributed to a small, fast-running coelurosaur from the Lower Jurassic, Mass.

F. *Anchisauripus.* Medium-sized theropod tracks made by a coelurosaur or a small carnosaur. Lower Jurassic, Massachusetts.

G. *Eubrontes giganteus.* Lower Jurassic carnosaur tracks from Massachusetts.

H. *Eubrontes glenrosensis.* Large, deep lower Cretaceous carnosaur tracks from Glen Rose, Texas. Often attributed to *Acrocanthosaurus.*

September). One interesting feature of Bird's sauropod trackways is that a set of large carnosaur tracks parallels the sauropod tracks, leading many (including Bird himself) to speculate that they record an ancient chase scene. Others point out that the paces are rather small and show unhurried gaits--suggesting that the carnosaur may have been stalking the sauropods from a distance, or simply using the same path.

The rear feet of sauropods contained five digits, decreasing in size from the inside toward the outside of the foot. The inner three or four digits (depending on the species) bore large claws, which record well in tracks, and which angle toward the outside of the foot (despite contrary depictions in some books and skeletal mounts). The fourth and fifth digits were generally small and clawless, and seldom record well. The overall shape of the rear prints is often somewhat bear-like, although others (even within the same "herd") are almost triangular, perhaps reflecting an age or sexual difference.

The front (manus) prints of sauropods resemble elephant tracks. Well-preserved specimens show evidence of five blunt, peglike digits: two on each side and another embedded in a fleshy pad at the anterior end. Often the front prints were overlapped by the rear prints (or mud pushed forward by them), reducing the front prints to crescent-shaped depressions, or obliterating them altogether. One mystery is why the front prints show only blunt digits marks, whereas skeletal remains of sauropod front feet include a large pointed claw. One idea is that the single claw was held in an elevated position. Another is that the claw was tucked within the fleshy pad at the front of the foot.

Other types of quadruped trackways are less well known. Some are attributed to iquanodonts, which sometimes alternated between bipedal and quadrupedal gaits. Their rear feet contained three wide, blunt digits like most other large ornithopods, and their front feet bore five digits of varying length. Many tracks attributed to iquanodonts show a strong inward (pigeon-toed) rotation of the feet. Only a few trackways are attributed to ceratopsians and ankylosaurs. Both were habitual quadrupeds. The feet of ankylosaurs were somewhat more robust and compact than those of ceratopsians, but otherwise their feet were similar--each having four digits on the back feet and five on the front feet. Only a few tracks have been attributed to stegosaurs, but even these do not closely match the foot bones of known stegosaur foot skeletons.

Naming and Classifying Dinosaur Tracks

Although determining the group of dinosaurs associated with a trackway is often straightforward, identifying a particular dinosaur genus as the trackmaker is much more difficult. Within each group many dinosaurs had similar feet, and many foot skeletons are poorly known (or missing altogether). Moreover, as noted above, footprints are often the result of many factors beside foot shape.

For these reasons, ichnologists have often given names (called **ichnotaxa**) to the track forms themselves, apart from body fossils. An **ichnotaxon** (ichnofamily, ichnogenus or ichnospecies) refers only to the shape and features of the track. They should not be confused with the names of the actual trackmakers. Often track names end in "pus" or "podus", referring to feet.

Ichnotaxa can be very useful--allowing workers to discuss and recognize various track forms whether or not the trackmakers are known. However, track names should be created and applied with care and moderation. Some early workers tended to create many new names based on insignificant or or highly variable track features such as print size or pace length. In order to bypass the existing complexity, some modern workers tend to lump most tracks into a handful of popular ichnogenera. This is convenient, but tends to replace excessive complexity with oversimplification. Other researchers are reevaluating many old names. Although not all workers agree on the criteria that should be used to name tracks, most would urge that the names be based on clear specimens and meaningful features. I agree, and recommend that the following specific criteria be met before a new track name is created, or an old one validated:

1. At least least three or four tracks in sequence.
2. Distinct track features, preferably with well delineated pads and claws.
3. A demonstration that the tracks differ in significant ways from previous ichnotaxa.
4. Diagnostic features that consistently appear in clear specimens, and which relate to aspects of foot anatomy, or specific behaviors or locomotor styles, rather than incidental or aberrant features relating to sediment consistency, erosion, infilling, or poor preservation.
5. Detailed descriptions and illustrations of the referred tracks and trackways. A clear specimen or cast should be designated as the holotype, and placed in a safe repository.

