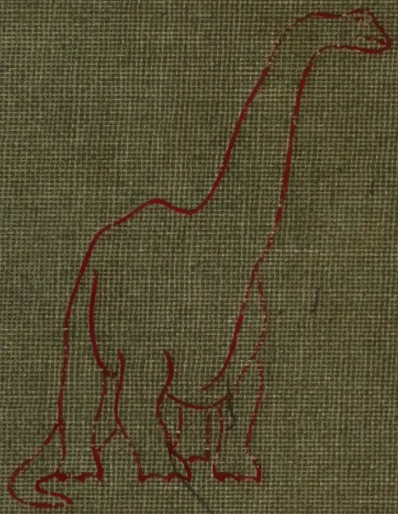

THE DINOSAUR BOOK

The American Museum of Natural History is devoted to exploration, research and education in the natural sciences for the purpose of encouraging and developing an understanding of nature for the advancement of all mankind.

The Dinosaur Book

THE RULING REPTILES AND THEIR RELATIVES

By Edwin H. Colbert

Curator of Fossil Reptiles and Amphibians
The American Museum of Natural History

ILLUSTRATED BY JOHN C. GERMANN

With additional illustrations, previously published,
by Charles R. Knight and others

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THE DINOSAUR BOOK

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TO

WILLIAM KING GREGORY

TEACHER, AUTHORITY ON FOSSIL AMPHIBIANS
AND REPTILES, AND PROFOUND STUDENT
OF VERTEBRATE EVOLUTION

Preface

THERE HAS BEEN considerable progress in the study of fossil amphibians and reptiles since *The Dinosaur Book* was first printed. However, in order to make this second edition available without a long and costly delay it was felt wisest to keep corrections and revisions on this new issue down to those which reflected the major recent advances. It is hoped that this new edition of the book will be useful to those who are interested in a broad outline of amphibian and reptilian evolution.

For many years there has been felt the need for a popular guide book on the fossil amphibians and reptiles, with particular attention given to the dinosaurs. *Dinosaurs*, by W. D. Matthew, published by the American Museum of Natural History in 1915, has long been out of print.

This book has been prepared to fill a definite need, namely, to tell the story of amphibian and reptilian evolution. The book is written to supplement the displays of fossil amphibians and reptiles in the American Museum of Natural History, but the subject matter is handled in such a way that it may be used by anyone interested in the subject, whether he has access to our Museum halls or not. Therefore it is written in general terms, and references to particular skeletons or fossils on exhibit are omitted. To the museum visitor, the label will identify the display. Moreover, the animals described in this book are illustrated by restorations showing their appearance in life, rather than by photographs of skeletons on exhibit. To the museum visitor the actual fossils are at hand, so it is superfluous to repeat them with pictures in a book such as this. To all readers, whether they have access to the Museum or not, it is felt that restorations give a more graphic picture and convey more information than do skeletons, the bones of which are unfamiliar to most people. Therefore much attention has been given to the restorations used. All of the new restorations have been made by Mr. John C. Germann, while, in addition, certain of the well-known restorations by Mr. Charles R. Knight have been repeated. They are worthy of constant repetition, for no better impressions of some of the former denizens of our land have ever been created.

Several people have aided the author in bringing this book to successful completion. Special acknowledgments are due to Professor William King Gregory of Columbia University and the American Museum of Natural History, to Professor Alfred S. Romer of Harvard University, and to Mr. Charles M. Bogert of the American Museum of Natural History. These eminent authorities were all kind enough to read the manuscript and to offer criticisms and suggestions.

EDWIN H. COLBERT

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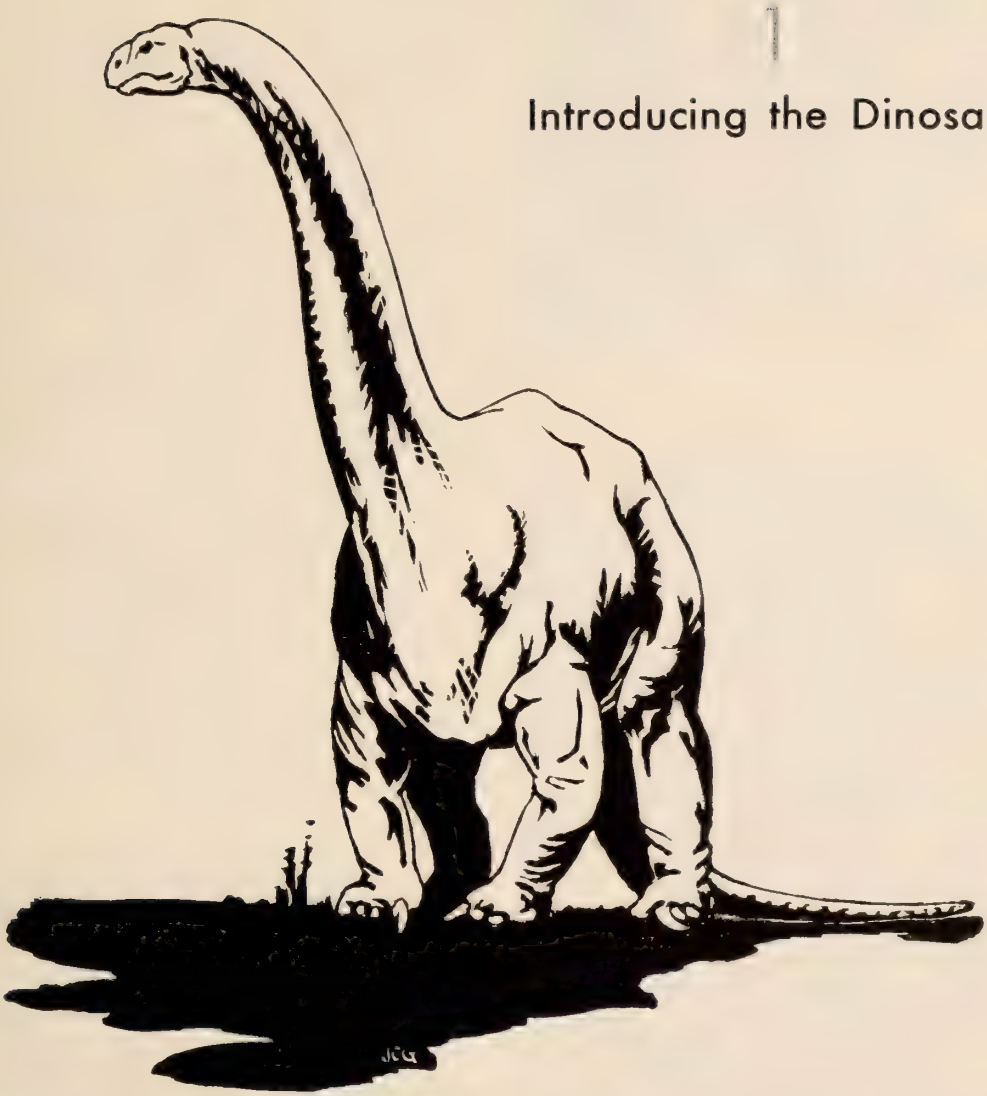

1
Introducing the Dinosaurs

Almost everybody knows that at one time, long ages ago, there were dinosaurs on the earth. Indeed, the public has become "dinosaur-conscious"—so much so, that the word "dinosaur" has become a common term in the English language, a word that stands for strength, size, and antiquity.

And it is no wonder that the average man has at least a slight nodding acquaintance with the dinosaurs, for in these days of widely disseminated thought they are all around him. Fossil skeletons are to be seen in the exhibition halls of many of our larger museums. Here also are pictures showing what these ancient animals looked like when they were alive. And from the museums they get into books of various kinds.

Now and then a dinosaur will show up on the Broadway stage or at a World's Fair. They are constantly popping out at us in humorous cartoons, and they frequently come to life in the movies. Their remains and the tracks they made can be seen in various localities throughout North America; one famous dinosaur collecting ground has been made a National Monument just so that visitors can see how dinosaurs are discovered and excavated from the ground. Modern man, whether he wants to or not, is sooner or later going to run into a dinosaur or something having to do with dinosaurs.

Not in the way that the cave men are sometimes portrayed as meeting the dinosaurs, with club or spear. No cave man ever saw a dinosaur. No human being ever met one alive, for the dinosaurs disappeared from the face of the earth *millions* of years before the first men appeared. Yet this idea of man and the dinosaurs living together at one time does persist, and it illustrates one of many misconceptions that are common with regard to the dinosaurs.

Indeed, so persistent is this idea that

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"It's hard to believe we're made like that inside!"

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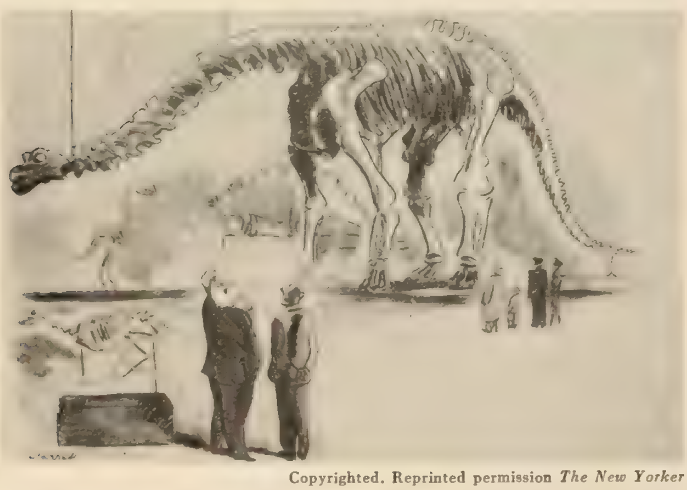
"I don't mind you boosting your home state, Conroy, but stop telling the children that dinosaur is a California jack rabbit!"



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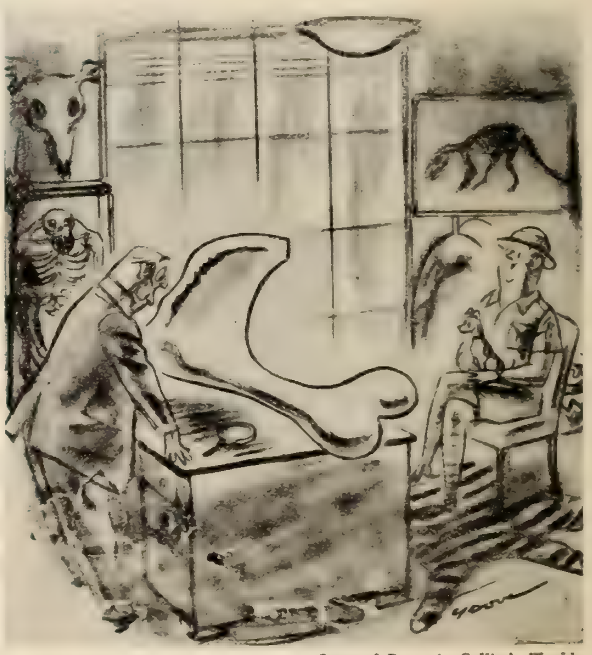
"And here is my first dinosaur—makes me feel like a kid again every time I look at it."



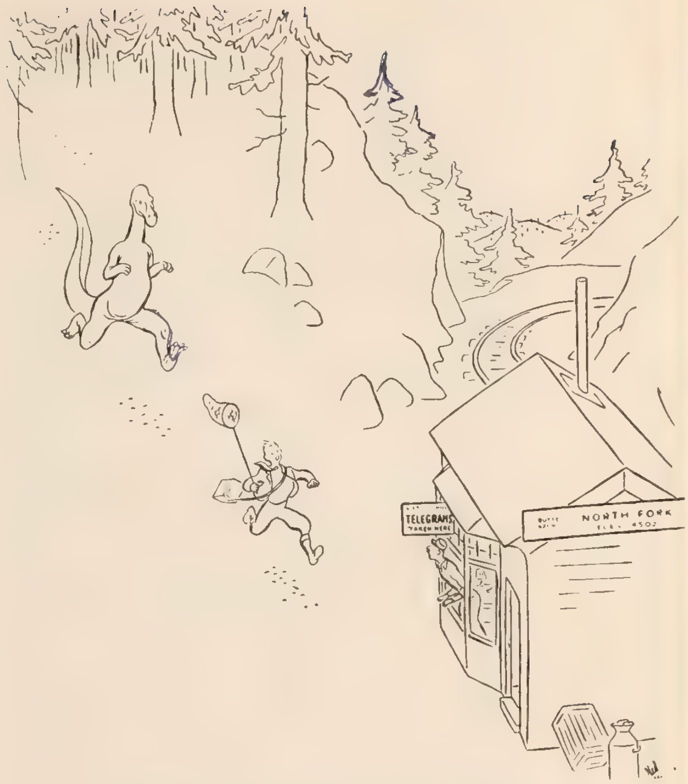
Leonard Dove, in *Collier's Weekly*

"We had seven hundred natives excavating the ruins, but you'll never guess who found it."

there are periodic outbreaks of sensational stories having to do with dinosaurs that are still living in some far corner of the South American jungles. Sir A. Conan Doyle's romantic novel *The Lost World* was based upon this idea. And no matter how often this misconception is killed by scientific facts, it keeps coming to life.

Another misconception is the common one that dinosaurs were all tremendously large beasts, crashing through the strange forests of an ancient world and tearing up trees by the roots. It is true that many of the dinosaurs were large, and some of them were the greatest animals ever to walk across the land, but it is equally true that there were many medium-size and small dinosaurs.

What, then, are the facts about dinosaurs? How did they live? What did they eat? How did they reproduce? What kinds



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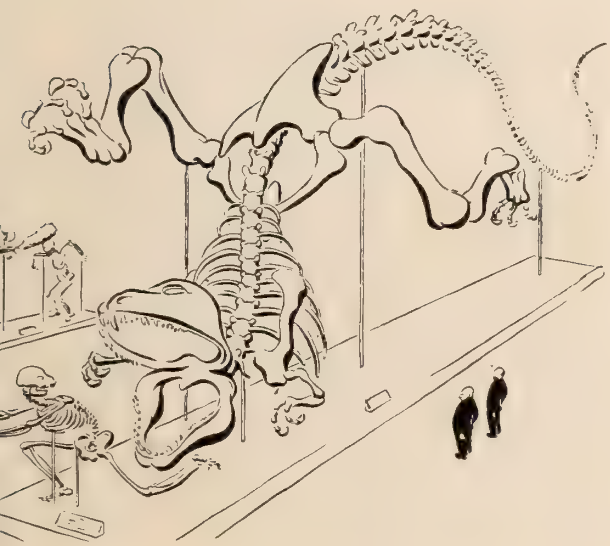
"Take a telegram to the Museum of Natural History."

DINOSAURS IN THE PUBLIC EYE



William Hayes in *Collier's Weekly*

"Adds a little life to the old place, don't you think?"

By Henry Boltinoff in *Maclean's*

"Homer told me before we were married he was a paleontologist. But I didn't know what it was!"

of enemies did they have, and how did they succeed in ruling the earth for so many millions of years? This seems like a lot to ask about animals that no one ever saw alive, yet the answers to these questions have been pretty well worked out through the scientific detective work that has brought us to our present rather complete knowledge as to the anatomy, the habits, and the environment of the dinosaurs. They are oft-repeated questions, too, for the subject of dinosaurs is a fascinating one to a very great many people.

Let us therefore get acquainted with the dinosaurs in a proper way, let us learn to know them instead of continuing to look at them from across the street.

The dinosaurs were reptiles, cold-blooded animals related to the crocodiles, lizards, and snakes. They lived during the Mesozoic period of Earth History, which began some 200 million years ago and ended about 60 million years ago, at which time the dinosaurs became extinct. The dinosaurs were of many kinds, some being of tremendous size, some small, some adapted to a carnivorous or meat-eating mode of life, some to an herbivorous or plant-eating existence. Large or small, meat-eating or plant-eating, the dinosaurs were dinosaurs by virtue of their anatomical structure—a subject that will be explained in more detail at another place in this book. They were the ruling land animals of Mesozoic times, and considering the great duration of the stage in Earth History through which they lived, they must be considered as among the most successful of the backboned animals.

It is the purpose of this book to present a picture of the various kinds of dinosaurs, to explain their relationships to one another and to other reptiles, to inquire into the manner in which they lived together, and to explore the environmental conditions that surrounded them and determined the separate courses of their varied life histories. Since there were other reptiles living with the dinosaurs, the picture cannot be thoroughly understood unless it is completely presented, so these contemporaneous animals will also be described, and their places in the general scheme of life will be evaluated. Finally, since the dinosaurs came from earlier reptilian ancestors, the primitive reptiles of earlier ages will be discussed, while the ancient amphibians, the ancestors of all four-footed animals will also be considered. In short, this will be a story of the evolution of vertebrate life on the land as it occurred between the emergence of the first land living animals, the amphibians, from their fish ancestors, some 340 million years ago, to the final culmination and the ultimate decline of reptilian dominance, almost 300 million years later.

It is a story of great proportions, stretching over long periods of Earth History. It is a story on so vast a scale as to dwarf our own history almost to insignificance. Yet great as are its dimensions, it is a story that is finished, for it is a tale of the triumph of brawn, a triumph that was long-lived, but which in the end gave way to the triumph of brain. The dinosaurs had their day, and while it lasted it was a Great Day.

2

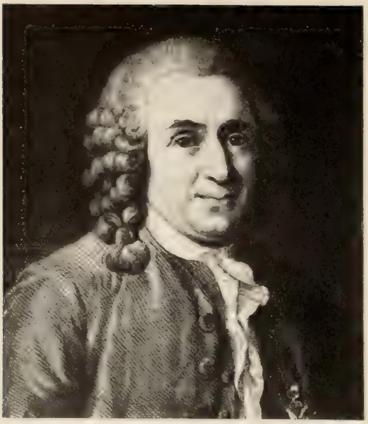
Pioneer Students of the Dinosaurs

A HUNDRED YEARS OR SO AGO the science of paleontology was in its infancy. There were no well-established techniques for the discovery and excavation of fossils, and the study of ancient life on the earth was carried on in a rather haphazard manner. Fossils were to a great extent the result of accidental finds. Some quarrymen would turn up a strange object while working out roofing slates or building blocks or road material; this strange object would be regarded with a suspicious eye, argued about, and finally presented to the nearest available "professor" for identification. Perhaps the professor would not be able to place it, in which case he would pass it along to another professor until finally the fossil, usually a pitifully small fragment, would come to rest in the collection, or the "cabinet" (as museums were then called), of some college or university or learned society. Fossil collections were largely the result of chance, and the study of fossils was therefore for the most part opportunistic. Naturally, the existing knowledge of past life on the earth was very spotty and incomplete.

Since knowledge of past life was incomplete, its interpretation was inadequate. But as men became more and more interested in the history of the earth they became more aware of the fact that the chance collection of fossils and their chance study would hardly suffice to give a true understanding of the development of ancient life. Consequently the subject began to attract serious students, who based their work on materials avowedly collected for study—not upon the chance discoveries of quarrymen. Thus began the pioneer period in the *science* of paleontology, the period when the study of fossils became a well-founded full-time subject of investigation by serious, trained scholars, rather than an avocation for gentlemen of broad interests.

The outstanding figure of the pioneer period was Baron Georges Cuvier, the great French anatomist and paleontologist. Cuvier (1769-1832) became interested in Natural History at an early age, and by the beginning of the nineteenth century he was established as Professor of Natural History at the Collège de France. From about 1798 until the time of his death he applied himself diligently to the study of fossil vertebrates (backboned animals), publishing many important papers and memoirs on the comparative anatomy and the classification of the vertebrates—both living and fossil. As a result of his labors the interrelationships of the backboned animals and the unity of their basic pattern were for the first time adequately elucidated to the scientific world. He may be said to have been the founder of the science of Vertebrate Paleontology.

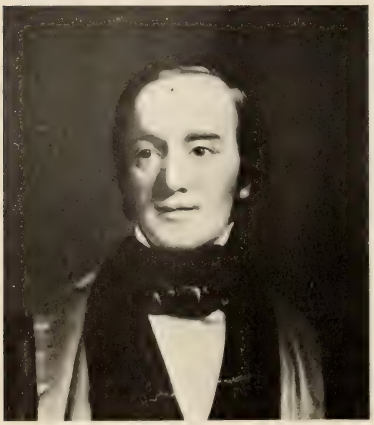
A contemporary of the great Cuvier was Dr. Gideon Mantell (1790-1852), an English physician, who during the early part of his life lived at Lewes, south of London. Doctor Mantell became interested in fossils to such an extent that he turned with vigor to the excavation and study of extinct animal life as it was preserved in the Wealden or lower Cretaceous sediments around Lewes. He justly attained eminence as a student of geology and paleontology through the important discoveries that he



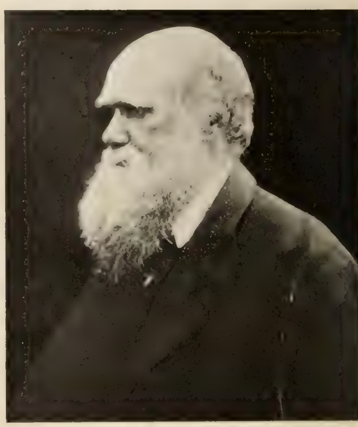
Engraved by C. E. Wagstaff

The great Swedish botanist Linnaeus (1707-1778) originated the system that is still used for naming and classifying all plants and animals

Georges Cuvier (1769-1832) won lasting fame by revealing the relationships among backboned animals, particularly as shown by their skeletons



Richard Owen (1804-1892), outstanding authority of his time, coined the name *Dinosauria* and established the study of extinct animals on a scientific basis in England



Charles Darwin (1809-1895) revolutionized scientific thought throughout the entire field of natural history and ranks as one of the world's greatest students of Life made and the lucid papers that he published, describing and interpreting his finds. Perhaps Mantell's chief claim to fame was his discovery and description of *Iguanodon*, the first dinosaur to be found in England. Indeed, his paper on *Iguanodon*, published in 1825, established Mantell as the pioneer student of the dinosaurs in England.

In Lewes the house of Gideon Mantell is still standing, and on a brass plate fastened outside the door of this house are these words:

"He discovered the Iguanodon"

However, the greatest of the early English students of dinosaurs and other extinct animals was Sir Richard Owen (1804-1892). If Cuvier may be called the founder of the science of vertebrate paleontology, Owen may be called the man who established the science in England. Like so many early students of Natural History, Owen prepared himself for the practice of medicine, but by the time he had completed his medical studies it became apparent to his professors that he was much too valuable a man to go into general practice. So he turned to anatomical research and in due course of time became Hunterian Professor at the Royal College of Surgeons. However Owen's interests ranged far beyond the field of human anatomy, and he became by virtue of his investigations the outstanding authority of his time on the anatomy of the backboned animals, both living and extinct. He was the first Director of the Natural History division of the British Museum, and was instrumental in establishing this institution in its present buildings in the South Kensington district of London.

Many of Owen's studies were on dinosaurs. It was he who first recognized that these extinct reptiles needed a name to designate them, and it was he who coined the word *Dinosauria*. Subsequently Owen's name became anglicized to *dinosaur*, and today it has acquired an established place in our common language.

Strange as it may seem, one of the first excavators of fossil reptiles (although the objects dug up were not dinosaurs) was not a learned student of paleontology but a young girl.

Mary Anning lived at Lyme Regis in southern England with her father, in the early days of the last century. In those days many people from London sought the fresh airs of the seacoast, and Richard Anning made a small living by collecting fossil seashells and selling them to the tourists. In this interesting trade he was aided by his daughter, Mary, who may be said to have been an early protagonist of the old tongue-twister—"She sells sea-shells."

When she was a little girl, but twelve years old, she discovered, while searching for fossil shells, the first skeleton of the marine fossil reptile, *Ichthyosaurus*. That was in 1811. She became interested in the fossil reptiles of the marine Jurassic beds of southern England, and from that time on she was ever on the lookout for skeletons. After the death of her father, Mary Anning continued the business of collecting fossil shells for the tourist trade, but her real interest was in the bigger vertebrate game. To make a long story short, she embarked upon a career of fossil reptile collecting, and she made good in a field that has been since its beginnings a man's game. In 1821 she found the first *Plesiosaurus* skeleton, and in 1828 she discovered the first skeleton of a pterosaur, or flying reptile, to be unearthed in England. She collected numerous fine specimens of ichthyosaurs and plesiosaurs and sold them to various individuals and institutions throughout the world.

Some mention should be made at this place of Charles Darwin (1809-1882) and his great disciple, Thomas Henry Huxley (1825-1895). Darwin, who must rank as one of the greatest men of all time, was not primarily a student of fossil reptiles, or of dinosaurs in particular, but it was his concept of organic evolution that revolutionized scientific thought throughout the entire field of Natural History. Since the publication of Darwin's *Origin of Species* in 1859, man has come to look at dinosaurs and all other remains of extinct life in a very different light than he had previously viewed them. Our modern understanding of the development of life on the earth is based upon Darwin's work; our philosophy has grown from the stem of Darwin's great philosophical truths. Of all the great students of Life, Darwin was the greatest.

Huxley worked ably and hard in the years following the publication of the *Origin of Species* as a champion of Darwinism. He was a brilliant scholar. He devoted considerable attention to fossil reptiles.

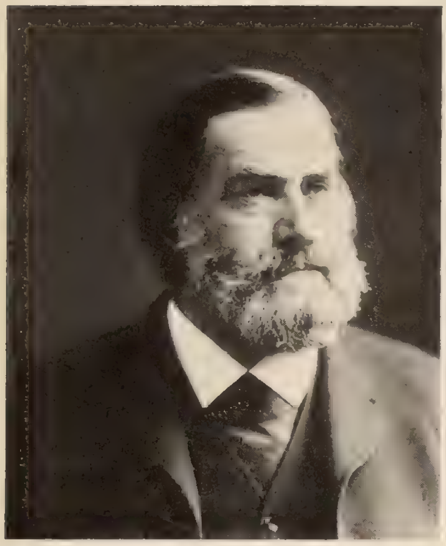
At about the time that Cuvier and Mantell were working in Europe, some queer, three-toed tracks were being found in rocks of Triassic age, in the Connecticut Valley. They excited the particular interest of Professor Edward Hitchcock, of Amherst College. He collected and studied examples of the fossils, many of which are still to be seen in the collection of the Amherst College Museum, and he came to the conclusion that these tracks had been made by some large, extinct birds. Later it was realized that these were actually tracks of early dinosaurs and other reptiles, so that Hitchcock may be considered as one of the first collectors on this continent of dinosaurian remains (or at least the evidences as to the existence of dinosaurs), even though he at first did not realize the significance of his finds. Of course Hitchcock's mistake is readily understandable, when it is remembered that in his day dinosaurs were virtually unknown and when it is realized that the tracks he saw, those of two-legged dinosaurs, closely resemble large bird tracks.

However, the first dinosaur skeleton to be discovered in North America was found, of all places, in a suburb of Philadelphia, the little town of Haddonfield, New Jersey. The fossil first came to light during the course of some excavations in a marl bed, and it immediately was an object of curiosity to the diggers, to their sisters and their cousins and their aunts, and to the public in general. As more bones of the animal came to light they were carted off as souvenirs, so that many of them came to rest on New Jersey mantelpieces, or served as doorstops in Pennsylvania homes.

Some years later, in 1858, this discovery came to the attention of Mr. W. Parker Foulke, a Philadelphian interested in the subject of Natural History in general and in the Philadelphia Academy of Natural Sciences in particular. Mr. Foulke reopened the excavation where the fossil had been partially disinterred, and he found a great deal more of the skeleton.

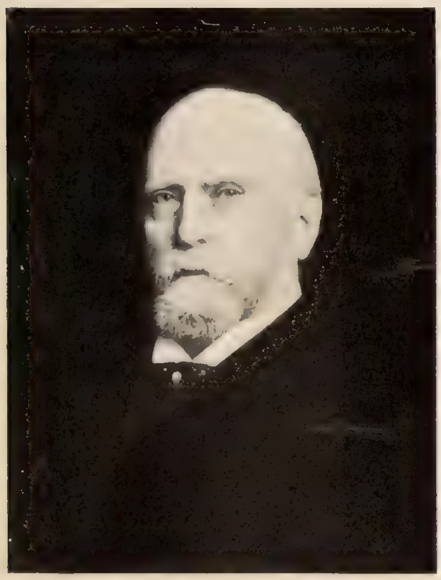
The skeleton, or such of it as still remained, was placed by Mr. Foulke in the Philadelphia Academy of Natural Sciences, where it was studied by the American paleontologist and anatomist, Dr. Joseph Leidy (1823-1891). Leidy, a man of great ability and learning, may be said to have been the founder of the science of verte-

FOUNDERS OF MODERN FOSSIL EXPLORATION AND RESEARCH



Joseph Leidy (1823-1891) inaugurated the period of continuous research in vertebrate paleontology in North America

Edward Drinker Cope (1840-1897), of Quaker ancestry, was a leading pioneer in the search for fossil animals in our West



Othniel Charles Marsh (1831-1899) had a genius for organization and led many fossil hunting expeditions into western North America. He and Cope were scientific rivals

Henry Fairfield Osborn (1857-1935) organized vertebrate paleontology on its modern basis with a staff of highly trained experts at the American Museum of Natural History brate paleontology in North America; it was from the beginnings he made in the subject that the science has continuously developed and grown to its present stature in this country. He was for many years Professor of Anatomy at the University of Pennsylvania and in addition served on the scientific staff of the Academy. While working on this fossil, Leidy was able to trace down some of the "souvenirs" and add them to his skeleton, although, unfortunately, many of the vertebrae and other parts first discovered were irrevocably lost. Nevertheless, the better part of the skeleton was obtained. It is the skeleton of a duck-billed dinosaur, *Hadrosaurus.*

In spite of the good work of the pioneer paleontologists during the first half of the nineteenth century, there was then no concerted program of fossil collecting in North America. This phase really began after the War Between the States when the great expanses of the West were being opened. At that time the United States Government instituted a series of "Territorial Surveys" of the West, in an effort to assess after a fashion the natural resources of the strange new land. The emphasis of these surveys was on the geological side, and a result was the discovery of many fossil localities. Arrangements were made whereby the fossils would be studied by two men who had independently begun to conduct and direct some ambitious collecting trips in the western territories. These men were Edward Drinker Cope of Philadelphia, and Othniel Charles Marsh of Yale University, and with them there began a new, interesting, and highly exciting period in American paleontology.

Edward Drinker Cope (1840-1897) was a man of extraordinary brilliance and ability; in fact, he was one of the greatest scholars that this country has ever produced. He was of Quaker ancestry, the descendant of an old and prominent Philadelphia family, yet in spite of his many gifts of position, wealth, and intellect he was a person of erratic temperament, a fact which conditioned many of his actions in later life.

Othniel Charles Marsh (1831-1899), a man of perhaps lesser intellect than Cope, was nevertheless a scholar of ability with a genius for organization. Like Cope, Marsh was a man of considerable wealth.

At first Cope and Marsh were friends, but when their work began to reveal the fossil wealth of the West, they soon became rivals, and eventually bitter enemies. They organized their own expeditions to collect fossils. Year after year, during the quarter-century between about 1870 and 1895, Cope and Marsh had exploring parties in the field, delving into the virgin fossil localities of the great Plains and of the Rocky Mountain basins. It was a race to see who could get the most material and describe it—a race that now seems fruitless, since we have come to learn how abundant are the fossils to be found by the trained and diligent fossil hunter. There is enough material for everybody. But Cope and Marsh didn't think so, and they engaged in a cutthroat competition which was perhaps one of the bitterest scientific feuds in history. The result was that both men published a great deal, much of which was good, some of which was bad; and two great fossil collections were built up. And in these collections dinosaurs loomed large.

It was the first attempt at large-scale, long-term, planned collecting of fossil vertebrates—collecting that envisaged a series of expeditions over a number of years to predetermined localities. New horizons were revealed to the world of science, and assemblages of fossils were recovered that literally astounded scholars throughout the world.

Perhaps the rivalry between these two men stimulated each of them to efforts much greater than they would have made if all had been sweet and serene. However that may be, the fact is that the work of Cope and Marsh, added to the earlier work of Leidy, formed the basis for modern vertebrate paleontology in America, and in the world for that matter, because these men established entirely new techniques of collecting, preparing, and studying fossils. Men such as these have transformed vertebrate paleontology from a comparatively passive science, based upon the chance discovery of isolated data, to a vigorous, active branch of study which owes its modern success to long-range co-ordinated planning of world-wide scope. And in this field of scholarly endeavor America has played a leading role, thanks in part to the solid foundations built by Leidy, Marsh, and Cope.

What might be termed the modern period in the exploration and study of dinosaurs and other fossil vertebrates had its beginnings in the last decade of the nineteenth century. At that time a generation of younger men who had been students of Marsh or Cope came to the fore in this country, while in Europe the subject was being expounded to enthusiastic students by such great authorities as Huxley in England and von Zittel in Germany. Coincidentally there was a flowering of the larger Natural History museums in America and in the Old World, with the consequent opening of opportunities for fossil collecting on an adequately planned and well-executed scale.

The beginnings of the modern period in America may very well be dated by the entrance of the American Museum of Natural History into the field of active fossil collecting and research. In 1891, Professor Henry Fairfield Osborn left Princeton University and came to New York to establish a new department of vertebrate paleontology at the American Museum. Osborn, with his lifelong friend Professor William Berryman Scott, was a disciple of Cope and had studied in Europe under Huxley and other famous teachers. With his arrival in New York, the American Museum began a vigorous program of active work in the field of vertebrate fossils, a program in which the collecting, study, and exhibition of dinosaurs played a large and important part.

One of Osborn's first acts was to gather about him a staff of highly competent men: Dr. Jacob Wortman, one of Cope's assistants; Dr. William D. Matthew, a gifted paleontologist who will always stand as one of the leading figures in the annals of American paleontology; Dr. Walter Granger, a collector who has never been surpassed; Dr. Barnum Brown, who has devoted his life to the collecting and studying of dinosaurs; Mr. Adam Hermann, who received his training in the preparation of fossils under Marsh; and under Hermann a corps of skillful preparators and collectors, notably Messrs. Albert Thomson, Charles Lang, and Otto Falkenbach. With a staff such as this the American Museum was bound to make great strides in the entire field of vertebrate paleontology.

Soon after Osborn's association with the American Museum, the institution was able to purchase, through the munificence of Morris Ketchum Jesup, the great collection of fossils amassed by Cope during the years of his most active collecting trips—a collection upon which Cope had spent his entire personal fortune and the most productive years of his life.

Late in the 1890's a series of expeditions for dinosaurs was inaugurated at a locality known as "Bone Cabin Quarry" in Wyoming. Here the great skeleton of *Brontosaurus* and many other fossils of Morrison age were recovered, and from that time on, the American Museum has collected many of these great Mesozoic reptiles, much of the work being done under the supervision of Barnum Brown. Expeditions have ranged far and wide over the western part of North America, in Wyoming and Colorado, in Arizona and Texas, in Montana and Alberta. Collections have been made in the deserts of Mongolia and South Africa. Exchanges have been made with museums throughout the world. The result is that the American Museum now has a collection and an exhibition of dinosaurs and of many other fossil reptiles that is absolutely unsurpassed.

But during this period there have been other institutions making great strides in the excavation, study, and exhibition of dinosaurs and other fossil reptiles.

There is, of course, the Peabody Museum of Yale University, where the fossils gathered together by Marsh are housed. Here is one of the earliest great assemblages of dinosaurs, a collection which is still of prime importance, and which has formed the background for the researches of Professor Richard Swann Lull, one of the leading American authorities on dinosaurs. The United States National Museum, due to the long-continued and persistent efforts of Mr. Charles W. Gilmore, one of the great modern authorities, has also given attention to the dinosaurs.

Early in the twentieth century Andrew Carnegie became interested in dinosaurs, with the result that the Carnegie Museum in Pittsburgh embarked upon a period of intensive dinosaur work. As a result a tremendous quarry of Morrison age was excavated in eastern Utah, and a great amount of material was taken to Pittsburgh for preparation, study, and display. At the same time the Field Museum of Chicago (now the Chicago Natural History Museum) was exploring for dinosaurs, with satisfactory results.

In more recent years the National Museum of Canada, in Ottawa, and the Royal Ontario Museum, in Toronto, have carried on extensive programs of dinosaur collecting, particularly in the fossil fields of Alberta. Fine exhibits of dinosaurs may be seen in these museums.

Thus it may be seen that there has been in this country since the beginning of the present century a vigorous program of dinosaur collecting among some of the larger museums, and the result is that in no other country can such a variety and number of dinosaurs be found on display.

Some mention should be made of the work on fossil reptiles other than dinosaurs. Many years ago, Cope made extensive collections in the Permian beds of Texas, and as a result of his studies he showed how important the early reptiles of Permian age are in drawing up a complete and satisfactory picture of reptilian evolution. With the coming of the Cope collection to the American Museum, the foundations for an important Permian collection were established. In those early days of paleontology many Permian and Triassic reptiles were being discovered in South Africa, and were being described by Sir Richard Owen and other authorities at the British Museum.

Professor Osborn realized the importance of having the South African fossil reptiles represented in the American Museum, so he instituted a policy of acquiring such specimens. As a result the American Museum possesses an important collection of Permo-Triassic reptiles from the Karroo desert, collected for the most part by Dr. Robert Broom, a South African authority on these ancient vertebrates.

More than a half-century ago one of Marsh's students, Professor Samuel Wendell Williston, went from New Haven to the University of Kansas. There he built up an unexcelled collection of aquatic reptiles from the Niobrara Cretaceous beds of Kansas, a work which so enhanced his scientific reputation that he was called to the University of Chicago as Professor of Paleontology. There, with the able assistance of Mr. Paul Miller, he instituted a program of Permian work extending over many years, and assembled an outstanding collection of early amphibians and reptiles. This collection is now at the Chicago Natural History Museum.

Other American institutions have important fossil reptile collections, notably the Museum of Comparative Zoology at Harvard University, where much work has been done on Permo-Triassic reptiles in recent years under the able direction of Professor Alfred S. Romer; the Museum of Paleontology of the University of California, with fine Triassic collections made under the guidance of Professors J. C. Merriam and Charles L. Camp; and the Museum of the University of Michigan, in which are to be found Permian and Triassic reptiles and amphibians collected and studied by Professor Ermine C. Case.

What is to be the future of fossil collecting? Many years ago it was thought by certain scientists that when intensive collections had been made, the fossil "lode" would, so to speak, "peter out." But the more the fossil fields are worked the more they produce, and all the time new fossil fields are being found. Chinese paleontologists, in the midst of war and tribulations unequalled in human history, discovered a dinosaur skeleton in Yunnan Province in the year 1938, excavated it, brought it to Chungking, and published a descriptive monograph in 1942. Which goes to show that fossils will out, whether there be flood, fire, famine, pestilence, or war.

One thing is sure, fossil collecting will go on as long as man remains a curious animal. And the search for dinosaurs, their contemporaries, and their forebears will be carried to the most distant reaches of the globe, to the Americas and Europe, to Asia and Africa and Australia. It is one field of collecting in which there is never any danger of extinction of the supply, where wise and co-ordinated policies will furnish ample collections for everybody.

A list of museums in North America where fossil amphibians and reptiles may be seen on display is presented below.

1. American Museum of Natural History, New York.

The exhibits are dominated by skeletons and skulls of dinosaurs, but there are also important displays of other fossil reptiles, notably pelycosaurs, mammal-like reptiles, thecodonts, turtles, crocodilians, ichthyosaurs, plesiosaurs, and flying reptiles.

2. United States National Museum, Washington, D.C.

Here are found many notable displays of dinosaurs, some of which were collected and studied by Professor Marsh. There are also exhibits of Permian reptiles, turtles, and in addition some unusual specimens of fossil lizards.

3. Peabody Museum of Yale University, New Haven, Conn.

The Peabody Museum collection is particularly important for the wealth of dinosaurs that it contains. A number of fine skeletons are on display.

4. Museum of Comparative Zoology of Harvard University, Cambridge, Mass.

The exhibits at this museum are noteworthy because of the Permian forms that are shown. There are also some important displays of aquatic reptiles.

5. Academy of Natural Sciences, Philadelphia, Pa.

Some fine specimens of ichthyosaurs and plesiosaurs, collected in England about 100 years ago.

6. Amherst College Museum, Amherst, Mass.

A mounted skeleton of the duck-billed dinosaur, *Trachodon.*

7. National Museum of Canada, Ottawa.

At this museum is housed a particularly fine exhibit of dinosaurs from the Cretaceous beds of western Canada.

8. Royal Ontario Museum, Toronto, Canada.

A notable display of dinosaurs from the upper Cretaceous beds of Alberta.

9. Carnegie Museum, Pittsburgh, Pa.

The fossil reptile exhibits in this museum consist for the most part of an extraordinary series of Jurassic dinosaurs, collected in the Morrison beds.

10. Museum of Paleontology of the University of Michigan, Ann Arbor, Mich.

A notable collection of Permian and Triassic amphibians and reptiles from Texas and adjacent regions.

11. Chicago Natural History Museum, Chicago, Ill.

At this museum may be seen some specimens of dinosaurs. Here, without doubt, is to be seen the finest display of North American Permian vertebrates in existence. There also are some important reptiles from the Karroo beds of South Africa.

12. Dyche Museum of the University of Kansas, Lawrence, Kans.

The fossil reptile collection in this institution is noted for the skeletons of the aquatic mosasaurs, from the Niobrara Cretaceous beds of Kansas.

13. University of Nebraska Museum, Lincoln.

Mounted skeletons of *Stegosaurus* and of a mosasaur.

14. Texas Memorial Museum, Austin.

Permian vetebrates.

15. Southern Methodist University, Dallas, Tex.

Permian vetebrates, plesiosaur.

16. Colorado Museum of Natural History, Denver, Colo.

Several dinosaur skeletons are on display in this museum.

17. University of Utah, Geological Museum, Salt Lake City.

Mounted skeleton of *Allosaurus*, dinosaur bones, tracks.

18. Museum of Paleontology of the University of California, Berkeley, Cal.

The fossil reptiles are mainly those found in the Pacific coast and the southwestern regions of the United States.

19. California Institute of Technology, Pasadena, Cal.

Reptiles from the Pacific coast region.

3

Hunting Dinosaurs

One of the questions most frequently asked of the paleontologist is, "How do you find these fossils?" Indeed, it is puzzling to the uninitiated how the paleontologist will announce in the spring that he is going out to hunt fossils and then go to some distant region in the summer and make good his promise. How does one know where to look for the things? How does one go about it? Does one start by digging a hole in the ground, which mysteriously brings to light a new and strange variety of dinosaur?

There is nothing really mysterious about the process of hunting—and finding—dinosaurs, or other fossils for that matter. The technique is mainly a combination of good geological judgment, horse sense, perseverance, and hard work.

The first requisite for the dinosaur hunter is to know where he should begin to look for the fossils. The dinosaurs lived during the Mesozoic age of Earth History; it necessarily follows that their remains will be found in rock strata of Mesozoic age, and nowhere else. (By the same token, if one is looking for primitive fish, attention is limited to early Paleozoic rocks, while if the search is concerned with the more advanced mammals, the regions explored are those where Cenozoic rocks are exposed.) Of course in the early days of fossil hunting it was pretty much a hit-and-miss affair, because the science of geology was so young that the rock layers of various ages were not well known nor were they adequately mapped.

The early expeditions of the Territorial Surveys and those of Cope and Marsh worked to a certain degree in a blind way, because the territory they were exploring was essentially a new region. And the same is true, although to a continually lesser degree, at the present time whenever expeditions go into relatively unknown parts of the earth—as for example the Central Asiatic Expeditions of the American Museum of Natural History to Mongolia. For many regions, however, the rocks of the earth have been studied and mapped in a fairly adequate manner, so that the paleontologist goes to localities where he will be reasonably certain of finding fossils of the type in which he is interested.

The entire procedure is really a rather interesting process of round robin reasoning. Most of the sedimentary rocks of the earth's surface are dated by the fossils they contain. Thus it is that in a new area, the first clues to the age of the beds exposed are obtained from fragmentary fossils, found haphazardly and by chance during the course of general exploratory work. Having thus established the age of the beds exposed in the new region, and having determined the extent of their exposures, subsequent work is carried out in a systematic way with definite ends in mind. Perhaps a season of intensive search for fossils fails to justify the hopes first entertained by the enthusiastic bone hunter. If so, the summer's work must be written off as "good experience," and fossil-avid eyes are cast in other directions. But the paleontologist of good judgment will rarely embark upon a program of intensive work unless he is pretty sure that the results will justify the expenditure of the time and money that are allotted to him; consequently the results obtained by most fossil expeditions are fairly consistently satisfactory.