If these principles are followed in evaluating old names, the names that remain will be more meaningful and useful. A good example of the proper way to name tracks was recently demonstrated by James O. Farlow, Jeff Pittman, and J. Michael Hawthorne. They illustrated the distinctive features of the Paluxy River sauropod tracks with clear descriptions, maps, and diagrams, and named the tracks ***Brontopodus birdi***. The generic name *Brontopodus* is based on an early suggestion by Roland Bird, and the specific name *birdi* honors Bird himself (Farlow *et al*, 1989).

Despite the difficulties of identifying particular dinosaur species or genera as trackmakers, sometimes such identifications can be made at least tentatively. Normally this requires that the tracks contain clear and unique features matching equally distinctive features on a foot skeleton, or that the tracks provide a good fit to skeletons found in close association with a tracksite. For example, the Glen Rose sauropod tracks have been tentatively associated with the sauropod ***Pleurocoelus***, since skeletal remains of that dinosaur have been found in nearby strata of the same age. Likewise, the large theropod tracks in Glen Rose have been attributed to ***Acrocanthosaurus***, a medium sized carnosaur whose bones were found in rocks of similar age in Oklahoma and Texas (one skeleton was found only a few miles from the tracksites). In order to learn as much as possible about a trackmaker and its environment, a tracksite must be cleaned and documented thoroughly, as outlined below.

Tracksite Preparation

As preparation for serious tracksite study, one should research any prior scientific literature on the site and the geology of the region, to get an idea of what is already known. One should also obtain permission from the owners or controllers of the site for whatever is work is planned.

In most cases tracks should be studied and documented *in situ* (in place), rather than being removed. After all, one advantage in studying tracks is that they are usually intact and still in their original positions, rather than being scattered and broken, as is often the case with bones. Attempting to remove dinosaur tracks often turns them into similarly damaged specimens, and in most locations is illegal. Removing tracks also prevents other workers from studying them in their proper context with other trails and surrounding features. Moreover, modern casting methods allow tracks to be replicated with extreme precision, eliminating the need to remove specimens. Exceptions are sometimes made for sites in imminent danger of destruction. Even in such cases, track removal should only be attempted by groups with proper tools and expertise, and with permission of the site owner.

The main object of site preparation is to clean the track surface well. This may entail merely brushing off superficial sediment, but more often will require removal of larger amounts of sand, gravel, water, or even overlying rock layers. The tools required to do this will vary with the type and amount of overlying material and the scope of the study. A basic set of equipment includes shovels, hand trowels, brooms, buckets, brushes, sponges, measuring devices (tape measure, meter stick, protractor, paper and pencil), photographic equipment, mold-making materials, and clean-up supplies. Of course, always keep a first aid kit handy. When working in a riverbed, sandbags may be useful. One should estimate how much can be cleaned and studied in the time available. It is generally best to leave tracks buried if they are not going to be worked on immediately. Once exposed, tracks are more susceptible to erosion, vandalism, and other hazards.

Cleaning the tracks surface as thoroughly as possible ensures that subtle but potentially important track features are not missed. However, care should be taken to avoid damaging the track bearing surface, especially when using metal tools such as shovels and pry bars. Final removal of superficial sediment (and any material within deep depressions) should be done with less destructive tools such as brooms, wisk brushes, plastic trowels, and hand scoops. A moist sponge is often ideal for final cleaning. Special care is needed where the track surface is coarse or friable, or when the overlying layer does not separate easily from the track bed. Small nooks and crannies in tracks should be cleaned out with brushes and other small implements, preferably made of plastic or wood rather than metal.

After a site is well cleaned, each track should be marked with an identification number, to be used in subsequent mapping and photography. Generally, it is best to mark the numbers with removable paint or chalk, rather than with permanent paint (since other workers may want to use other numbering schemes, and casual visitors may wish to view and photograph the tracks later without distracting markings). One of the easiest and simplest numbering methods is to assign a number to each trackway, and then assign each track in the trail a number following the letter. For example, Trail "A" would contain tracks A1, A2, A3, and so on.

Photographs

Photographs are an important part of site documentation, and a valuable aid in site mapping. Photos should be taken after the tracks are well cleaned, preferably in morning or late afternoon light, which brings out subtle track features. The most scientifically useful photos are close-ups of individual clear specimens (taken from directly above, rather than to the side), and high overhead photos showing multiple tracks in succession. For high shots, ladders or cameras mounted on extension poles are often useful. Supplemental photos may include oblique shots of various tracks and trails to help depict track contours and depth. For scientific purposes, the photos should include the identification numbers discussed above and a meter stick or other familiar object for scale. Some workers like to highlight tracks with water during photography. Although this helps increase the contrast of the tracks against the surrounding substrate, one should be careful not to create the illusion of depth or contours that are not clearly recorded in the tracks themselves.