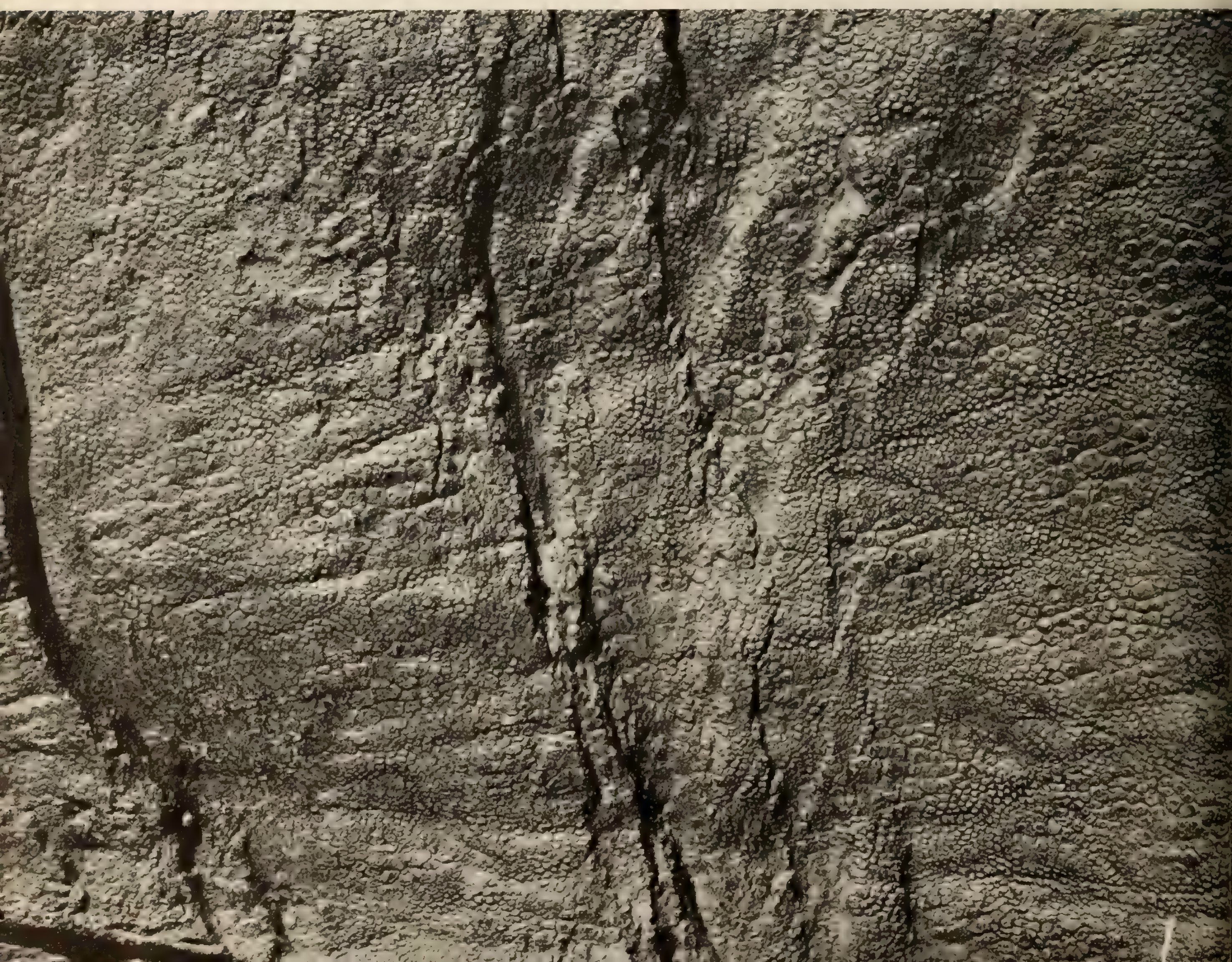
Having picked a region for exploratory work, the fossil hunter follows a definite and systematic procedure for ferreting out the dinosaurs, or fishes, or phytosaurs, or mammals, or whatever he may be after. First, by a method of trial and error, he learns just which levels or "horizons" in the rock layers are the fossil-bearing ones. Then he "walks out" the level, with one eye peeled for the precious fossils he is seeking, the other busy searching for the next place to step. Which latter is more important than it may sound at first, for much of the business of "walking out" a formation involves a constant scramble along cliff faces, up and down the sides of canyons, in and out of arroyos or washes.

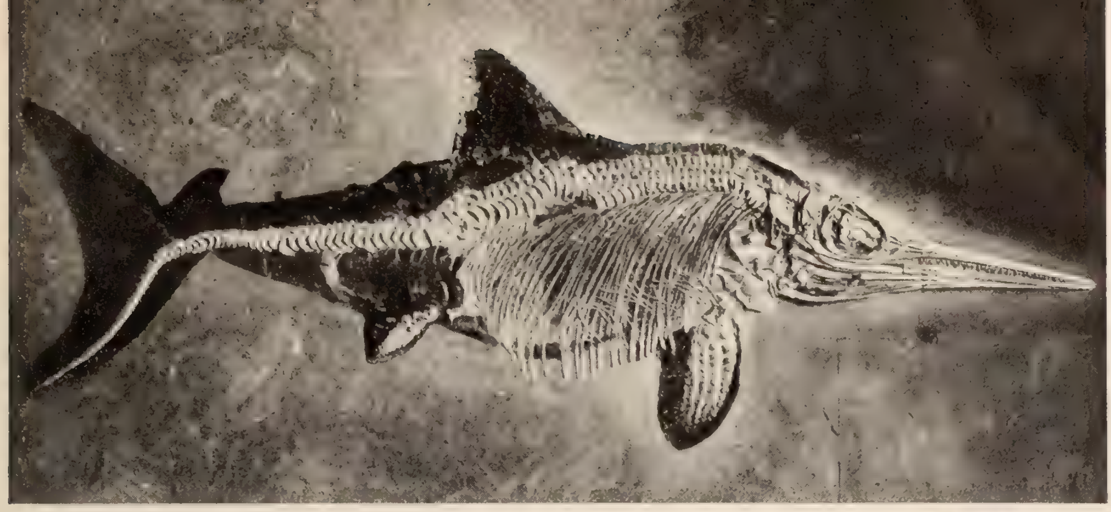
Of course it is important for the fossil hunter to know just what he is looking for—indeed, much of the secret of successful collecting is the recognition of a fossil as it is exposed in the strata, usually with merely a trace of the entire organism show-

Fossils are of many kinds

Sometimes only an imprint of the skin is preserved. Here the skin itself has been replaced by minerals. (From a Duck-billed Dinosaur)

skin





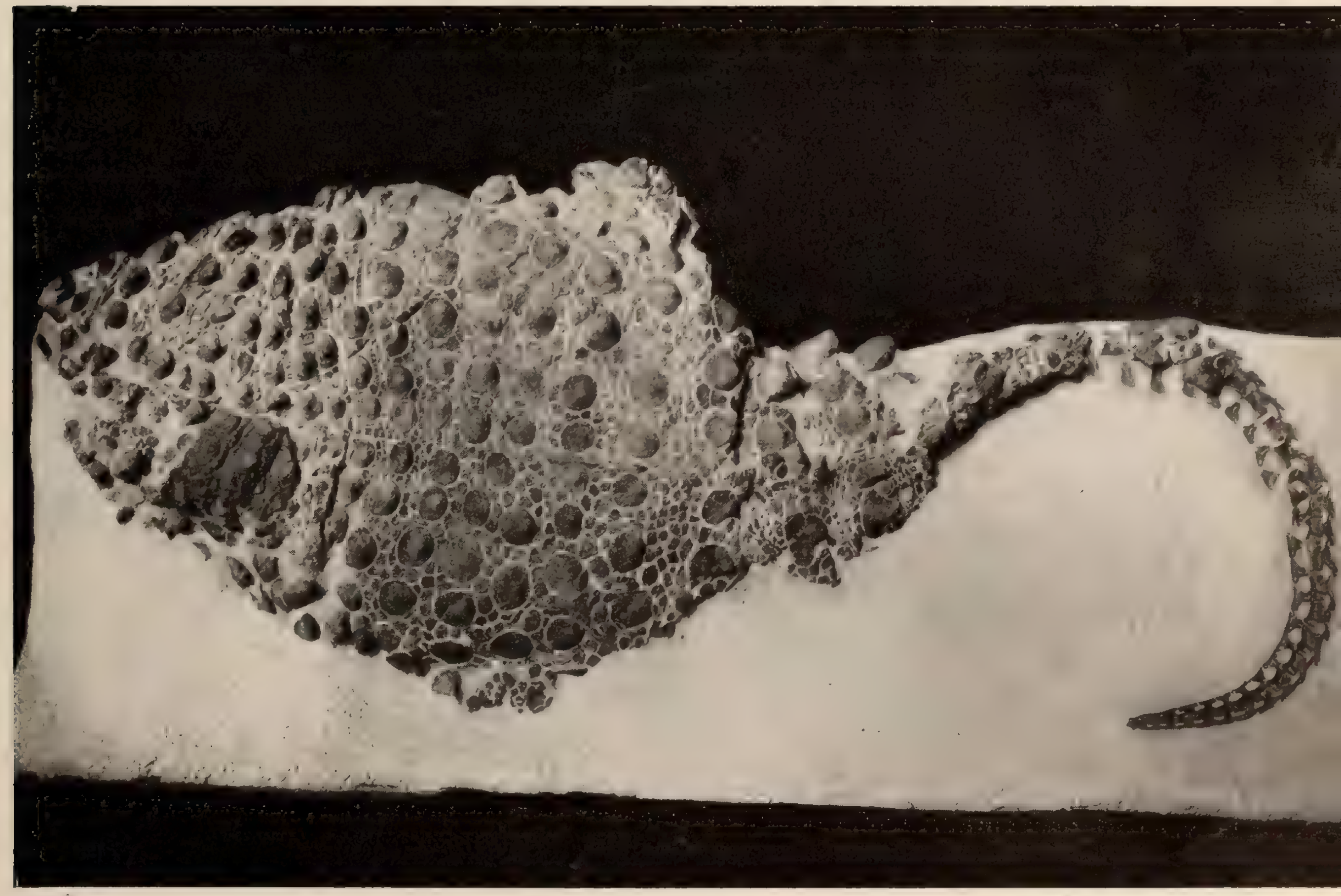
Here the form of the animal is retained as well as the skeleton: a fine example of the preservation of soft parts. (An ichthyosaur)

body outline

A.M.N.H. photographs

bony armor

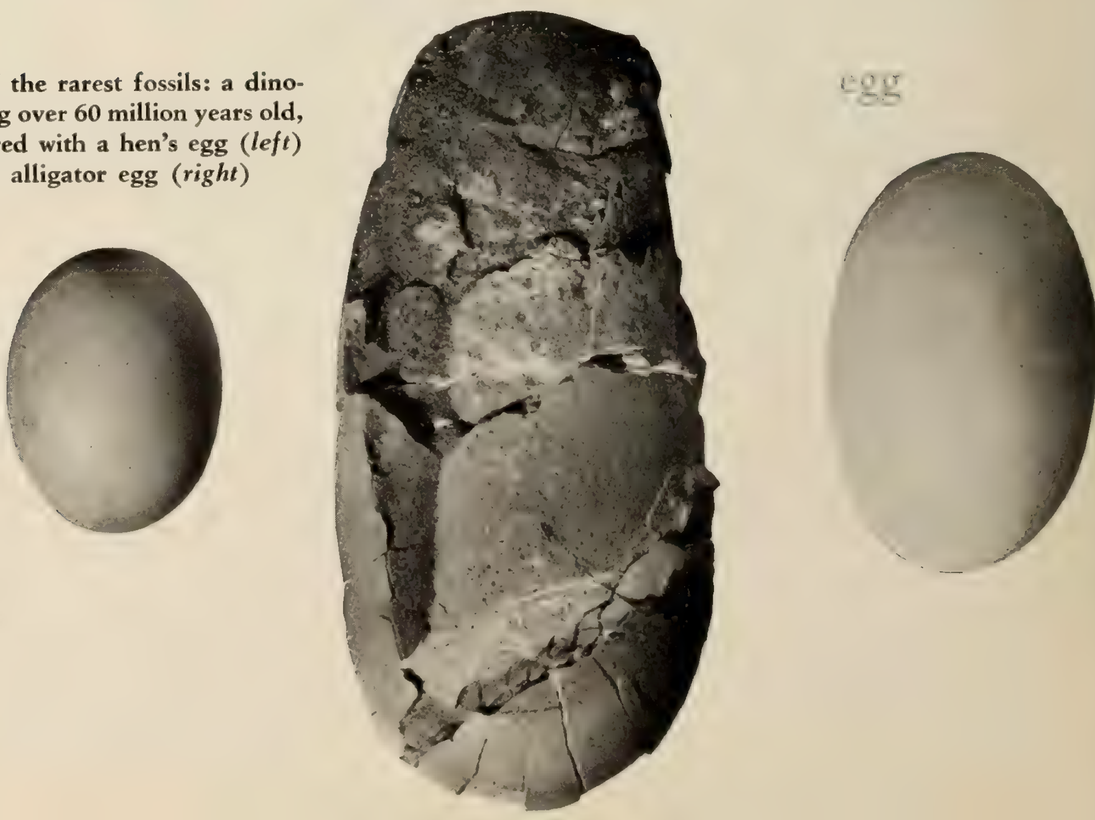
Beneath the skin, a coat of mail protected this animal and was fossilized. (A nodosaur)



A typical example of the parts usually found fossilized: portions of the skeleton of a small dinosaur from Mongolia

A.M.N.H. photographs

One of the rarest fossils: a dinosaur egg over 60 million years old, compared with a hen's egg (*left*) and an alligator egg (*right*)



footprint

Photograph by courtesy of Roland T. Bird

Fairly common are tracks made by dinosaurs in mud and later changed to stone. This one held eighteen gallons of water

ing. And that brings us to the question of "What is a fossil?"

A fossil is the remains or the indication of past life upon the earth. Originally the word fossil, derived from the Latin *fossilis* (dug up) applied to anything dug out of the earth, whether it were the remains of animal or vegetable life, or minerals. In modern usage, the term fossil is restricted to the remains or indications of organisms which once lived on the earth.

Fossils are preserved in a variety of ways. Usually fossils are replacements in stone of materials which were originally organic. A living animal, a sea-shell, a fish, a dinosaur, a mammal, died and its body was covered by the ooze of the ocean bottom, by the mud of a shallow river, or by the shifting sands of a desert. Thus entombed, decay of the organic materials oftentimes was retarded, especially as regards the hard parts, such as shell or bones. Consequently the breaking down of these hard portions of the organism was a slow process. And if conditions were just right, it was accompanied by another process, namely the replacement of the original material by mineral matter, deposited by the waters that percolated through the sediments in which the animal was buried. This replacement was complete and molecular in nature, so that not only the external shape of the shell or the bone was preserved in rock, but also the internal microscopic structure. So it is that we are able to study a thoroughly mineralized fossil shell or bone just as completely as if we had the original shell or bone to look at.

Such is the form of many fossils, but not by any means all. For instance, some fossils are actually the original shells and bones, with little or no mineral replacement. This is often the case with fossils of a relatively recent age, in which there has not been time for fossilization or "petrification." Although the remains are not mineralized, they are nonetheless fossils, because they represent the remnants of something that was once alive on the earth.

Some fossils are found as molds or casts. In these instances, the original organism has decayed or dissolved, leaving a hollow impression in the sediment or the rock in which it was entombed. The hollow impression is a mold. If that mold becomes filled with sand or mud, which eventually solidifies to form stone, a cast is produced, a fossil which preserves the external form but *not* the internal microscopic structure of the original.

In some cases even the soft parts are fossilized, although this is unusual. When we find a fossil of this type we can be sure that conditions were such that the soft parts were protected in some fashion against immediate decay, while mineralization was comparatively rapid. On page 26 the fossilized skin of a Duck-billed Dinosaur is pictured.

Sometimes fossils are formed by unusual minerals, such as iron pyrites, or opal.

Many fossils are not the remains of the animals or plants, but merely the indications of such organic structures. Fossilized tracks are fairly common. Often fossilized burrows are found, or fossilized insect nests. Even the marks made by leaves brushing across the mud are sometimes preserved as fossils.

So it is that fossils may assume a variety of forms, and the fossil-hunter must be able to recognize fossils of these several types in the field, and interpret them properly. That is why he keeps one eye peeled as he scrambles along the face of a very hard and high cliff, under a very hot sun, barking

➔ Bad lands are good lands for fossil hunters. But rough cliffs like this one in Utah have scraped the shins of many a prospector who thought he saw something just a little higher

A.M.N.H. photograph

← Once discovered, the ancient bones are uncovered by careful work with pick, awl, and brush. During this delicate operation, the fossil hunter must often endure scorching sun, sandstorms, and sudden showers

Photograph by Barnum Brown

➔ From inaccessible locations fossilized bones weighing several hundred pounds can be taken to the wagon road only with difficulty. Careful engineering is necessary to ensure their safe transportation

A.M.N.H. photographs

← Finally the prehistoric treasure is hurried on its way to the railroad platform and the museum, where it will be his shins, tearing his trousers, and sunburning his back.

Sooner or later he will find the traces of a fossil—perhaps some broken bits of bone or teeth, if he is out for dinosaurs. Then he looks around to see if he can locate the place that is producing these broken bits—the place where the more complete animal is buried. Usually he has little success, the broken bits were merely broken bits, the fragments of an isolated bone or tooth. (Skeletons have a disconcerting trait of getting thoroughly dismembered and scattered before they are ever fossilized.) But every now and then the fragments lead to something bigger—above his head 20 feet up on the side of the cliff some bones are protruding from the face of the rock.

Then comes the process of clambering up to the fossil and establishing a place to work, oftentimes with many a prayer for "sky hooks" to help the struggling bone hunter defy the law of gravity. After that there is the tedious business of removing the "overburden," the tons and tons of rock that are usually piled on top of the fossil and must be gotten out of the way. That is one of the great gambles in fossil hunting. Sometimes considerable effort will be expended in removing the overburden, only to find that the fossil "peters out" six feet in from the face of the cliff. But at other times the dreary work of picking, shoveling, hauling, and often blasting, will be rewarded by the exposure of a fine skeleton, or even a whole series of skeletons. Sometimes fossils are found out on open flats, with little or no overburden. The fossil-hunter then offers fervent thanks to a benign providence for giving him (at least for one time) all gravy.

Then comes the work of exposing the fossil so that it can be removed. This involves a careful uncovering of the bone with pick, hammer, awl, and brush, so that the extent of the skeleton may be judged. Usually when this work is being done the sun is uncommonly hot and the air still and stifling. Or it is windy enough to blow the harassed fossil hunter "into the next county," and at every move he gets his eyes and mouth full of sand. Or there are a series of sudden desert rain storms that necessitate a series of frantic efforts to get the precious specimen covered by a canvas tarpaulin before it gets wet. Or there are flies and hornets.

At any rate, the work must be done, and done carefully. Every bone or tooth that is exposed must be shellacked and covered with tissue paper, otherwise it is apt to crumble to powder. Then the skeleton is removed, bone by bone, or else in blocks each containing several bones. To do this it is necessary to cover the part being removed with strips of burlap dipped in liquid plaster or in flour paste. When the burlap and plaster or paste covering has dried and hardened, it forms a strong cast over the bone or the series of bones, and thus prevents the fossil from breaking when it is moved. In other words, the fossil is "immobilized," in the same manner that a broken arm or leg is immobilized by a doctor. Then, when the top and sides of the specimen have been so secured, it is carefully freed from the rock on which it is resting, turned over, and the bottom is encased in the plaster and burlap bandage or cinch. If the specimen is very large, sticks of wood, or splints, are attached to the bandaged fossil to keep it from breaking of its own weight.

Next the fossil has to be moved to a suitable place and packed in a wooden box, in straw. Then the box is hauled to the

→ In the museum laboratory, the shellacked wrappings and the excess rock are removed from the fossil. This requires skill, patience, and great delicacy of touch

A.M.N.H. photographs

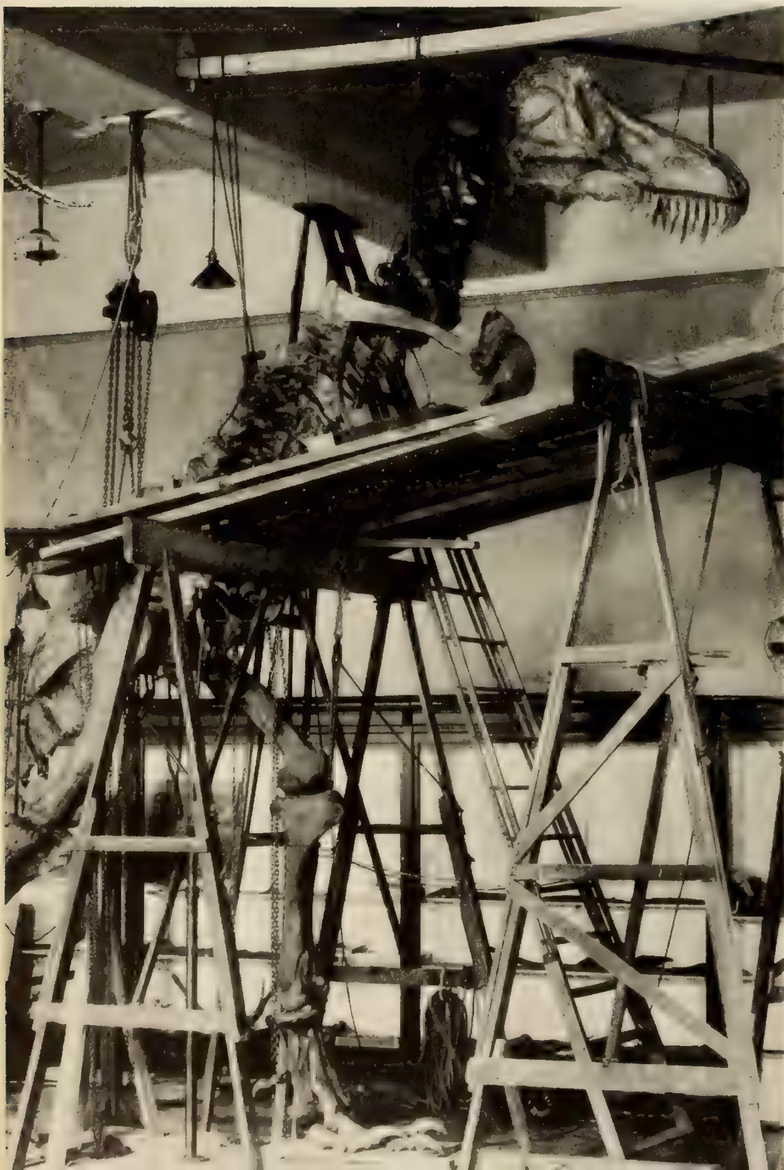
↓ Illustrations of the fossil for publication include not only photographs but careful drawings made by scientific artists

nearest railroad shipping point, and the specimen begins its trip to the museum.