Measuring and Mapping Trackways

Good site documentation requires detailed measurements of trackways and individual tracks. Ideally the entire site should be mapped; however if time does not permit this, focus should be on the clearest tracks and trackways. Important track measurements include **length**, **width**, and **depth**. Because there are several possible ways (and no universal standard) to take such measurements, it is crucial that authors describe and illustrate exactly how they were taken. Other useful track measurements include their **directions** (usually taken in relation to magnetic north), the total digit **divarication** (angle made between the outermost and innermost digits).

Key *trackway* measurements include **pace, stride,** and **pace angle**. The terms "pace" and "stride" were often used inconsistently in the past. However, today the term **pace** (or step) refers to the distance from one footprint to a corresponding point on the next succeeding print (in other words, from a right to a left, or a left to a right). The **stride** is the distance from one footprint to a corresponding point on the next print of *the same foot* (say, from a right to the next right print). **Pace angle** (the same as step angle) is the angle formed between two successive paces. For a quadruped trail, separate pace, stride, and pace angle measurements should be taken for the front and rear prints. Long measuring rods such as two-meter sticks are useful for taking pace and stride measurements. While taking these measurements, a consistent reference point should be marked on each track. Some authors use the posterior-most or anterior-most point of each track, but since these points vary considerably on indistinct tracks, I prefer to use a more central point, such as the base of the middle digit. Whichever method is used, it should be clearly spelled out. Once pace and stride measurements are made, pace angles can be calculated using trigonometry; however, if time permits it is best to take direct stride measurements, which serve as a check on pace and pace angle measurements.

Other useful trackway measurements include **trackway width** and track **rotation**--the degree to which individual tracks are turned inward ("pigeon toed") or outward ("duck-footed"). These measurements are usually taken in reference to the trackway centerline. Measuring the total length of a trackway gives a good check on the accuracy of pace and stride measurements. If more than one trackway occurs on a site, the distance between the trails at different points should be measured.

Constructing a chalk or string grid can greatly assist overall site mapping. After the grid is laid out on the site, it is fairly easy to sketch of all tracks and trails on grid paper. When combined with photographs and measurements, an accurate site map can then be drawn. However, one should not rely solely on photographs or sketches for mapping, since neither provides the level of accuracy ensured by direct measurements. Another mapping technique is to stretch a sheet of transparent plastic across the surface, onto which the tracks are traced. However, because the plastic will not conform exactly to the track surface, the tracings will be less exact than direct measurements.

Molds and casts

Molds and casts are excellent means to make permanent records of choice specimens. Before doing any mold making, be sure to secure permission from the site or specimen owner. Workers differ on whether an impression taken directly from a track should be called a mold or a cast. Assuming the track is indented, a direct impression of it can be viewed as a rough cast of the dinosaur's foot, since the track is a type of natural mold. However, if one views the track itself rather than the foot as the original specimen, then any direct impression taken from the track is a *mold* of the track, and any replicas made from the mold are *casts*. The latter usage is most common, and will be used here.

Common mold-making materials include plaster, latex rubber, and silicone. Plaster is quick and easy to use, but should only be applied to smooth, hard tracks lacking undercuts, and only with the application of a release agent such as petroleum jelly. Otherwise, the mold may become stuck in the track. Plaster molds are also heavy and brittle, and record less detail than rubber molds. Liquid latex rubber yields lightweight, flexible molds, and requires no separating agent. The latex is brushed on in several layers. Embedding gauze or burlap between layers makes the mold stronger and sturdier. However, even with gauze reinforcement latex molds tend to be "floppy," and when made from deep tracks, the molds should be supported with a rigid backing or "mother mold." The backing can be made of plaster, fiberglass, or expandable urethane foam. Always pull up and then reposition a latex peel before applying a rigid backing (otherwise the mold will be difficult to remove from the print).