When one is hunting dinosaurs, which are usually found in the most out-of-the-way places possible, and which often have single bones weighing two or three hundred pounds, the difficult nature of the work of fossil-hunting becomes painfully apparent. But in spite of the hard and hot work, the sand and the flies, the bad water, and the many natural discomforts that flesh is heir to, the fossil-hunters love it. Take a paleontologist's field trips away from him and he is apt to get savage, or at least to acquire a rather sour outlook upon life.

Collecting the fossil and sending it to the museum is only part of the story. In the museum the entire process that was gone through in getting the specimen out of the rock has to be reversed. First the fossil must be unpacked. Then the burlap and plaster cinches must be removed. After that there comes the long process of "preparing" it for study or exhibition. The bone must be freed completely from its rock matrix, a procedure that requires skill, patience, and a great delicacy of touch. Indeed, the process of preparation is usually the longest and most tedious part of paleontological technology. As the rock is chipped away from the bone, the fossil is hardened with shellac. Large bones are drilled, and steel rods are inserted into them to support their dead weight. Missing parts are filled in with plaster. Thus it may be seen that the preparation of a fossil skeleton is a long job, and when the work involves something as large as a big dinosaur, the task is truly colossal, requiring the full-time efforts of several skilled men for many months, or even years. That is why only the large institutions are able to go after the big game of dinosaurs.

After the fossil is fully prepared, the paleontologist at last begins his examination of it. The fossil must be compared with other fossils, and identified. Perhaps it is new. Then it must be carefully studied and a description written for publication in a technical journal. For it is only through publication that a fossil collection has any real value. Unless the information gained from the collecting and preparing of fossils is made available through the printed page, the assemblage of specimens is essentially a pile of meaningless junk. The reputation of a scientist and of the institution for which he works depends largely upon his publications. Without a solid foundation of scientific publications emanating from its



← If the extinct animal is to be placed on exhibition, the skeleton is mounted in position. The bones may have been greatly disarranged when found; here they are accurately assembled and held in a natural posture by concealed supports that will be scarcely visible when the scaffolding is removed

A.M.N.H. photograph

activities, a paleontological museum is not a museum but merely a warehouse or a showplace. Thus the publication of the studies made on the fossils is one of the most important functions of the museum. The scientist studies the material and prepares a manuscript. A trained scientific artist working with him makes drawings of the fossils to illustrate the publication. Together they produce the scientific paper which makes the information on the fossil available to students all over the world, and gives to it its true value.

If the specimen is sufficiently well preserved, and of sufficient importance, it will be placed in the exhibition hall. Only the more choice fossils, however, are placed on public exhibit; the bulk of the collection is retained in storage for study and future reference. This is modern museum practice, for we now believe that exhibits should tell a story by well chosen examples, rather than serve as dismal arrays of specimens on shelves, which was the philosophy of museum display a half-century or so ago.

If the specimen to be exhibited is a skeleton, it must be properly assembled, and this again is a job requiring a great deal of skill and considerable time. Irons must be bent to support the bones, and fastened together to make a sort of frame upon which the skeleton is hung. The preparator and the scientist work together on this, and oftentimes the job requires a great deal of supplementary study in order that the pose will be anatomically correct and at the same time interesting. But they keep at it in the museum laboratory, and after weeks or months of work the specimen finally stands articulated, a thing of real structural beauty, ready for the exhibition hall.

But the end may not yet be in sight. For the paleontologist may decide that a painted restoration is needed, to show the museum visitor how the dinosaur or the phytosaur or the pterosaur looked in life. So, that long-suffering and patient being, the artist, is called in again, this time to project himself in his mind's eye back to a distant age, to make a portrait of a beast long since gone from the face of the earth. He works with the paleontologist on this. Together they compare the fossil with the nearest related animal extinct or living. Together they figuratively hang muscles on the bones and then stretch a skin over the muscles and then brush a color over the skin. At last the animal stands as he may have appeared in life, and in all fairness it must be said that there is every reason to believe that a careful restoration made by a competent artist, working with a competent paleontologist who knows his anatomy, is pretty close to the truth. There remains only the task for the artist of putting in some contemporaneous scenery and vegetation (and that is no mean job), and the restoration is ready to go on exhibition along with the fossil, or in a book such as this.

But is that all? Not quite, for the labels must be written. One explanation of a good museum exhibit is that it consists of a series of excellent labels illustrated by good specimens. Well, the labels are prepared, and then the exhibit *is* ready, at long last.

It has been a long story, from the fossil in the field to the exhibit in the hall, a story involving the expenditure of many man-hours of time by various trained persons. But in the end the results are worth the price, for we have learned more about the past history of the earth and the proper interpretation of our modern world depends greatly upon our knowledge of its past.

Some of the more important localities at which fossil amphibians and reptiles have been found are discussed in Chapter 17.

4

The Age of Reptiles

We are living in the Age of Man, the period in which man rules the earth. For better or for worse we are supreme over all other forms of life. No longer is our existence threatened by large animals, as was the case with some of our not very distant forebears. No longer are we so seriously threatened by the less spectacular but much more deadly microscopic parasites, as were our ancestors of a few hundreds of years ago. There is nothing to challenge the supremacy of man upon the earth, except man himself.

It is readily understandable that having achieved this supremacy, we are apt to think of ourselves as the culmination of evolutionary history. And from our present-day standpoint this is true. No animal in the history of the earth has risen to the supreme dominance over the lands and the waters that is ours. Therefore, we can say that no animal, to our way of thinking, has been so successful as we are.

Yet there is another way of looking at this matter. Let us forget our natural bias as human beings and regard the question from an objective viewpoint.

Many ages ago, in the dim past of Earth History, lived the dinosaurs. These animals arose, evolved, and became extinct at ages so far distant from us that we can hardly stretch the imagination sufficiently to comprehend the immense passage of time that separates them from us. Since they are gone from the face of the earth, we are inclined to regard them as "failures" in the long history of life. Were they really failures?

Man has lived on this earth for perhaps a half-million to a million years, which seems like a long time. Of that great period, man has written the last seven thousand years of it into his record; before the period of recorded history man was a primitive savage, wresting his living from the soil and from the chase, ever surrounded by large beasts that challenged his right to the fields and forests.

The dinosaurs lived for a period of about *100 million years,* during which time they were the dominant animals of the earth. For a period at least *100 times as long* as the *entire* history of man, these ancient animals lived and fought and died—the lords of creation. Who are we to say that they were not successful?

Perhaps you are wondering about the rather casual bandying about of time figures so astronomical as these. What right have we to say that the dinosaurs lived so many millions of years ago, or that they persisted for so many millions of years?

This brings us to the subject of geologic time.

The immensity of geologic time is so great that it is difficult for the human mind to grasp readily the reality of its extent. It is almost as if one were to try to understand infinity.

The earth is about two billion years old. This is not a mere guess but is the result of careful, cumulative studies by many investigators working over a long period of years and along various lines of evidence. Of particular use are the investigations of radioactive materials in rocks of ancient age—indeed, it is by the study of the slow disintegration of radium and uranium into lead that we have extended our conception of geologic time to its present tremendous limits.

Of the two billion years of Earth History, only about one-fourth, or 500 million years of it contain adequate fossil records. In other words, 500 million years ago life on the earth had reached a stage so that the remains of plants and animals were of sufficient density and complexity as to be preserved in the form of fossils. In this 500-million-year fossil record we find the dinosaurs appearing some 170 million years ago and persisting through a period of about 100 million years' duration, to become extinct about 70 million years ago.

Perhaps these are mere figures. Let us look at the record in another way.

The recorded history of man goes back about seven thousand years, to about the time of 5000 B.C. Within this stretch of time are encompassed the events of history, as we know them, from the rise of the early civilizations of the Middle East to the present stage of our modern machine age.

The days of ancient Egypt seem vaguely distant to us, yet as compared to the entire history of man on the earth they are as but yesterday, for man first appeared about one million years ago. The 7000 years of history seem indeed of rather insignificant proportions when compared with the one million years of prehistory as revealed by the science of archaeology.

Man, even in his most primitive manifestations, is a relatively late product of evolutionary history, as compared with most of the life on this earth. Comic strips and jokes to the contrary, the dinosaurs had been gone and forgotten for a great many million years before man ever made his first appearance in a troubled world. In fact, there was a time lapse of some 69 million years between the disappearance of the last dinosaurs and the appearance of man, as revealed by the science of paleontology.

The 70 million years during which the warm-blooded mammals attained their supremacy may seem like an immensely long stretch of time, yet it was only a little more than half as long as the reign of the dinosaurs on earth.

Carrying the story still further into the distant mists of geological antiquity, it may be seen that the age of dinosaurs, tremendously vast to our way of thinking, occupied but a fraction of the time since the first well-preserved fossils appeared in the geologic history of the world.

Finally, the period of fossil history is but one-fourth of the period of Earth History, as was mentioned above.

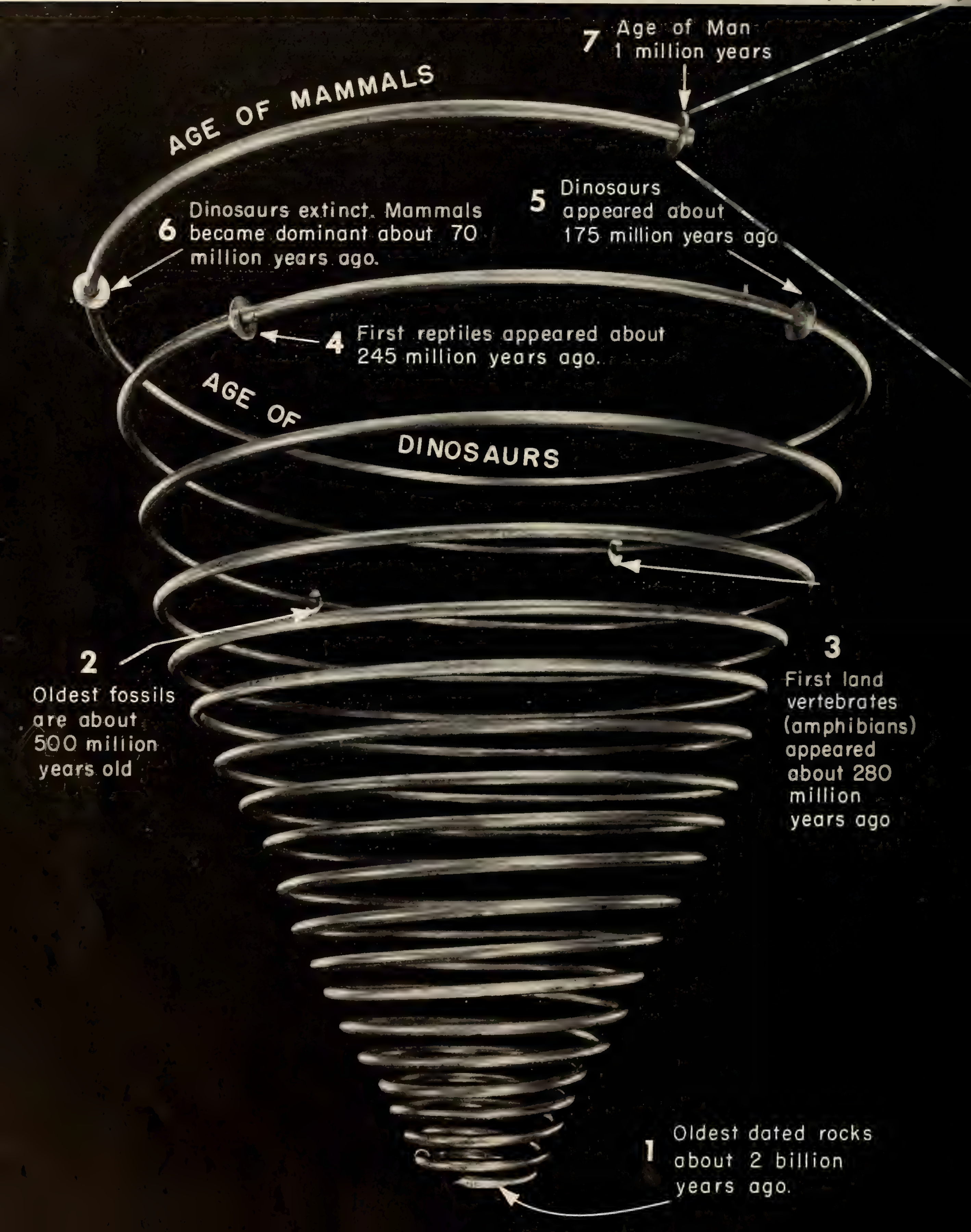
Just as our own written history may be subdivided into stated periods, marked by certain events or by certain series of events, so is geologic history divided by the sequence of events of Earth History.

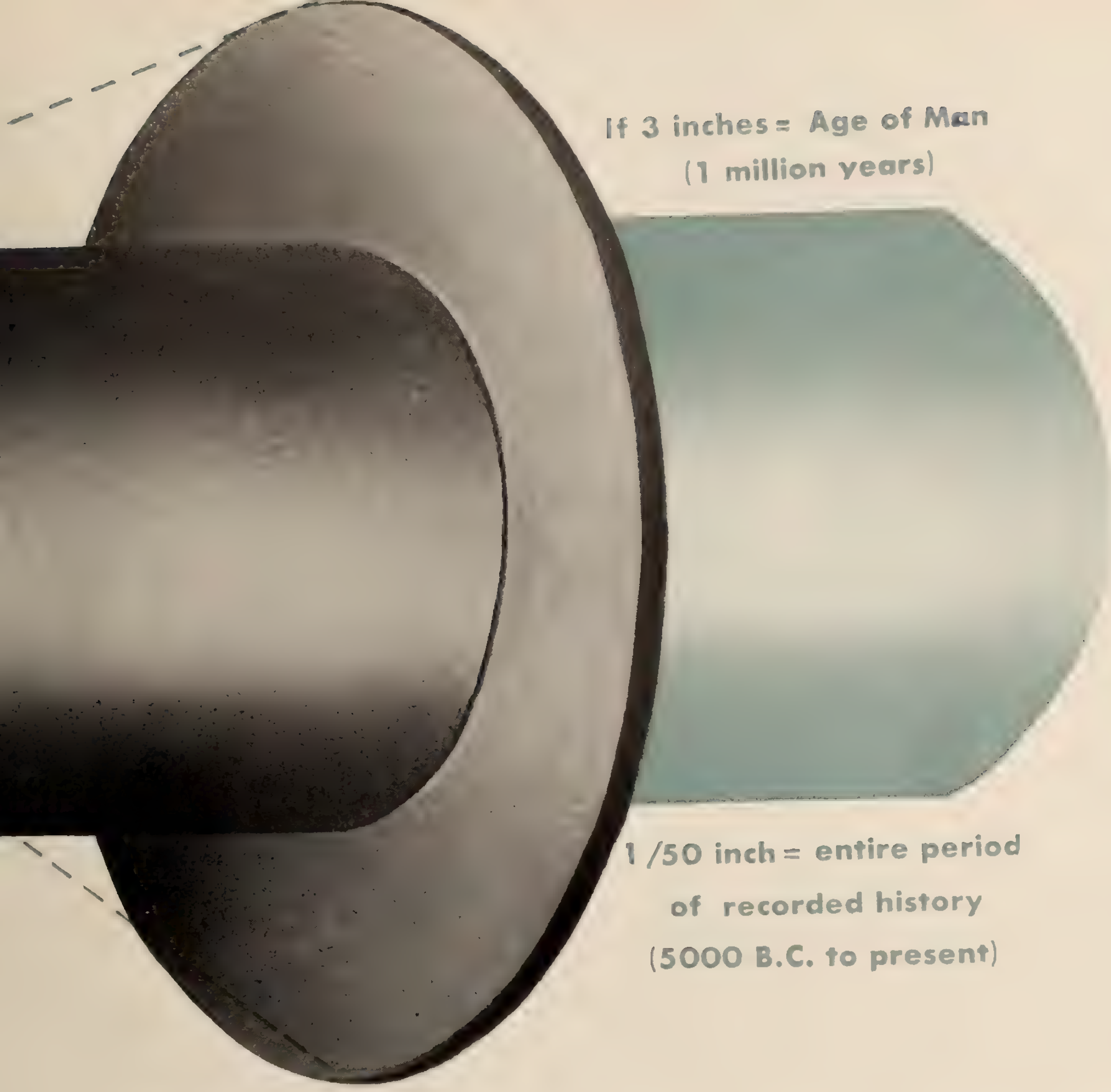
The Mesozoic era was primarily the age of dinosaurs. Of course, there were other types of animals living at that time: fishes and aquatic reptiles in the water, flying reptiles and primitive birds in the air, and small, archaic warm-blooded mammals on the land. But these animals, important as some of them might be in view of the subsequent history of animal life, played for the most part relatively insignificant rôles in the great drama of Earth History during Mesozoic times. The real actors on this stage were the dinosaurs.

The Mesozoic is often known as the "Age of Reptiles," since dinosaurs are reptiles and were dominant at that time. This, however, may not carry quite a true picture of things as they were, for as may be seen by the

DINOSAURS are extremely old when compared with the earliest human remains. But they are relatively late in the 2-billion-year history of the earth

A.M.N.H. photograph



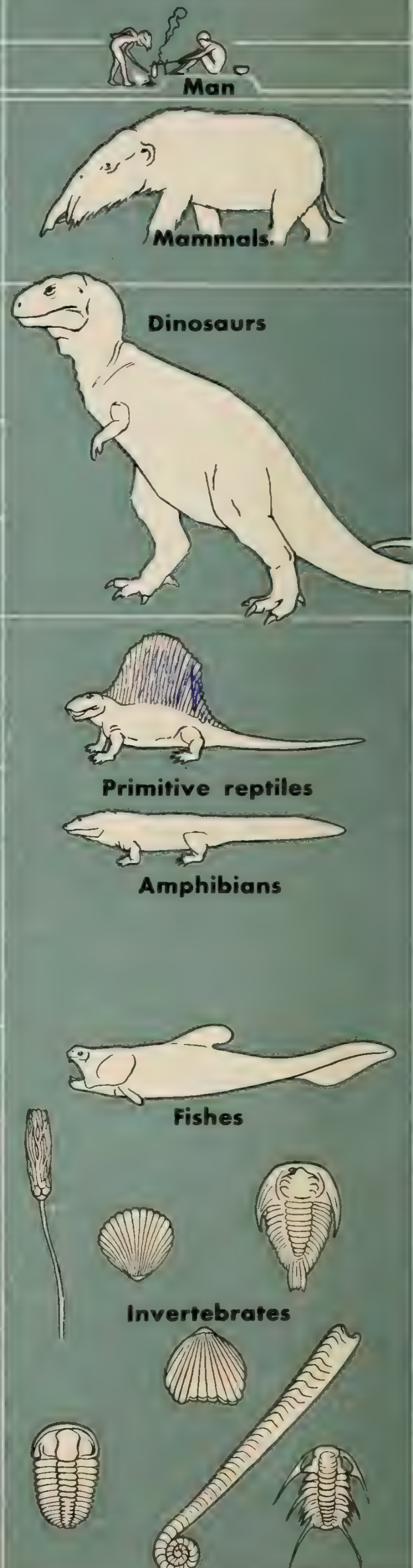


accompanying figure, the reptiles appeared on the earth approximately 245 million years ago (Late Paleozoic era), and were even then dominant on the land. So the "Age of Reptiles" might be thought of as extending at least from the beginning of the Permian period (about 225 million years ago), at which time the primitive reptiles had become well-established upon the earth, to the end of the Mesozoic era, when reptilian dominance ceased with the disappearance of the last dinosaurs.

Preceding this Age of Reptiles was an Age of Amphibians, including in a general way what the geologist refers to as Mississippian and Pennsylvanian times. This was the period during which the first land vertebrates were evolving from their fish ancestors. It was the period during which the basic patterns for reptilian evolution began to be established.

These, the Age of Amphibians and the Age of Reptiles are the periods of Earth History with which we shall be especially concerned in the following pages of this book. We are interested particularly in the dinosaurs, but in order to understand them properly it will be necessary to give some attention to their predecessors and their contemporaries. So it is that our story begins with the emergence of the vertebrates from their watery ancestral home.

Time Scale	ERAS	Duration of periods	PERIODS	DOMINANT ANIMAL LIFE
0			Recent	Man
			Pleistocene	
10–70	CENOZOIC 70 million years duration	70	Pliocene Miocene Oligocene Eocene Paleocene	Mammals
80, 90, 100	MESOZOIC 120 million years duration	50	Cretaceous	Dinosaurs
150		35	Jurassic	
		35	Triassic	
200	PALEOZOIC 350 million years duration	35	Permian	Primitive reptiles
		20	Pennsylvanian	
250		30	Mississippian	Amphibians
300		65	Devonian	
350		35	Silurian	Fishes
400		75	Ordovician	Invertebrates
450, 500		90	Cambrian	
	PROTEROZOIC ARCHAEOZOIC		1500 MILLION YEARS DURATION	BEGINNINGS OF LIFE



5

The First Land Animals

WE DO NOT KNOW when life began on the earth, and it seems likely that the answer to this question will remain forever hidden from us. What we do know is that it was some 500 million years ago when the plants and animals of early geologic history had reached a stage of development where they produced hard parts capable of being preserved as fossils.

At that distant date there seemingly was no land life; all life was in the sea. Moreover, there were no vertebrates, or backboned animals, living—at least none of sufficient complexity that they left hard structures to be preserved in the form of fossils. According to the fossil record, the animals of that time were mostly various types of sea-shells and crablike forms. It is probable, however, that even by the beginnings of Cambrian times, about 540 million years ago, the basic patterns for the backboned animals had been established, for it was at an early stage in the Paleozoic era that the first vertebrates appeared. These were primitive, fishlike forms.