Silicone rubber also produces light-weight, flexible molds. It is available in two-part compounds (a base and a catalyst) that are mixed together and poured onto the specimen. Silicone molds are somewhat sturdier than latex, resist decay better, and can be made in a shorter period of time if certain "fast" catalysts are used. However, silicone is more expensive than latex, and requires the use of a separating agent. Also, if the specimen is deep, the mold should be supported with rigid backing. Once a mold is made, a cast can be made using a rigid material such as plaster or fiberglass. A well made mold or cast will record the finest details of a track, allowing specimens to be studied, handled, and displayed without risk of damage to original specimens.

Naturally, if a site study is published, all of the data gathered should be compiled in a clear format, along with a complete and accurate site map. Although measurements are important and should be included, accurate maps allow one to grasp the essential features of a tracksite and the shapes and directions much more readily than pages of numbers and statistics.

Interpreting Trackway Data

One popular exercise using trackway measurements is to estimate the speed of the trackmaker. Generally, if the pace distance is four or more times the track length, one can describe the gait as "running." The estimated speed of the travel can be calculated using formulas developed by R. M. Alexander and others (Alexander, 1989). Most dinosaur trackways indicate unhurried gaits of 2 to 12 km/hr. However, several bipedal trails indicate speeds of over 40 km/hr (about 25 mph)--faster than a human sprinter. Evidently many dinosaurs were capable of running, even though they seldom did so. This is not surprising; even the fastest animals spend very little of their time running.

Digitigrade locomotion and narrow trackways (both common features of bipedal dinosaur trails) are also interpreted as signs of cursorial animals and efficient locomotion. Some bipedal trackways are so narrow that prints almost form a straight line. The small digit divarication typical of small theropod tracks is also indicative of agile animals. Overall then, track evidence suggests that bipedal dinosaurs went about their business at a leisurely pace most of the time, but were capable of running fast when the need arose. These conclusions coincide well with recent work on dinosaur anatomy and biology. Even sauropod trackways are relatively narrow in comparison to reptiles such as lizards or turtles. It is unlikely that sauropods could run (no running sauropod tracks are known), but they may have been able to trot like elephants.

Conclusions

After decades of neglect, the study of dinosaur dinosaur tracks has blossomed into a mature, dynamic, respected branch of mainstream paleontology. As more of these fascinating prehistoric trails are uncovered, there is no telling where they will lead, or how far they may take us in our efforts to learn more about dinosaurs and their ancient world.

For those who wish to visit an actual tracksite, a good place to start is at one or more of the excellent exhibits protected and prepared for public viewing, a number of which are listed below.

Where to See Dinosaur Trackways

All of the locations listed below include some form of interpreted track display. Several show tracksites still in their original locations.

Dinosaur State Park, Rocky Hill, Connecticut. A large tracksite still in its original position, but entirely enclosed in a modern display center. An elevated, circular balcony surrounds the dramatically lighted track floor, which is covered with hundreds of theropod tracks, most of which represent the ichnogenus *Eubrontes*. Surrounding the tracks are interpretive displays and track replicas from other areas. Several excavated tracks are set aside in an outdoor courtyard, where visitors are allowed to mack molds.

Pratt Museum, Amherst College, Amherst, Mass. The basement of Pratt Museum houses the famous Hitchcock collection, featuring thousands of lower Jurassic dinosaur tracks from the Connecticut Valley of New England. Most were collected by Edward Hitchcock during the 1800's, including many type specimens. It is probably the world's largest and most important dinosaur track collection.

Holyoke Site, Holyoke, Mass. A natural tracksite located along the Connecticut River, marked with a an interpretive sign. Although the tracks have eroded somewhat since their first exposure decades ago, many are still recognizable. Most are identified as the ichnogenus *Eubrontes*, although some small tracks (either *Grallator* or *Anchisauripus*) also occur there.

Dinosaur Valley State Park, Glen Rose, Texas. The park is situated along the Paluxy River, just west of Glen Rose, Texas. When the river is low, one can see many large Cretaceous carnosaur and sauropod tracks still in their original positions. Park personnel try to keep an area of distinct tracks cleaned off, but visitors may wish to bring their own broom to sweep out additional tracks. A visitor center at the park entrance includes interpretive displays and trackway replicas.

American Museum of Natural History, New York. Features a remarkable display of Cretaceous sauropod and carnosaur tracks excavated by Roland Bird from the Paluxy Riverbed. Mounted above the trackway is a *Diplodocus* skeleton, which is not the dinosaur that made the tracks, but very similar.

Clayton Lake State Park, Seneca, New Mexico. A large tracksite still in its original position, containing hundreds of ornithopod and theropod tracks. Included are infilled specimens and metatarsal tracks, as well as a few tail impressions. Elevated walkways meander across the track bed allows easy viewing.