The fishes rose and evolved at a rapid rate, so that by middle Paleozoic times, in the Devonian period (340-275 million years ago), they were abundant and dominant in the waters of the earth. There were many kinds of Devonian fishes, some large, some small, some fast-swimming and predaceous hunters, others flattened burrowers and grovelers in the muds of shallow bottoms. Among the Devonian fishes there were certain ones, belonging to a group known as the *crossopterygian* (cross-op-ter-IJ-e-yan) or lobe-finned fishes, which were destined to play a very important rôle in the history of evolution, for these were the immediate, direct ancestors of the first land-living vertebrates.

The lobe-finned or crossopterygian fishes were of medium size and were covered by a heavy armor of scales. Some of the significant structures characterizing these early fish were:

a.

The arrangement of the bones in the skull according to a pattern that is comparable, bone by bone, with the skull pattern of the early land-living vertebrates.

b.

The microscopic structure of the teeth,

Into a world of primitive backboned animals came many kinds of fishes in the period between 275 and 340 million years ago. Among these, the *crossopterygian* or lobe-finned group represented above by *Osteolepis* were to become the direct ancestors of the first backboned animals to live on land

← Only during the last 500 million years have plants and animals produced hard parts capable of being fossilized. Here is a simplified chart of that quarter of the earth's history

Drawings by John C. Germann

which is virtually identical with the structure of the teeth in the early land-living vertebrates.

c.

The presence of internal nares—the inner openings of the nose—a character found in land-living, air-breathing animals.

d.

The arrangement of the bones in the fins in a manner that is comparable with the arrangement of the bones in the limbs of the early land-living vertebrates.

The transition in the vertebrates from an aquatic to a terrestrial or land-living mode of life was one of the great forward steps in evolutionary history. Indeed, it was a step of such magnitude that it might be considered as an important revolution in the history of life on the earth.

Consider the facts.

a.

The fish lives in a dense medium, which buoys it up. Therefore to the fish gravity is a problem of little consequence. But to the land-living animal gravity becomes a problem of the greatest consequence, because the body must support itself against a constant downward pull.

b.

The fish is prevented from drying up by the life-long bath to which it is subjected. In the air, on the other hand, there is constant evaporation, so that in the land-living animal provision must be made against the drying up of the fluids within the body.

c.

The fish extracts oxygen from the water by means of gills. The land vertebrate develops in the lung a new means of obtaining oxygen from the air.

d.

The fish moves largely by means of rhythmic undulations of the body, passing to the tail and acting against the dense water in which it lives. The fins are used mainly as balancing organs. In the land animals the paired limbs, derived from the fish fins, become the propelling mechanisms, while the tail, in part the propelling structure of the fish, becomes a balancing member.

e.

Finally, the fish lays its eggs in the water, by which medium they are kept moist and able to function for the purpose of hatching a new generation of fishes. In the land-living vertebrates there must either be a return to the water to deposit the eggs, or new methods must be developed for preventing desiccation and destruction of the new generation during its embryonic life.

The transition among vertebrates from life in the water to life on land took place in Upper Devonian times, about 300 million years ago. Certain crossopterygian fishes struggled out onto the land and the first land-living *amphibians* came into being.

The amphibians are those cold-blooded land animals which typically return to the water to lay their eggs. The young are hatched as fishlike tadpoles and go through a water-living, gill-breathing stage, after which they come out onto the land to live as air-breathing adults. We know them today as the salamanders, the toads and frogs, and certain legless tropical forms, the Gymnophiona, Coecilia, or Apoda (jim-no-fee-o-na) (see-SIL-ee-ya) (a-POAD-a).

The amphibians as we know them are the meek descendants of a long line, living their harmless lives in the shelter of the grassy banks that line our streams and ponds, or unobtrusively hunting insects in the leafy shadows of the garden or woodland. However, for a geologically brief period of time—that time when the vertebrates were first invading the land—the amphibians enjoyed a period of terrestrial dominance, a period when they were the masters of the solid earth.

This dominance had its beginnings in the first venturings of vertebrates from an aquatic to a terrestrial mode of life, when there was nothing to dispute the claims of the primitive amphibians to the firm ground as a new environment. It had its beginnings with certain Upper Devonian forms such as *Ichthyostega* (ik-thee-o-STEEG-a), an early amphibian from Greenland that shows in its structure the heritage of its crossopterygian ancestors.

The development of the Amphibia reached its culmination in a line of late Paleozoic and early Mesozoic forms known as *labyrinthodonts* (lab-i-RINTH-o-donts), so named from the labyrinth-like internal structure of their teeth—a direct inheritance from their crossopterygian fish ancestors. The labyrinthodont amphibians appeared in Mississippian times, seemingly as direct descendants from the ichthyostegids (see *Ichthyostega*, above), and they persisted through the Permian period, finally to become extinct in the Triassic some 170 million years ago. During this time they developed so that some of them became rather large, the giants of their kind.

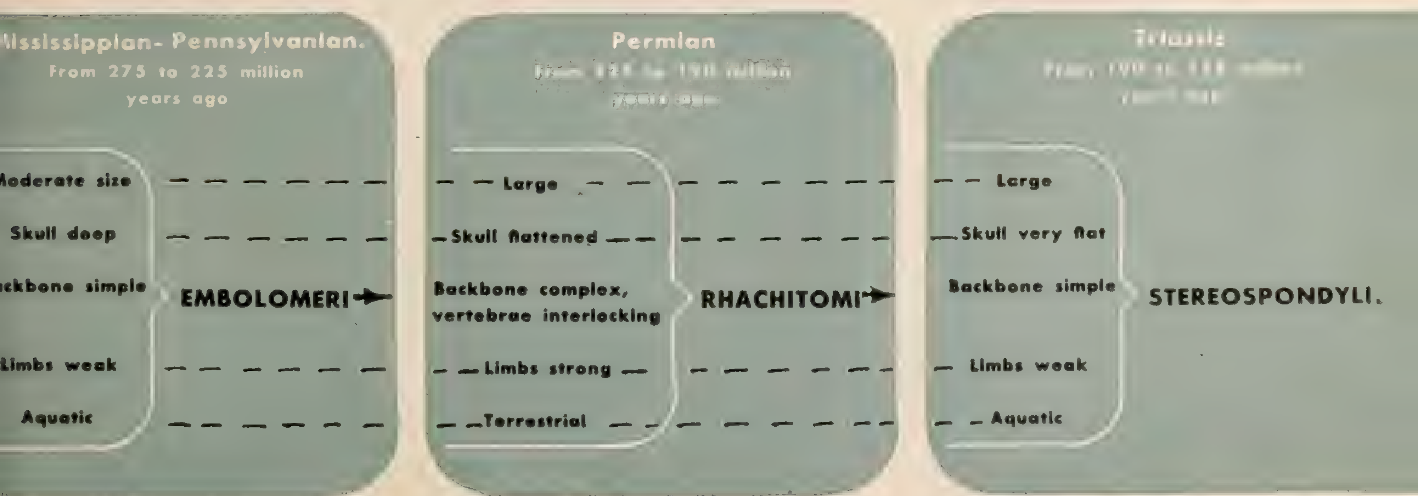
The evolution of the labyrinthodonts, which is rather interesting, may be outlined briefly as follows.

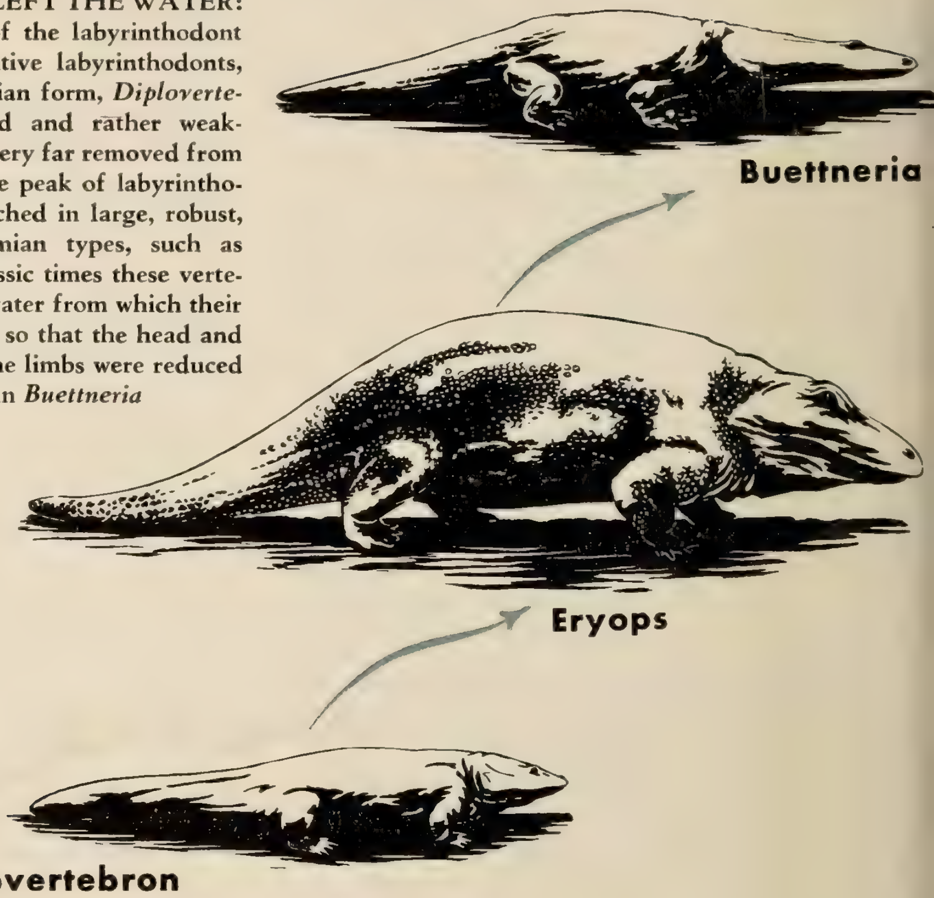
These amphibians began their evolutionary life in Mississippian and Pennsylvanian times as predominantly water-living forms, having relatively weak limbs. These early labyrinthodonts are known as the Embolomeri (em-bol-o-mer-ee). From the Embolomeri there evolved large, robust, land-living types with strong legs, the Rhachitomi (rak-IT-o-me). The Rhachitomi, living in the Permian period, were among the largest and most powerful of the terrestrial vertebrates, and at first glance it would look as if they were admirably suited to establish a successful line of aggressive land-living animals. Such, however, was not the case, for in Triassic times the evolution of the labyrinthodonts turned backward, so to speak, and these animals returned to a water-living mode of existence. These Triassic forms are known as the Stereospondyli (ster-ee-o-SPON-dil-ee), and they were the last of the labyrinthodonts. At the end of the Triassic they became extinct, and thus ended the bid of the amphibians for a position of dominance or partial dominance among the land-living animals.

Perhaps the evolution of these amphibians may be made clearer by outlining it as shown below.

One of the best known and very characteristic labyrinthodonts was *Eryops* (ER-ee-

Evolution of the Labyrinthodontia





CREATURES THAT LEFT THE WATER: **The rise and decline of the labyrinthodont amphibians. The primitive labyrinthodonts, such as the Pennsylvanian form, *Diplovertebron,* were long-bodied and rather weak-limbed animals, not so very far removed from their fish ancestors. The peak of labyrinthodont evolution was reached in large, robust, rather aggressive Permian types, such as *Eryops.* Finally in Triassic times these vertebrates returned to the water from which their ancestors had emerged, so that the head and body became flat and the limbs were reduced in size and strength, as in *Buettneria***

Restorations by John C. Germann

ops). This large amphibian is found in the Permian beds of Texas, and as may be seen, it was a strong, heavy, land-living animal. Here was the high point in amphibian evolution. Look at *Eryops* and you see the culmination of development in the Amphibia, an animal that was a truly dominant element in his environment. All that went before was building up to this climax in amphibian history, all that has come since is in a sense an anticlimax.

There were various amphibians contemporaneous with *Eryops.* Some of them were small, active labyrinthodonts. Others were not labyrinthodonts at all, for at that time there were several lines of amphibian development evolving side by side. Perhaps one of the most interesting of the non-labyrinthodont forms was *Diplocaulus* (dip-lo-KAWL-us), belonging to a group known as the Nectridia. This was a peculiarly flat, wide, water-living amphibian with an extraordinarily bizarre skull, shaped somewhat like a tremendously broad arrowhead.

The ancestry of our modern amphibians, though obscured in the mists of geologic time, is probably dual in pattern. There is indication that the frogs and toads are descended from a labyrinthodont stem, while the salamanders and perhaps the coecilians are derived from certain small, salamander-like amphibians of Pennsylvanian age known as lepospondyls (lep-o-SPON-dils).

The frogs and toads have become highly modified. The head is large, the neck and body short. The elongated hind legs serve as efficient springs to propel the animal in long leaps, while the short forelegs are firmly attached to the body and strengthened, to take up the shock of landing. The tail, so typical of most vertebrates, has been lost. All in all these melodious friends of the swamp and stream are highly successful animals. They had their beginnings in Triassic times, and from the Jurassic to the Recent period they have persisted in essentially their present highly modified condition.

The salamanders are seemingly rather primitive amphibians that have returned to a life spent largely in the water or in moist places. Consequently they show a certain amount of "regressive evolution," such as the secondary development of cartilage in parts of the skeleton that once were completely bony. Some of the Pennsylvanian lepospondyls seem to indicate an ancestry for the salamanders.

It is possible that the Gymnophiona or coecilians also were derived from a lepospondyl ancestry, but since no fossils are known, the history of these small, legless, tropical amphibians must remain largely a matter of conjecture.

An extraordinary skull shaped somewhat like a broad arrowhead distinguished the early amphibian known as *Diplocaulus*

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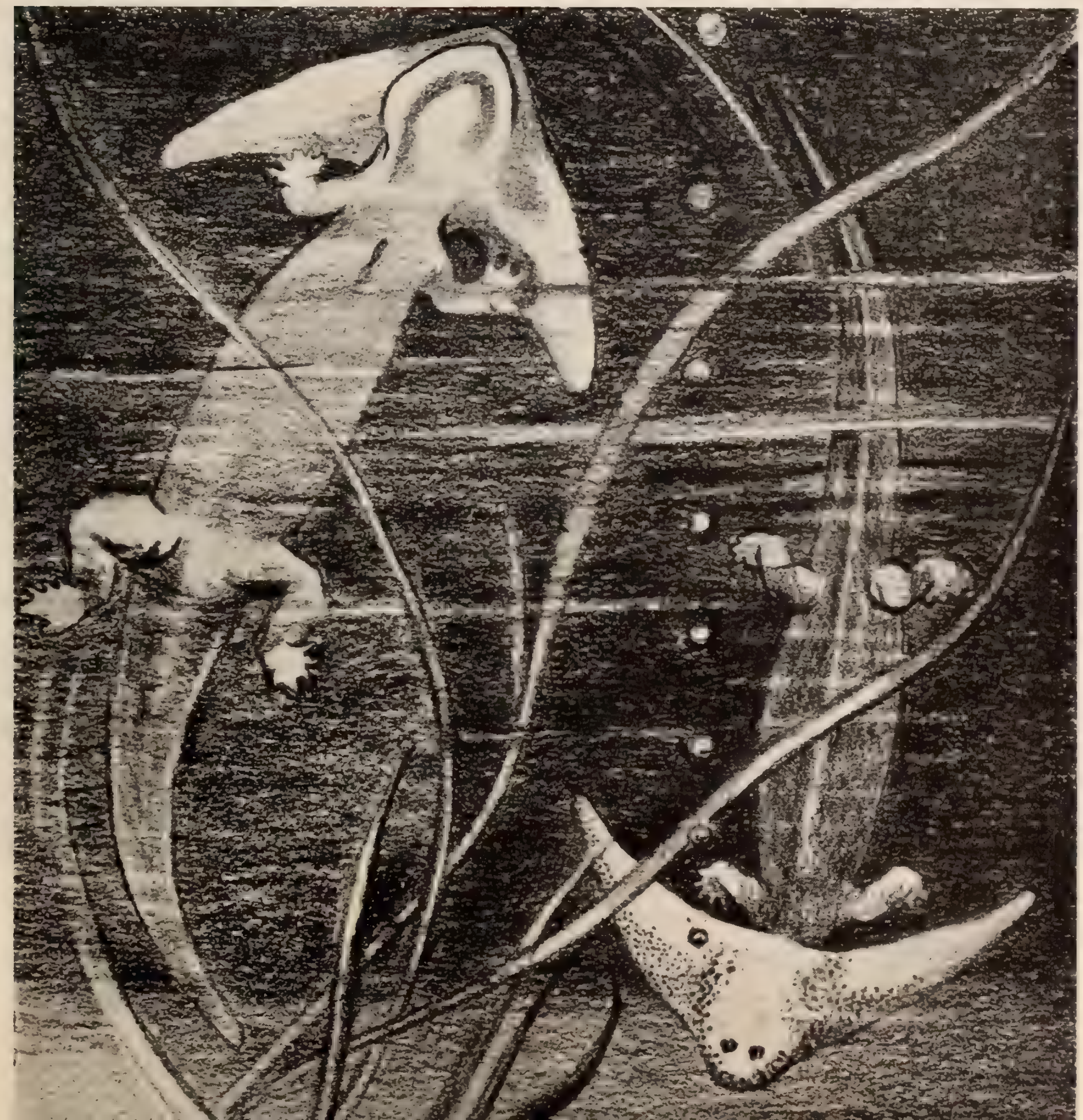

EVOLUTION OF THE AMPHIBIA. The present-day frogs and toads apparently descended from one stem; the salamanders (and perhaps the coecilians) from another

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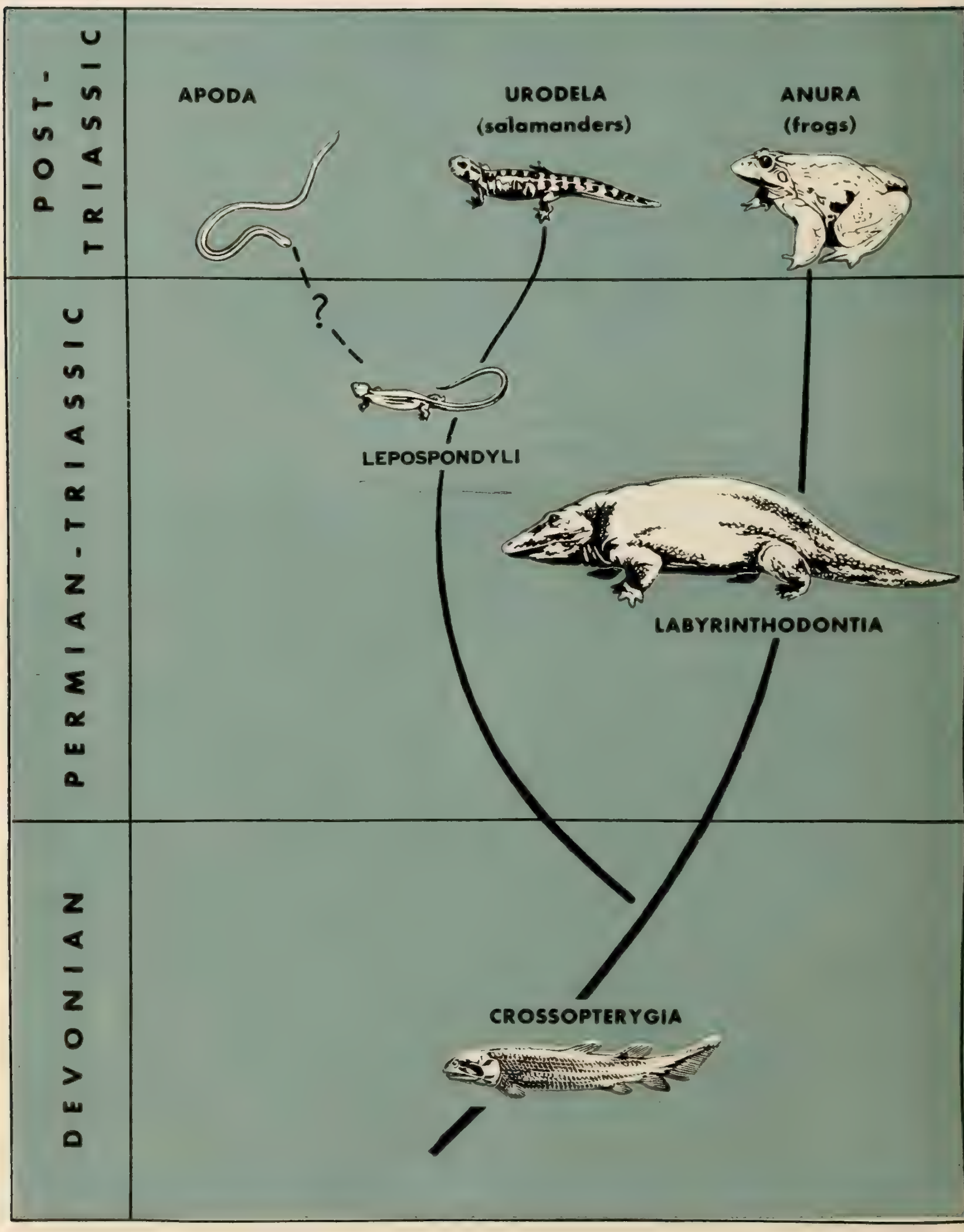


6

Primitive Reptiles

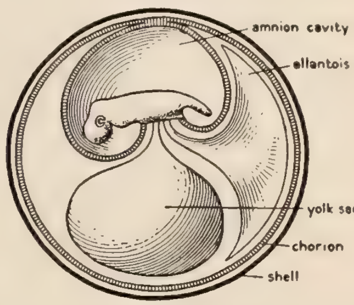
We have seen how the amphibians arose, reached the culmination of their evolutionary development and for a geologically brief period enjoyed a certain degree of dominance among the animals living on the land. We have seen how this culmination and dominance of the amphibians was attained by the late Paleozoic labyrinthodonts, the giants, and in many ways the most highly evolved of these primitive land vertebrates.

The labyrinthodonts, in spite of their evolutionary progress, were unable to evolve to any great eminence because at an early stage in their history they suffered from the competition of other land vertebrates that were better adapted to a terrestrial environment than they were. These were the *reptiles,* the cold-blooded land animals in which the young develops directly without any tadpole stage.

The reptiles arose soon after the appearance of the labyrinthodonts and developed side by side with them. By Permian times there was actually a certain amount of "pushing and shoving" between the reptiles and the amphibians for elbow room upon the surface of the land. But the amphibians lost the battle; the last of the labyrinthodonts retreated once again to the primitive home for all life, the water, there to enjoy a brief respite of existence before they finally became extinct, while the reptiles, ever evolving and increasing, reached hitherto unscaled heights in the climb up the evolutionary ladder.

Why did the amphibians lose the evolutionary race to the reptiles? The answer probably is to be found in one word, reproduction. The reptiles prevailed because in them a new method of perpetuating the species had evolved. It is probable that the labyrinthodont amphibians had to return to the water for the laying of the eggs, just as is the case with most of the amphibians of the present day. In the early reptiles, however, it is probable that the specialized *amniote egg* had been perfected. Indeed, the appearance of the amniote egg was one of the great forward steps in vertebrate evolution, for with the development of this new type of reproduction the vertebrate was henceforth freed from its bondage to the water.

The amniote egg is, briefly, the encased egg of reptiles and birds; the egg in which the developing embryo is protected by an enveloping sac, the amnion, while the entire egg is generally enclosed in a hard, protective shell.



The protected egg which presumably gave the early reptiles their initial advantage over the amphibians. Here for the first time the developing embryo is freed from its prior bondage to the water, by means of a hard, protective shell and an enveloping sac (the amnion) —hence the name, amniote egg

From Romer's *Man and the Vertebrates,* The University of Chicago Press

It was probably the development of this egg that marked the first divergence of the early reptiles from the amphibians, for just as certain fish were the progenitors of the amphibians, so were certain amphibians the progenitors of the reptiles. And the basic reptilian grandparents were labyrinthodonts. Therefore, while the thesis of labyrinthodont extinction before the onslaught of their reptilian competitors is valid, it is in a way equally valid to say that one branch of the labyrinthodont line was continued by the reptiles because certain early labyrinthodonts were transformed into reptiles.

The first reptiles had great evolutionary potentialities. They were free of the water. They could venture over the face of the earth and continue their kind in regions where the less efficient amphibians could not survive. Thus was born a mighty race.

The "grandfather" of the reptiles: Seymouria. This animal formed an almost perfect intermediate link between the early amphibians and the ensuing reptiles, and represents the structural ancestral type from which all the reptiles evolved

Restoration by F. L. Jaques

The earliest reptiles were very much like their amphibian ancestors. In fact, some of the most primitive reptiles were so very amphibian-like that there has been a great deal of argument as to whether these basic reptiles might not more properly be regarded as advanced amphibians. So it goes. The more we know about the classification of animals, the less distinct become the lines of demarcation separating one form from another or one group from another. In other words, we find the intermediate stages which prove the validity of evolution.

Certainly there could hardly be an animal more exactly intermediate in its anatomical features between the amphibians and the reptiles than the Permian genus, *Seymouria* (see-MOOR-e-ya), from the rocks known as the red beds of Texas. This animal approximates structurally the stem for all reptilian life; it is the "grandfather reptile."

The reptiles may be classified in a broad, general way on the basis of skull design, as follows:

a.

Anapsida (an-APS-i-da)

Skull roof solid, without any openings behind the eye.

b.

Synapsida (sine-APS-i-da)

Skull roof perforated by a lower opening behind the eye bounded above by the postorbital and squamosal bones.

c.

Parapsida (par-APS-i-da)

Skull roof perforated by an upper opening behind the eye, bounded below by the postfrontal and supratemporal bones.

d.

Euryapsida[1] (your-e-APS-i-da)

Skull roof perforated by an upper opening behind the eye, bounded below by the postorbital and squamosal bones.

e.

Diapsida (dye-APS-i-da)

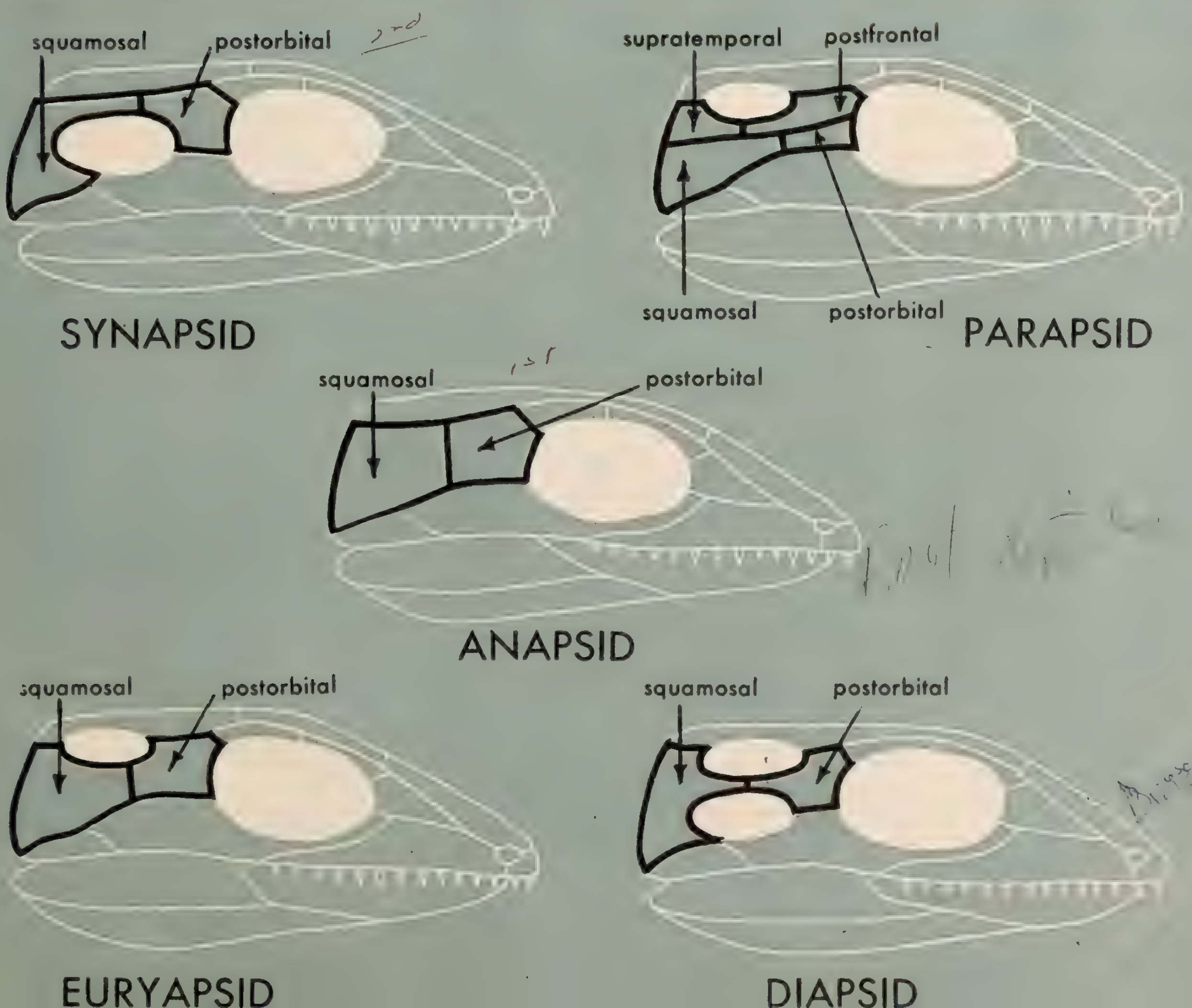
Skull roof perforated by a lower and an upper opening behind the eye, these openings separated by the postorbital and squamosal bones.

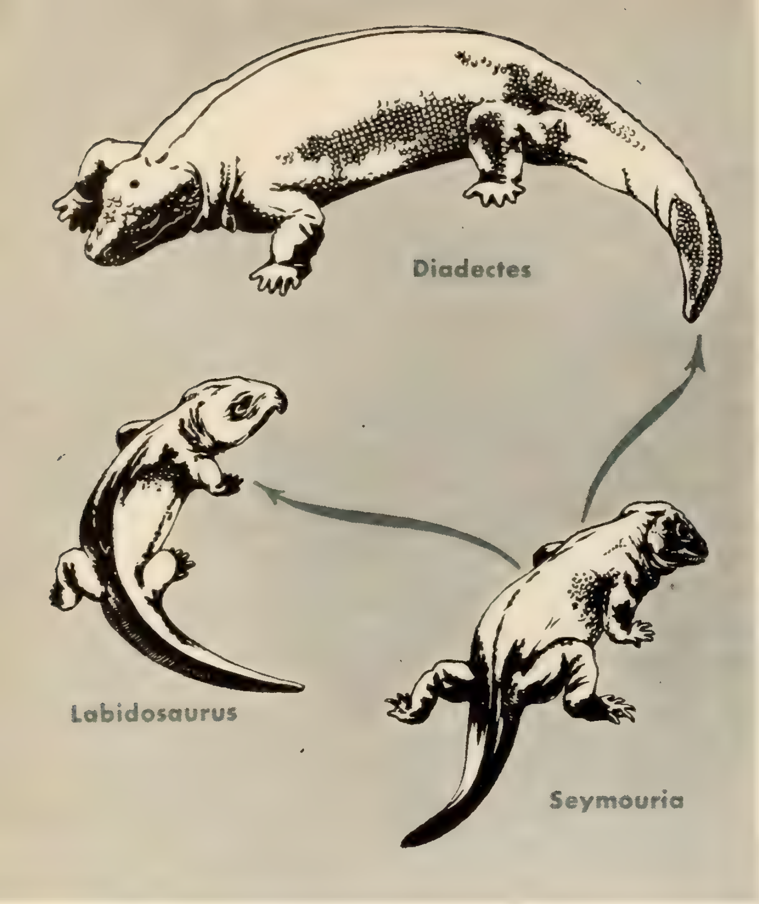
The first reptiles were anapsids. They were the reptiles with solidly roofed skulls,

[1] I am indebted to Professor A. S. Romer of Harvard University for the suggestion as to the derivation and the use of this name.

THE FIVE BASIC TYPES of reptilian skulls. The anapsid skull had no openings behind the eye. The synapsid skull had a temporal opening behind the eye, below the squamosal and postorbital bones. The parapsid skull had a temporal opening behind the eye but above the supratemporal and postfrontal bones. The euryapsid skull had one above the squamosal and postorbital bones. The diapsid skull had two temporal openings behind the eye, separated by the squamosal and postorbital bones

Drawings by John C. Germann





From "grandfather" *Seymouria*, two general lines of reptiles descended. In one, the animals remained small, like *Labidosaurus*. In the other, there was a tendency to giantism, as may be seen in *Diadectes* from North America and in the large pariasaurs from the Old World, one of which is shown opposite

Restorations by John C. Germann

an inheritance from the solid, bony skulls of their labyrinthodont ancestors. Of these anapsids, the first to appear were reptiles belonging to the order known as the Cotylosauria (ko-TILE-o-sawr-e-ya). The seymouriamorphs, typified by *Seymouria*, are perhaps the primitive ancestors of the cotylosaurs. Some authorities have included the seymouriamorphs among the labyrinthodont amphibians rather than among the primitive reptiles.

The cotylosaurs evolved through Permian and Triassic times and then became extinct. Their evolution was divided along two lines of development. There was a line of small Permian cotylosaurs, showing certain specializations, known as the labidosaurs (LAB-i-do-sawrs) or captorhinomorphs (kap-to-RINE-o-morfs). In contrast the other group of cotylosaurs, known as the diadectomorphs (dye-a-DEKT-o-morfs), consisted of quite large reptiles living in the Permian period, and small, highly specialized survivors persisting through the Triassic period.

Labidosaurus was small, like *Seymouria*. It had the long body and the sprawling, weak limbs of the primitive reptile. The skull, as in all anapsids, was roofed over by solid bone, and was abruptly truncated behind. A characteristic feature of this animal was the overhung, or hooked upper jaw.

Diadectes (dye-a-DEKT-eez) was a rather large Permian reptile, some five or six feet in length. The legs were sprawling, as in the other primitive anapsids, so that this animal must have been rather clumsy when walking. *Diadectes* seemingly was a plant-eating reptile, for the teeth were blunt and peglike, and not at all suited to catching animals as were the pointed, spikelike teeth of *Seymouria* and *Labidosaurus*. A remarkable feature of *Diadectes* was the large pineal opening on the top of the skull, showing that this reptile had a very large "pineal eye"—an organ sensitive to light, which still persists in a much reduced form in the recent lizards and the tuatara (*Sphenodon*) of New Zealand.

Closely related to the American diadectids were the Permian pariasaurs (par-EYE-a-sawrs) of South Africa and Russia. These were really massive reptiles, as big as small cattle. Like the other large cotylosaurs they were seemingly plant eaters, large, heavy, and sluggish. They had very broad, robust bodies and strong, heavy legs, and as in other primitive anapsids there was no clearly defined neck.

The last of the cotylosaurs, living through Triassic times, were diadectomorphs which were smaller than the large *Diadectes* of North America and the massive pariasaurs of Europe and Africa. Their development ran counter to the earlier trend towards giantism in this branch of the cotylosaurian reptiles. Known as procolophonids after the characteristic genus *Procolophon* (pro-KOL-o-fon), these animals evidently ranged widely throughout the world in Triassic times, since they are found in South Africa, central Europe, Scotland, and North America.

An early type of procolophonid is to be found in the Lower Triassic genus, *Procolophon*, of South Africa. Although small, *Procolophon* was robustly constructed. It had a deep skull, narrow in the front and broad at the back. The pineal opening on the top of the skull was very large. The teeth were limited in number, and those in the back portion of both upper and lower jaws were somewhat broadened for chopping or cutting green plant food.

In Lower Triassic times the procolophonids appeared also in central Europe where they had become specialized to the extent that in some of them there were spikes on the sides or the back of the skull.

Finally, the Middle Triassic of Scotland and the Upper Triassic of New Jersey yielded the most highly specialized procolophonids, the last of the cotylosaurs. They were characterized by a flattening of the skull and an excessive development of the spikes on the sides and the back of the head. As in the other diadectomorphs, the pineal "eye" was large. The teeth had become far fewer but were highly specialized, for the back teeth were broad, sharp chisels, evidently useful for chopping and cutting food. A particularly fine specimen is the almost complete skeleton of *Hypsognathus* (hips-og-NATH-us), recently discovered near Passaic, New Jersey, and now in the American Museum of Natural History.

With the passing of the procolophonids, during the late stages of Triassic history, the cotylosaurs became extinct. They had lived out their evolutionary life span—they had to give way to the more highly developed reptiles of later Mesozoic times.

Such were the beginnings of the reptiles. Let us now follow their interesting evolution through its many ramifications.

A LARGE PARIASAUR, *Scutosaurus*, from the Permian beds of Russia, showing an early trend to giantism in the reptiles. This animal was as large as an ox and perhaps heavier, but it retained a primitive form. Notice the proportionately small head, the out-bowed legs, and the clumsy body

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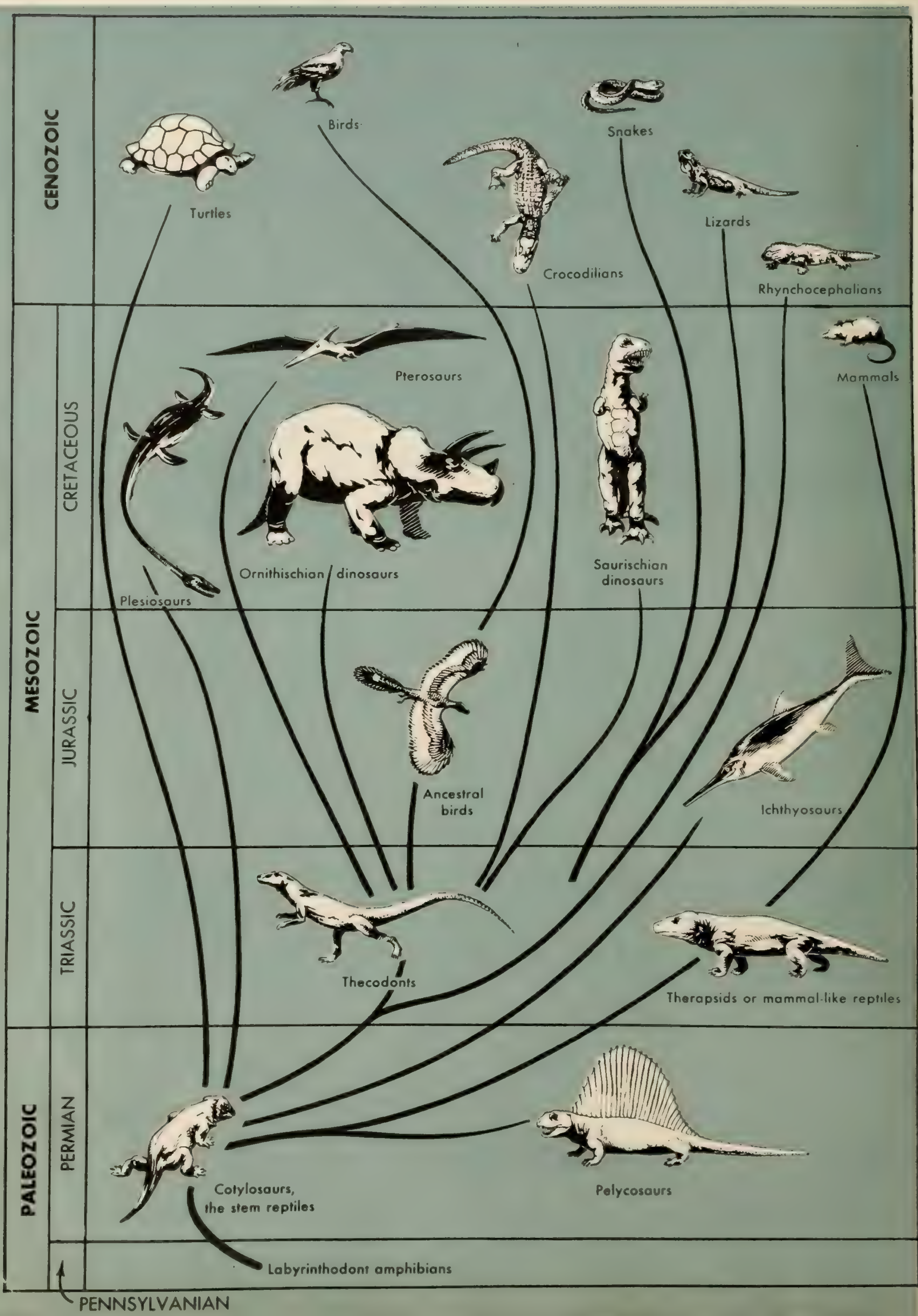
CENOZOIC
MESOZOIC
CRETACEOUS
JURASSIC
TRIASSIC
PALEOZOIC
PERMIAN
PENNSYLVANIAN
Turtles
Birds
Snakes
Lizards
Crocodilians
Rhynchocephalians
Pterosaurs
Mammals
Plesiosaurs
Ornithischian dinosaurs
Saurischian dinosaurs
Ancestral birds
Ichthyosaurs
Thecodonts
Therapsids or mammal-like reptiles
Cotylosaurs, the stem reptiles
Pelycosaurs
Labyrinthodont amphibians

7

The Mammal-like Reptiles

IT MUST NOT BE THOUGHT that during the early days of reptilian evolution in Permian and Triassic times, the primitive anapsid reptiles, the cotylosaurians, had the world all to themselves. The labyrinthodont amphibians presented a certain amount of competition to these early reptiles in the struggle for existence on the land, but the really serious antagonists of the anapsids were other reptiles, for this was the age when most of the great evolutionary lines of reptilian development were getting their start. The evolution of the reptiles was mushrooming out, so that there was a strong overlapping of the evolutionary generations. Grandfathers and grandchildren were living side by side.

One large division of the reptiles that arose, developed, and died out during the early phases of reptilian life in the Permian and Triassic periods, was that of the synapsids. These were the reptiles that, as shown by the drawings on page 49, were characterized by a lower opening in the skull roof behind the eye.

The history of the synapsids was, geologically speaking, of comparatively moderate length. The first of these reptiles made their appearance about 250 million years ago in Pennsylvanian times; the last of their kind had disappeared by the end of the Triassic period, 80 million years later. Nevertheless this is one of the most important reptilian groups, because from certain branches of it there sprang the mammals, the warm-blooded furry animals that subsequently were destined to inherit the earth.

The synapsids were widely spread over the face of the earth, for their remains are found on all of the major continents. Their evolutionary record, however, is confined for the most part to North and South America, eastern Europe, and South Africa. The subclass can be divided into two large groups, the *Pelycosauria* (pel-i-ko-SAWR-e-ya), found for the most part in the Upper Pennsylvanian and Lower Permian of North America, and the *Therapsida* (ther-APS-i-da), mainly found in the Middle and Upper Permian and the Triassic of the Old World and South America.

Our knowledge of the pelycosaurs is derived mainly from fossils found in the Permian red beds of Texas. These fossils show that the pelycosaurs had their beginnings as long, lizard-like reptiles, with rather sinuous bodies and sprawling limbs. (The term lizard-like is used here to convey a word picture. Such a term does not imply any relationship with or ancestry to the lizards, for it was to be many millions of years before the first lizards made their appearance on the earth.) *Varanosaurus* (var-AN-o-sawr-us) was a form typical of the primitive pelycosaurs. From such a beginning the pelycosaurs developed along several radiating evolutionary branches.

In *Varanosaurus* the basic structural pattern for the pelycosaurs was set, that of elongated, sprawling-limbed, four-footed reptiles. Evolution in these animals was mainly a process of skull and backbone modifications.