Tuba City Site, Arizona. Located on a Navajo reservation 5 miles west of Tuba City, along highway 160 (not far from the Grand Canyon), this natural site contains many lower Jurassic theropod tracks. Navajo children often serve as informal guides.

Alameda Parkway (Dinosaur Ridge), Denver Colorado. Located along the Alameda Parkway road just west of Denver are several Cretaceous dinosaur trackways still in their original position.

Dinosaur Valley, Museum of Western Colorado in Grand Junction, Co. Displays a variety of dinosaur tracks and some interpretive displays. Nearby are other interesting dinosaur exhibits.

Tyrrell Museum of Paleontology, Alberta, Canada. Houses a vast collection of dinosaur tracks from the Peace River of British Columbia, some of which are on display, along with one of the largest exhibits of dinosaur skeletons.

The College of Eastern Utah Prehistoric Museum, Price, Utah. Displays include about 50 Cretaceous dinosaur tracks (mostly ornithopod tracks) collected from coal mine roofs.

References

Alexander, R. M. 1989. *Dynamics of Dinosaurs and Other Extinct Giants*. Columbia University Press, New York.

Bird, R. T. 1941. A Dinosaur Walks into the Museum. *Natural History*, 47: 74-81.

Bird. R. T. 1953. We Captured a Live Brontosaur. *National Geographic*, 105 (5): 707-22.

Bird, R. T. 1985. *Bones for Barnum Brown: Adventures of a Dinosaur Hunter*. Texas Christian University Press, Fort Worth.

Farlow, J. O. 1981. "Estimates of the Speeds of Dinosaurs from a New Trackway Site in Texas," *Nature*, London, 294: 747-8.

Farlow, J. O. 1987. *A Guide to Lower Cretaceous Dinosaur Footprints and Tracksites of the Paluxy River Valley, Somervell County, Texas*. Baylor University, Waco, Texas.

Farlow, J. O. 1993. *The Dinosaurs of Dinosaur Valley State Park*. Dept. of Geosciences. Indiana-Purdue University at Fort Wayne, Fort Wayne, IN.

Farlow, J. O., J. G. Pittman, and J. M. Hawthorne, 1989. *Brontopodus birdi*, Lower Cretaceous Sauropod Footprints from the U.S. Coastal Plain. In *Dinosaur Tracks and Traces* (D.D. Gillette and M.G. Lockley, Eds.). Cambridge University Press, Cambridge, 371-94.

Frey, R. W., Ed. 1975. *The Study of Trace Fossils*. Springer-Verlag. New York.
Gillette, D.D. and M. G. Lockley, editors. 1989. *Dinosaur Tracks and traces*. Cambridge University Press, Cambridge, England.

Hitchcock, E. 1958. *Ichnology of New England. A Report on the Sandstone of the Connecticut Valley, Especially its Fossil Footmarks*. W. White, Boston. Reprinted 1974, by Arno Press, New York.

Kuban, G. J. 1986. A Summary of the Taylor Site Evidence. *Creation/Evolution*, 6 (1): 10-18.

Kuban, G. J. 1989. Elongate Dinosaur Tracks. In *Dinosaur Tracks and Traces* (D.D. Gillette and M.G. Lockley (Eds.) Cambridge University Press, Cambridge, 57-72.

Kuban, G. J. 1989. Color Distinctions and Other Curious Features of Dinosaur Tracks Near Glen Rose, Texas. In *Dinosaur Tracks and Traces* (D.D. Gillette and M.G. Lockley, Eds.). Cambridge University Press, Cambridge, 426-440.

Lockley, M. G. 1991. *Tracking Dinosaurs*. Cambridge University Press, Cambridge, England.

Lull, R. S. 1953. Triassic Life of the Connecticut Valley (revised edition). *Bulletin of the Connecticut State Geological and Natural History Survey*. 81: 1-331.

Mossman, D. J. and W. A. S. Sarjeant, 1983. The Footprints of Extinct Animals. *Scientific American*, 248 (1): 75-84, 138.

Norman, D. B. 1985. *The Illustrated Encyclopedia of Dinosaurs*. Crescent Books, New York.

Sarjeant, W. A. S., 1975. Fossil Tracks and Impressions of Vertebrates. In *The Study of Trace Fossils*, Robert Frey (Ed.) Springer-Verlag.

Thulborn, T. 1990. *Dinosaur Tracks*. Chapman and Hall, London.