Some of the pelycosaurs grew large, and the skull deepened. They had numerous sharp teeth, the design of which indicates that these were fish-eating animals, a sup-

← The family tree of the reptiles: a pictorial diagram summarizing the history of the reptiles as discussed in the following pages

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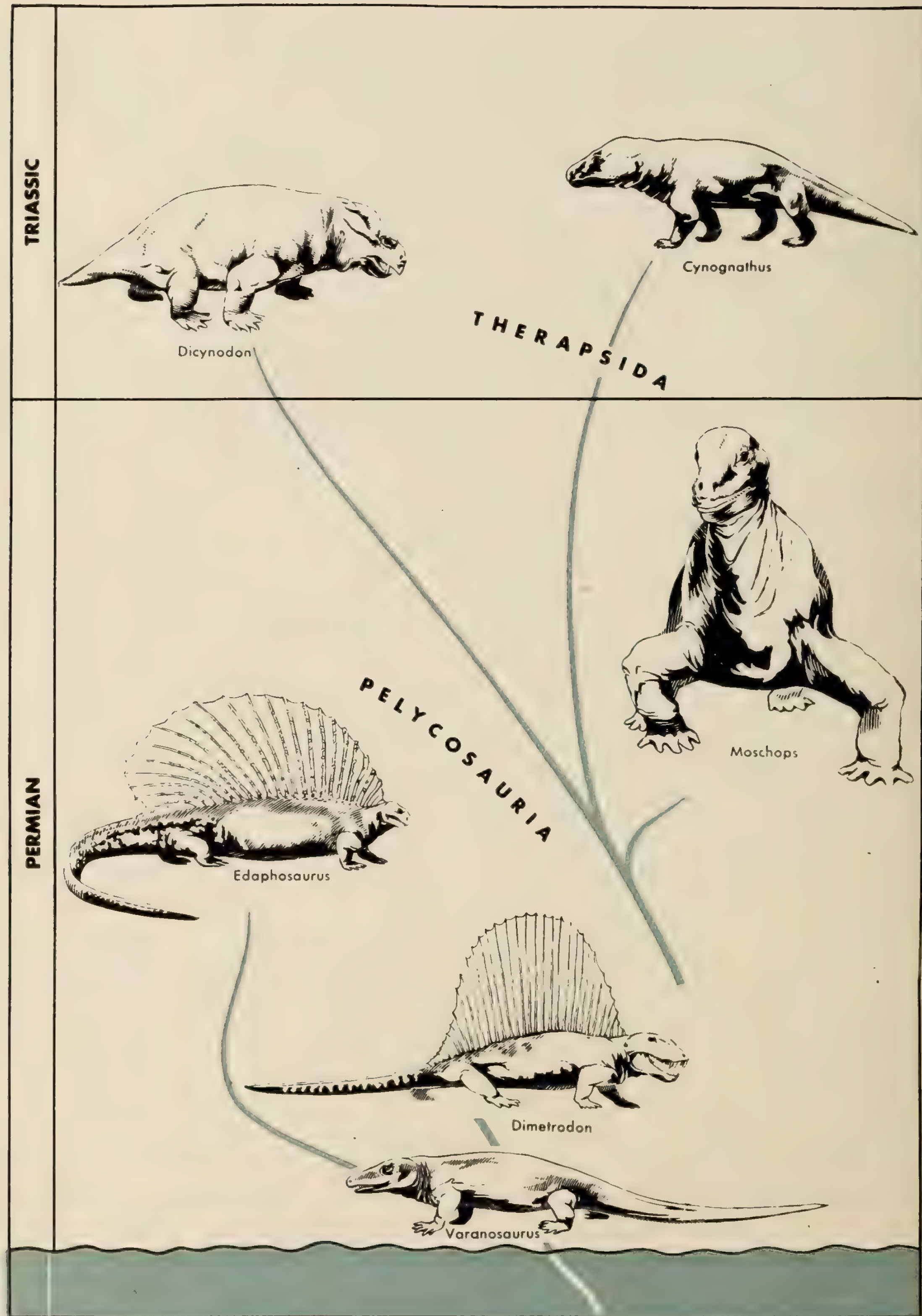

↑ The evolution of the synapsid reptiles. As seen here, they showed wide variation in form, but their relationship is always indicated by the skull pattern shown on page 49

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position that is strengthened by the fact that these reptiles are found in stream deposits together with the remains of fishes. Such was *Ophiacodon* (o-fee-A-ko-don).

Certain pelycosaurs evolved tremendously long spines on the vertebrae, spines which in life must have supported a membranous sail that ran down the middle of the back. These were the sphenacodonts or finbacks, typified by the genus *Dimetrodon* (dye-MET-ro-don), a good-sized reptile, six or seven feet in length. *Dimetrodon* had a deep skull, armed with many cruel, dagger-like teeth. The sail on the back was tall, thrusting up two or three feet above the line of the backbone.

What was the purpose of this huge sail, seemingly so cumbersome, and certainly a serious drain upon the blood supply and the energy of the animal? Much thought and discussion has been given to this problem, with suggestions ranging from the not-so-sublime to the downright ridiculous. According to one idea, the long spines on the vertebrae of *Dimetrodon* afforded a protection for the spinal column—a protection against the attacks of savage enemies. The only thing wrong with this theory is that there were no other large, active carnivorous reptiles at that time to prey upon *Dimetrodon*. *Dimetrodon* was the lord of his small universe, he was one of the largest and certainly one of the most active and predaceous of the animals living in Texas during Permian times. Another idea had it that the "sail" of *Dimetrodon* really was a sail, that this animal ventured out onto the surface of the Permian lakes and rivers, scudding along before the wind, tacking back and forth in a fashion approved in the best yachting circles. Such a theory is, of course, one on the ridiculous side.

Perhaps the truth is that the sail of *Dimetrodon* is not to be explained upon any functional grounds. It may very well be that this represents an unbalanced growth,

This grotesque "sail" has been a subject of much conjecture. Probably it is merely a case of hereditary maladjustment. In this Permian scene of over 200 million years ago, *Edaphosaurus* is fleeing from his flesh-eating relative *Dimetrodon* (in the background). Both were about five or six feet long

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that it is an example of heredity "gone wild." The ophiacodonts, for instance, had rather tall spines on the vertebrae, spines that served for the attachment of strong muscles to help hold up and stiffen the back. It may be that there was some sort of a hereditary upset, so that the spines elongated much faster than the animal grew, and since this strange adaptation was not particularly deleterious, the animal survived in spite of it. We frequently see such developments in nature.

For instance, there was a herbivorous pelycosaur, known as *Edaphosaurus* (e-DAF-o-sawr-us), in which the spines were not only elongated but equipped with numerous transverse processes, like the yardarms of an old square-rigger. It is certainly difficult to assign any functional purpose to such a development. It is much more logical to assume that this peculiar growth was merely a case of a hereditary maladjustment.

The pelycosaurs are extraordinarily interesting to us, not only because of the bizarre adaptations shown by some of them, but also because some of these animals, particularly the sphenacodont-like forms, were the ancestors of those synapsid reptiles known as therapsids. The therapsids were the "mammal-like reptiles," a descriptive term that delineates not only their general appearance but also their morphological relationships, for these were the reptiles that were in part actually the direct ancestors of the *Mammalia*, that division of the animal kingdom of which we are members.

The therapsids are found in many localities in the several continental areas, but it is in South Africa and in Russia that our evidence for the past history of these animals is especially complete.

The mammal-like reptiles had their beginnings in small synapsids known as dromasaurs, from which they radiated through later Permian and Triassic times along two general lines of adaptation. One of these evolutionary lines followed a trend toward the development of bulk. The other line was one in which highly advanced and correlated structural features appeared, as will be shown below.

The large heavy therapsids appeared in the Permian and became dominant elements in the animal assemblages of their day. These animals developed along two lines, one known as the Dicynodontia (dye-SINE-o-dont-e-ya), the other as the Dinocephalia (dye-no-sef-A-lee-ya). The dicynodonts were exceedingly numerous and rather varied. Some were comparatively small, others were very large, as

The Permian reptile Moschops, as it might have appeared in South Africa some 200 million years ago. This animal typifies the large plant-eating Therapsids of South Africa

Restoration by John C. Germann

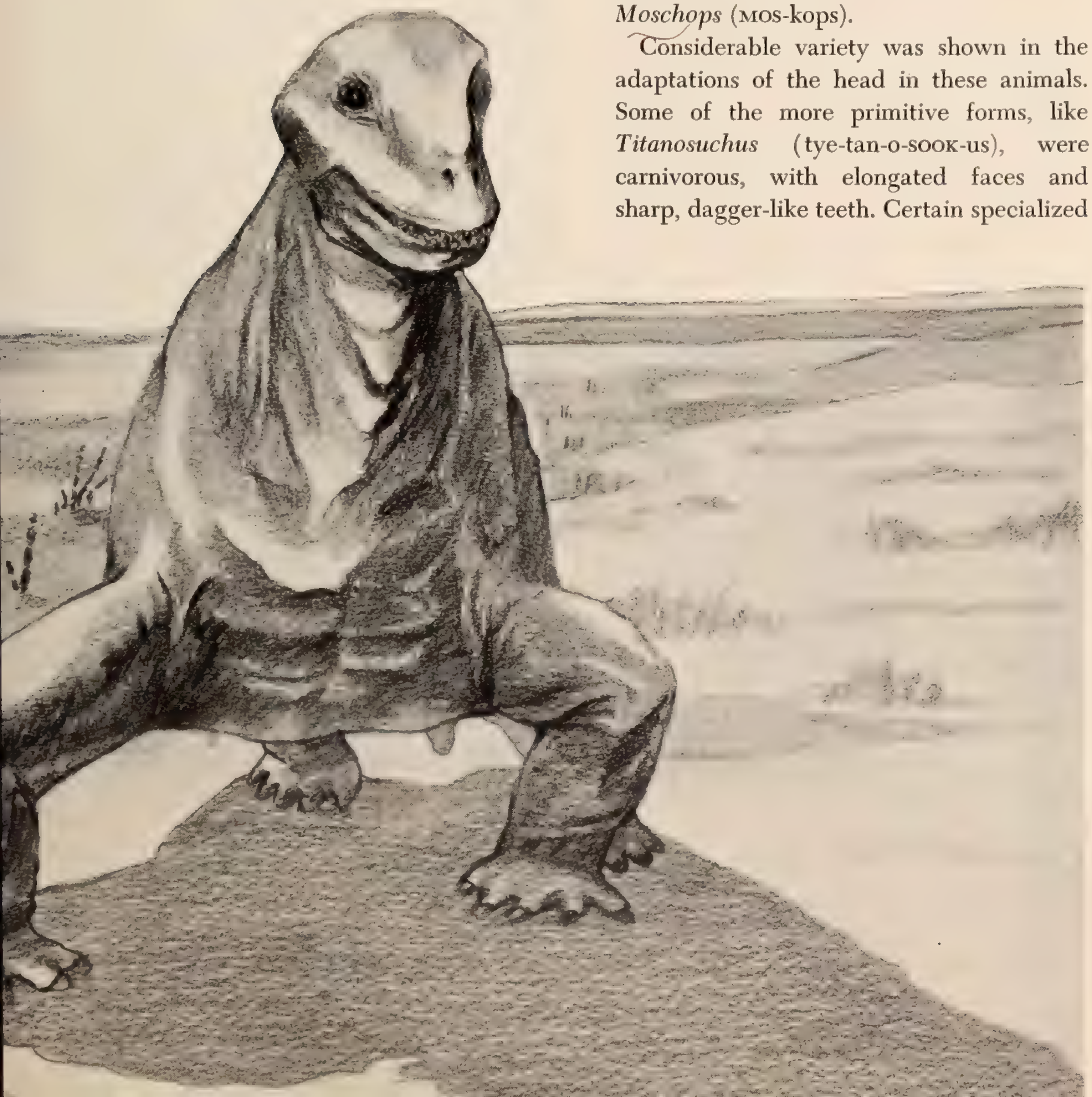
bulky as present-day oxen. But all of them, whether large or small, seemingly were rather active, for these reptiles literally "got up on their legs," the better to move across the land in which they lived. In short, these animals could walk with their feet underneath their bodies, so that the legs could be brought in for support against the constant downward pull of gravity.

Perhaps the most striking feature of the dicynodonts was the specialization of the skull, for in these animals the head had undergone a profound transformation. The upper and lower jaws were beaklike in form. The teeth were usually lost, except in the males, which retained two enlarged spikelike teeth in the upper jaw. The skull itself was modified so that the bones of its back portion formed a series of strong arches, probably as attachments for powerful jaw muscles. *Dicynodon* was typical.

Although the preserved remains of dicynodonts are particularly abundant in South Africa, it is evident that these animals had a cosmopolitan distribution. *Stahlekeria* (stal-le-KER-e-ya) is a giant dicynodont found in Brazil; other dicynodonts are known from North America, China, and Europe.

The dinocephalians were rather similar to the dicynodonts in body form. They were large, powerful reptiles with strong limbs. The back sloped giraffe-fashion in typical members of the group, as for example in *Moschops* (MOS-kops).

Considerable variety was shown in the adaptations of the head in these animals. Some of the more primitive forms, like *Titanosuchus* (tye-tan-o-SOOK-us), were carnivorous, with elongated faces and sharp, dagger-like teeth. Certain specialized



types, such as *Moschops,* were vegetarians, with rather weak jaws and peglike teeth. They all had very heavy thick skulls, and as a group were remarkable for the great development of the light receptor, the pineal organ or "eye" on the top of the head.

From our own anthropocentric viewpoint all other reptiles pale into insignificance as compared with the theriodonts (THER-e-o-donts) and the ictidosaurs (ik-TID-o-sawrs). These were the mammal-like reptiles *par excellence,* and as has already been said they were indeed the ancestors of our own blood kin, the mammals.

The theriodonts, of which *Cynognathus* (sine-og-NATH-us) and *Bauria* (BOWR-e-ya) were typical, were for the most part rather small or medium-size carnivorous reptiles, and like the other therapsids they had the body lifted up off the ground on strong legs —a sign that these were active animals. They had long, rather doglike skulls, which in their entirety show features directly antecedent to those of the warm-blooded, furry mammals. Thus in many of the theriodonts there was a double ball-joint or condyle that accommodated the rotation of the head on the neck as in the mammals, whereas most of the reptiles have a single ball-joint. In the theriodonts there was a secondary palate as in the mammals, separating the nasal passage from the throat, a distinct advance over the typical reptilian conditions. In the theriodonts the bone in the lower jaw that bore the teeth was greatly enlarged, while the other bones were reduced—again an approach toward the mammalian condition. And correlative with this development there was a foreshadowing of one of the most remarkable transformations in evolutionary history, the shifting of the two bones forming the joint between the reptilian upper and lower jaws to form, surprisingly enough, two of the chain of three bones in the mammalian middle ear.

One of the most striking features in the skull of the theriodonts was the specialization of the teeth. In most reptiles the teeth are all more or less alike, and they keep coming in during the life of the animal as fast as their predecessors are worn away or broken. In the theriodonts, however, there were some small front teeth, evidently for nipping and grasping, some large, broad back teeth, evidently for chewing or grinding, and between them some elongated, dagger-like teeth, evidently for slashing and tearing. Here we see an exact counterpart to the front incisors, the long, pointed canines, and the grinding teeth (the premolars and molars) of the mammals. Moreover, there is every reason, from the evidence of the fossils, to think that the differentiated teeth in the theriodonts were directly ancestral to the differentiated teeth of the mammals. Also, the evidence indicates that the manner of tooth succession in certain theriodont reptiles led finally to the condition typical of mammals, in which there are but two sets of teeth, milk or deciduous, and permanent.

It is not, however, the evidence in the skull and teeth alone that points to the direct descent of mammals from the theriodont reptiles. For in these remarkable reptiles the vertebrae of the backbone, the shoulder blade, the hip bones, the limbs, and the feet all show many characteristics that clearly foreshadowed the typical mammalian plan.

In the ictidosaurs the mammal-like specializations are carried to such a high degree of development that it is a moot point whether these animals should be classified as reptiles or as mammals. Certain features, such as the articulation of the jaws, indicate that by definition the ictidosaurs are reptiles. But they are so close to the dividing line between reptiles and mammals that they are in effect intermediate between these two great vertebrate classes.

Such is a composite picture of a true "missing link," one of the very important stages in the history of vertebrate evolution, the link between the cold-blooded reptiles, which for so many millions of years were the undisputed rulers of the earth, and the warm-blooded mammals which were destined to supplant them.

By the end of Triassic times the mammal-like reptiles, and more particularly the theriodonts and ictidosaurs, had gone through their course of evolutionary development and had become extinct. However, the mammals were not yet to take over domination of the earth from their reptilian ancestors. The first mammals, the descendants of the theriodonts, appeared in the Triassic, some 200 million years ago, but through the millions of years that constituted the Jurassic and Cretaceous periods the descendants of these first mammals played a relatively insignificant part in the economy of life. The world still belonged to the reptiles; in fact, it was during the lush days of Jurassic and Cretaceous times that the reptiles rose to the greatest heights of their long history on this sphere. Those were the days of the dinosaurs, when there were giants on the earth.

A type of reptile that stood close to the ancestry of mammals: the flesh-eating therapsid reptile *Cynognathus*, an active and predaceous animal

Restoration by F. L. Jaques

8

Ancestors of the Dinosaurs

THE REIGN OF THE DINOSAURS was founded some 200 million years ago in Triassic times, the first division of the Mesozoic era. The last of the labyrinthodont amphibians were seeking refuge in such streams and ponds as they could find, primitive turtles were continuing the history of the ancestral, roofed-skull reptiles, and the active, mammal-like reptiles were ranging across the land in search of their food. At that time the dinosaurs made their earliest appearance on the earth. Yet even though the lines of dinosaurian radiation became established in the Triassic period, the story of these great reptiles begins still further back in geologic time, in the distant days of the Permian, when the first diapsid reptiles made their debut on the stage of Earth History.

The 225-million-year-old records of Permian diapsids are rather scanty. Perhaps the best evidence as to the nature of these forerunners of a great line of evolutionary development is to be found in the little reptile, *Youngina* (young-EYE-na) or its close relative, *Youngoides* (young-OY-deez) from the upper Permian rocks of South Africa.

Youngina was small, and generally lizard-like in appearance. (Please remember that this is a comparison, and is not intended to suggest any relationships with the lizards, which appeared at a much later stage of geologic history.) *Youngina* had a long body and slender limbs. The head was pointed and the jaws were armed with sharp, needle-like teeth. The key to the relationships of this animal is, of course, in the back portion of the skull, which had *two* temporal openings, an upper one and a lower one, separated each from the other by bars of postorbital and squamosal bones.

From an ancestry typified by reptiles such as *Youngina* the diapsids evolved in various directions during Mesozoic times, to become the dominant land animals of that great era of Earth History. The differentiation of the several lines of diapsid development was largely achieved during the Triassic period, and it was then that the most important diapsid stem was established. This was the order of reptiles known as the Thecodontia (theek-o-DONT-e-ya)—more commonly called the thecodonts—the ancestors of certain dominant Mesozoic reptilian groups, notably the dinosaurs, the flying reptiles, and the crocodilians.

The skull of a primitive diapsid reptile, *Youngoides*, from the Permian of South Africa

Redrawn after Olson and Broom

The thecodonts had narrow, deep skulls, a trend of development that was foreshadowed in *Youngina* and was well established in the early Triassic forms. In these reptiles there was an opening on either side of the skull, in front of the eye. This opening, or fenestra, seemingly contributed to the lightness of the skull, for in the thecodonts and their descendants the skull was in general light, yet strong and well braced.

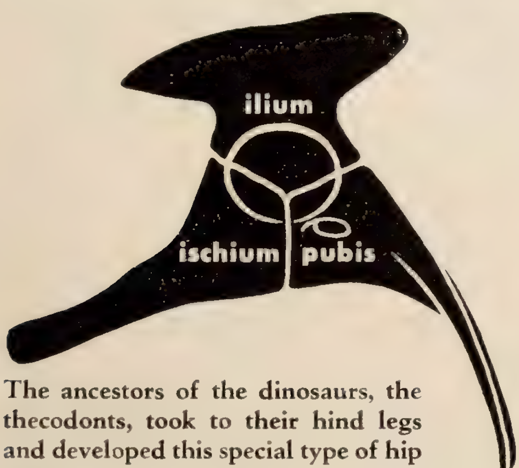
In addition, the pineal opening or "eye," so characteristic of the early reptiles, had disappeared. Finally, so far as skull characters are concerned, the thecodonts were typified by the limitation of the teeth to the edges of the upper and lower jaws; in other words, there were no teeth on the palate, as was so often the case among the more primitive Paleozoic reptiles.

It was, however, in the pose and the manner of progression that the thecodonts developed their greatest difference from all other reptiles. We have seen in the foregoing pages how the first land-living vertebrates—the early *tetrapods* (TETT-ra-pods) evolved from certain fish, and how during the course of this evolution the four paired fins of the fish were transformed into four supporting limbs which enabled the animal to progress on land. Now in many of the reptiles the evolutionary specializations that have taken place have involved a strengthening or a modification of the four limbs, and there has been a retention of the four-footed method of walking. In the thecodonts, on the contrary, there was an early adaptation for two-footed locomotion. These animals rose up on their hind limbs. There was a division of labor between the two sets of limbs; the hind legs became long and strong, for rapid running, while the fore limbs became very much reduced and handlike, to be used for grasping. Such a profound change in the posture of these reptiles naturally was reflected in their bodily structure.

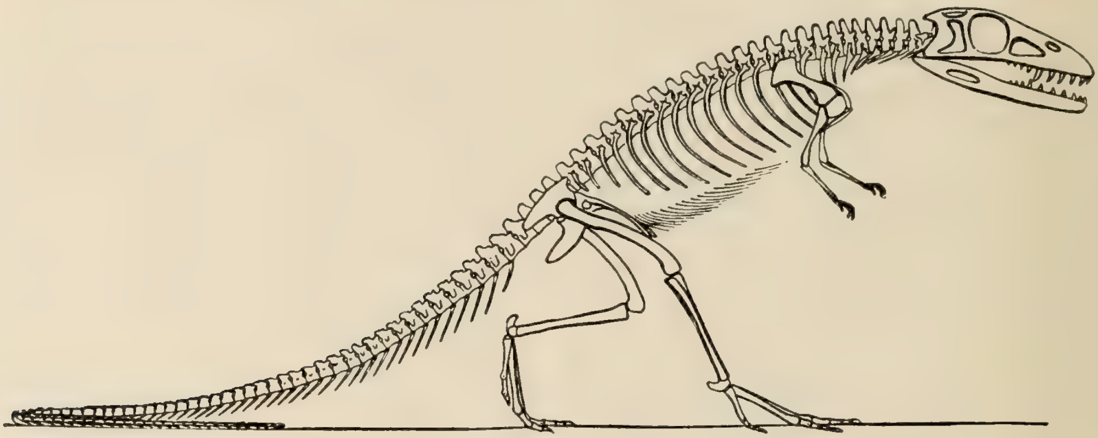
The body, instead of being supported fore and aft in the usual fashion, was "slung" at the hip joint, so that this joint became a sort of fulcrum on which the movements of the entire animal were pivoted. There was a long tail, to serve as a counterbalance for the body. The hip girdle or pelvis necessarily became strong, for it had to develop a long, stout articulation with the backbone as well as a deep socket to accommodate the ends of the upper leg bones. Therefore it became in the primitive diapsids a triradiate structure, serving admirably as a strong connection between the body and the hind limbs,—to take the stresses and strains that are inherent in a partially upright pose.

Of the primitive thecodonts none were more characteristic than *Euparkeria* (yoo-park-ER-e-ya) from South Africa, or *Ornithosuchus* (ORN-i-tho-SOOK-us) or *Saltoposuchus* (sal-to-po-SOOK-us) from Europe. When we look at one of these little reptiles, we see the ground plan for the dinosaurs. Let us therefore look at them carefully and remember them, for an understanding of this ground plan is the key to the understanding of the dinosaurs. It is the blueprint to dinosaurian body form.

One group of thecodont reptiles became



The ancestors of the dinosaurs, the thecodonts, took to their hind legs and developed this special type of hip girdle



FROM THIS SORT OF PATTERN, all of the varied dinosaurs developed: the skeleton of *Saltoposuchus*, a Triassic thecodont reptile only about four feet long

Modified from von Huene

specialized in an interesting manner. These were the reptiles known as the phytosaurs (FITE-o-sawrs), which, like all thecodonts, lived in Triassic times. The phytosaurs are found in various parts of the earth, particularly in Europe, Asia, and North America. Whereas the primitive thecodonts were small, the phytosaurs were rather large, ranging in size from six to 20 feet or more in length. And while the primitive thecodonts were mostly two-footed, the phytosaurs were four-footed. It is perhaps significant, however, that even in these four-footed phytosaurs, the front limbs were noticeably smaller than the hind limbs.

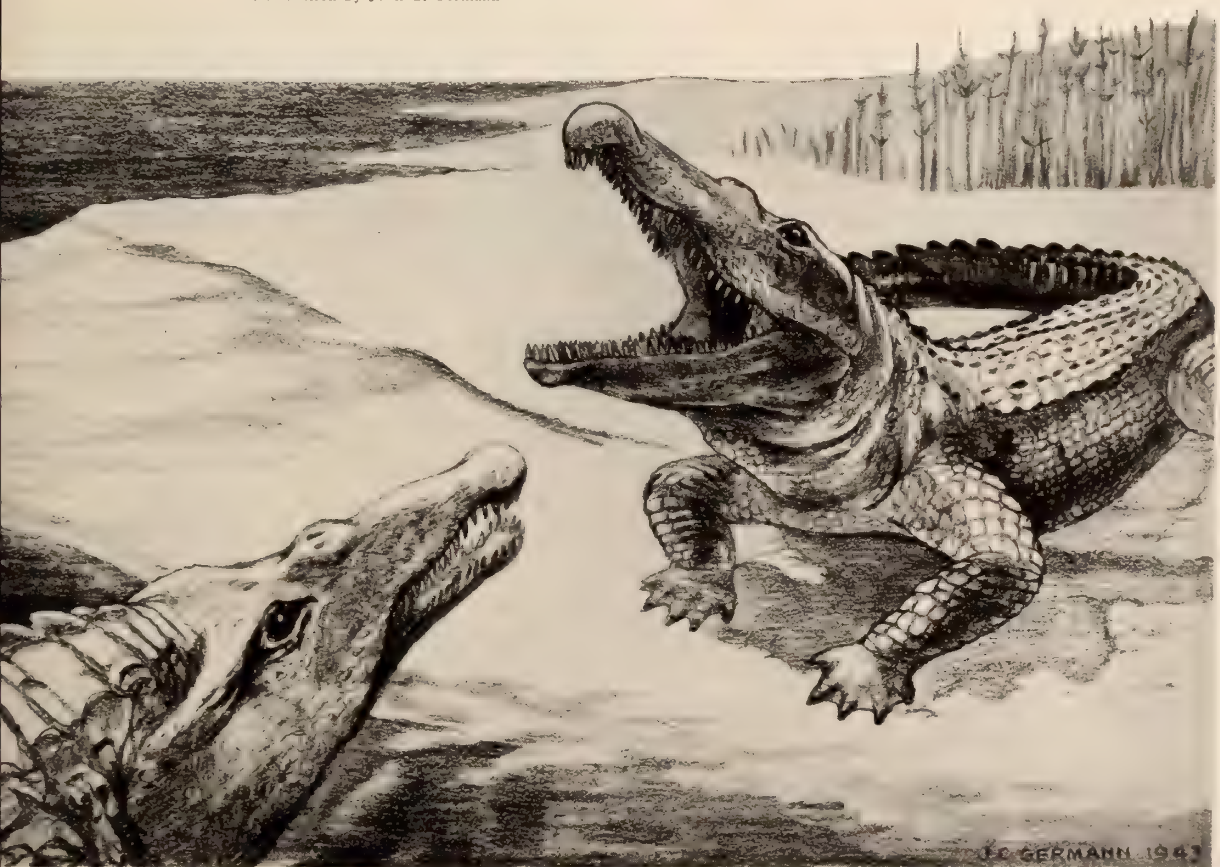
The return of the phytosaurs to the primitive four-footed mode of life was only one phase of their adaptation, for these were semi-aquatic reptiles. They lived a crocodile-like existence in the streams and lakes of the Triassic landscape, spending most of their time in the water, preying upon such hapless animals as might come within their reach, and crawling out on the sandy bars and banks to sun themselves. The phytosaurs had a very crocodile-like appearance, not only in the body but also in the head itself; indeed, to a casual eye, the skeleton of a phytosaur might easily be mistaken for one of a crocodile. The most noticeable difference is that in the phytosaur the nostrils are located on the top of the head, immediately in front of the eyes, rather than at the tip of the snout as they are in the crocodiles. It should be emphasized here that in spite of this similarity of appearance between the phytosaurs and the crocodiles, they were quite distinct groups of reptiles. The phytosaurs were *not* the ancestors of the crocodiles.

Here is a prime example of *parallelism* in evolution,—the similar development of distinct but related animals. The phytosaurs were like crocodiles, at a time when crocodiles had not yet evolved. Perhaps it might be more accurate for this reason to say that the crocodiles are like phytosaurs; the phytosaurs came first and then died out—the crocodiles then appeared and evolved in a fashion that imitated to a remarkable degree the development of the phytosaurs.

This parallelism between the phytosaurs and the crocodiles was due to the fact that both groups of reptiles occupied the same "ecologic niche," both groups played the same role in life history at the time in which they lived. In each case these were highly predaceous, water-loving reptiles that made their way in life by hunting. The phytosaurs, like the crocodiles of today, were the scourge of their environment. They feared nothing; they were the stealthy foes of whom all other animals of that day had to beware.

THE PHYTOSAURS resembled crocodiles but were not their ancestors. They lived the same kind of life as crocodiles but did not survive beyond the end of the Triassic period, about 155 million years ago, before the crocodiles evolved in a parallel direction. Notice the nostrils immediately in front of the eyes. (Genus *Machaeroprosopus,* from Arizona)

Restoration by John C. Germann



9

The Kinds of Dinosaurs

All of this time it has been our purpose to get some idea of the course of reptilian evolution that went before the development of the dinosaurs, not only to give us a background for the proper understanding of dinosaurian evolution, but also because the Permo-Triassic history of the reptiles was in itself highly important in its bearing upon the later history of life on the earth.

In the last chapter we had a glimpse of the immediate diapsid ancestors of the dinosaurs, how they developed, and in which directions their evolutionary progress led them. Now we are ready for the dinosaurs themselves.

As has been mentioned, the dinosaurs were diapsid reptiles, characterized by the two openings on each side of the skull behind the eye. Now it will probably come as a distinct surprise and perhaps a disappointment to the reader to learn that the word "dinosaur" does not denote a single and natural group of reptiles, but rather two quite distinct reptilian orders. Why then all this glib talk about "dinosaurs" if in using this term we are not utilizing a precise or definite name?

The explanation is relatively simple. In the first place, dinosaurs were virtually unknown only a little more than a hundred years ago. When first the bones of these animals were studied by scientists in England and in Europe, there was no term to indicate them collectively. Then in 1842 the great English paleontologist and anatomist, Sir Richard Owen, invented the name Dinosauria, from the Greek *deinos,* "terrible" and *sauros,* "lizard," to apply to the remains of large land-living reptiles found in rocks of Mesozoic age. Only later did it become apparent that the dinosaurs belonged to two quite distinct orders of reptiles, as distinct from each other as, for instance, cattle and horses. So the term "dinosaur" assumed a general rather than an exact meaning. Even so, it remains a useful name. It indicates a large category of prehistoric beasts, but it is a "loose" term. It may be compared with "hoofed animals" or "ungulates," the suitable term used when we wish to speak about our modern cattle and horses in one breath.

Two great orders of reptiles made up the dinosaurs. These were the "Saurischia" and the "Ornithischia," names which mean merely "reptile hips" and "bird hips." The Saurischia (sawr-ISS-kee-ya) were those dinosaurs having the three bones of the hip arranged more or less according to the typical reptilian plan, while the Ornithischia (orn-ith-ISS-kee-ya) were those dinosaurs in which the bones of the hip resembled in their arrangement the pelvis of birds.

This is the primary, fundamental division of the dinosaurs, extending back to the beginnings of dinosaurian history. All of the dinosaurs had a common ancestry, in that they were all descended from certain thecodont reptiles. But once the separation between the saurischians and ornithischians was established—and that came about during Triassic days—these two groups of reptiles remained quite distinct from each other.

It is this structural plan of the pelvis and of other parts of the skeleton as well that distinguishes the two orders of dinosaurs—

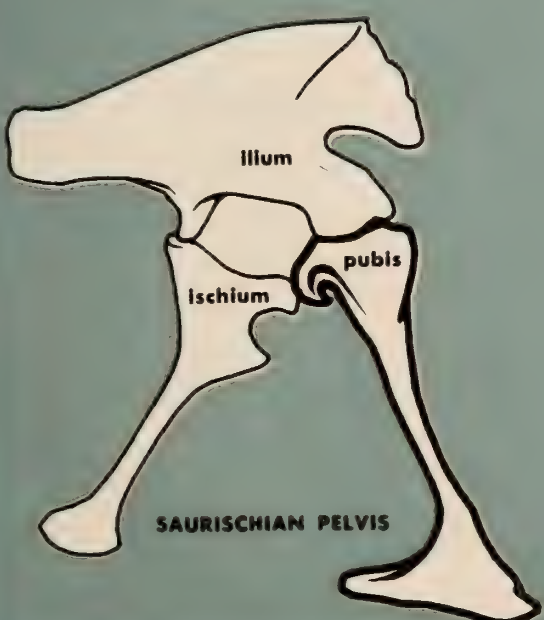
no other standard will suffice. For instance, it is a common misconception to suppose that dinosaurs were all huge reptiles, carrying their heads high in the clouds, and borne on stout legs having the general dimensions of small redwood trees. Nothing could be more erroneous. Some of the dinosaurs were large, but others were very small. Indeed, there are some dinosaur skeletons that are hardly more than a foot in length; others are no larger than rabbits or turkeys. But given the structural pattern, the pattern that was established in the Triassic thecodonts, the saurischian and ornithischian dinosaurs can all be adequately defined and the picture of dinosaurian evolution limned. This picture in simplified form is given in the chart on the following page.

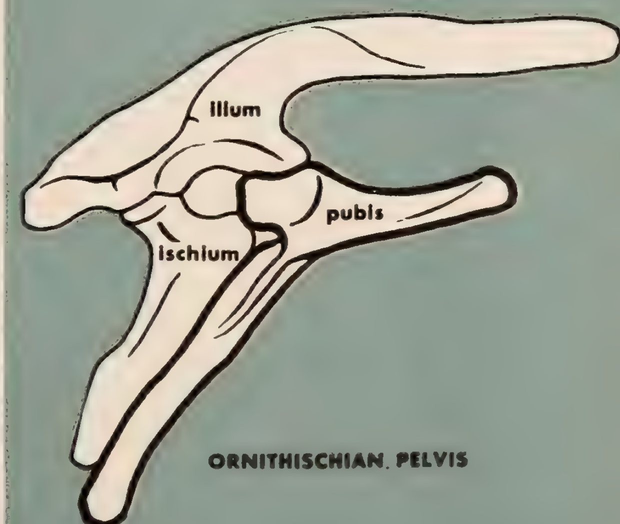
It is a picture in which we see the perfection and modification of the basic thecodont plan, the plan which had for its foundation a two-footed posture, a deep, light skull, and a carnivorous diet, with all of the implications of hunting and rapid movement imposed by such a diet and by such a mode of life.

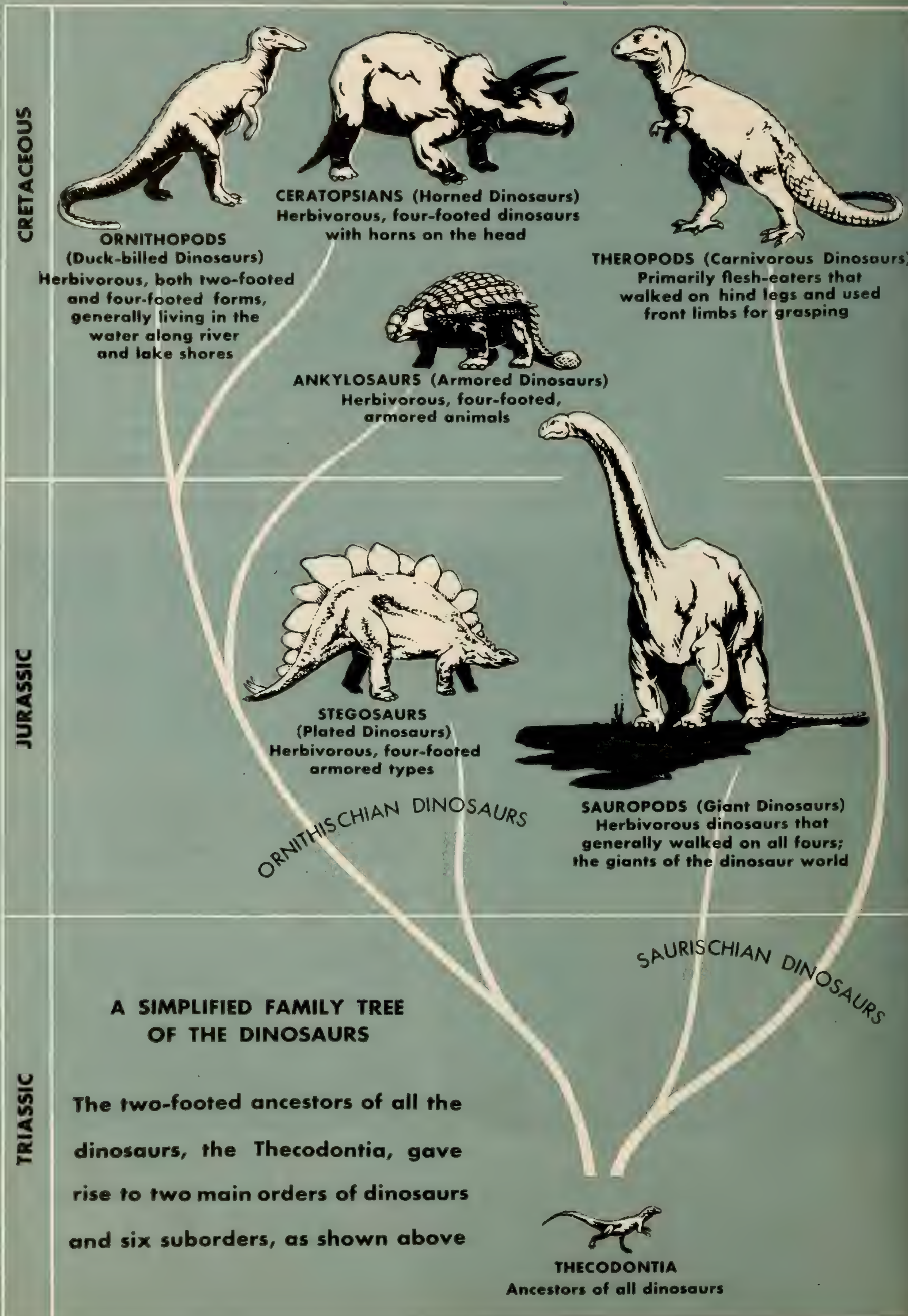
Two trends are to be seen in the development of saurischian and ornithischian adaptations from a thecodont ancestry. One of these was the general trend towards an increase in size. The ancestral thecodonts were small reptiles; many of the later dinosaurs were comparatively large—though this is not invariably the case. The other was the trend towards a modification of the

ALL DINOSAURS are divided into two groups according to the plan of the hip bones. On the left is the typical reptilian arrangement seen in the Saurischia. On the right is that of the Ornithischia, which resembled the pelvis in birds

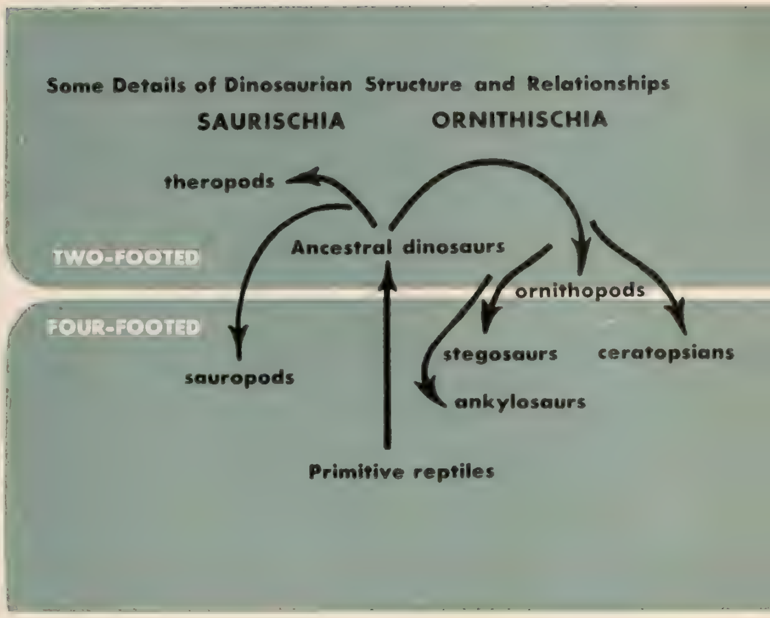
Drawings by John C. [illegible]






CRETACEOUS
JURASSIC
TRIASSIC
ORNITHOPODS
(Duck-billed Dinosaurs)
Herbivorous, both two-footed and four-footed forms, generally living in the water along river and lake shores
CERATOPSIANS (Horned Dinosaurs)
Herbivorous, four-footed dinosaurs with horns on the head
THEROPODS (Carnivorous Dinosaurs)
Primarily flesh-eaters that walked on hind legs and used front limbs for grasping
ANKYLOSAURS (Armored Dinosaurs)
Herbivorous, four-footed, armored animals
STEGOSAURS
(Plated Dinosaurs)
Herbivorous, four-footed armored types
SAUROPODS (Giant Dinosaurs)
Herbivorous dinosaurs that generally walked on all fours; the giants of the dinosaur world
ORNITHISCHIAN DINOSAURS
SAURISCHIAN DINOSAURS
A SIMPLIFIED FAMILY TREE
OF THE DINOSAURS
The two-footed ancestors of all the dinosaurs, the Thecodontia, gave rise to two main orders of dinosaurs and six suborders, as shown above
THECODONTIA
Ancestors of all dinosaurs

primitive or ancestral, two-legged posture —a very marked trend in the dinosaurs. Only in the persistently carnivorous theropods was the purely two-footed pose of the thecodonts retained. In all of the other saurischians and ornithischians there was a definite drifting away from the ancestral carnivorous mode of life, and from the bipedal pose. The sauropods and most of the ornithischian dinosaurs became large plant-eaters. A big bulky animal would be at an obvious disadvantage in attempting to carry himself about on two legs; consequently these dinosaurs came down on all fours. But it must be remembered that this was a *secondary* return to the primary four-footed pose, and this can be seen because the front



The small theropod dinosaur *Ornitholestes*, represented in the act of catching the first known bird, *Archaeopteryx*. Its food probably consisted mostly, however, of other small reptiles, eggs, insects, and the like. *Ornitholestes* preserved many of the features of the ancestral dinosaurs. From animals similar to this the great carnivores and sauropods evolved

Restoration by Charles R. Knight

legs of even the most completely four-footed of these animals were almost always noticeably the smaller. The heritage of the ancestor was retained in the descendant.

Saurischia

Theropoda (The carnivores)

The theropods (THER-o-pods) preserved more completely than any of the other dinosaurs the primitive characteristics of their thecodont heritage. They remained the true two-leggers, and for the most part they were flesh-eaters.

In such persistently small animals as the Jurassic *Ornitholestes* (orn-i-tho-LES-teez) we see a general retention of ancestral dinosaurian features. *Ornitholestes* was no more than five or six feet in length—and this includes the long, attenuated tail which served as a lever to balance the weight of the body. All in all this was a remarkably light and graceful little dinosaur, with strong, birdlike hind limbs, on which it could probably run through the dense tropical greenery with considerable swiftness and agility, darting in and out in search of its prey. The front limbs of *Ornitholestes* were relatively small as in all the theropods, and there were long, grasping fingers with which this little animal could hold its food. The skull, too, was small and light, deep and narrow, and armed with sharp teeth well adapted to biting and tearing. On the whole this was an efficient little mechanism for the catching of Jurassic small fry, and thus *Ornitholestes* fulfilled his role in the ecological or environmental scene of that day. This was the seeker of small game, of other ground-living reptiles that hid in the shelter of rock crannies or climbed up the stems of ferns.

A decided contrast to this graceful little dinosaur was his giant contemporary, the huge theropod known as *Allosaurus* (al-lo-SAWR-us), one of the mighty hunters of the Jurassic, an animal some 35 feet in length that swung across the landscape in majestic and awful splendor. In a sense *Allosaurus* was an enlarged edition of his little relative, *Ornitholestes*, for this giant was a two-legged meat-eater. But giantism in nature is more than a simple process of something little being reproduced on a large scale, for with size there come many mechanical problems of weight and accompanying stresses and strains, so that the big animal shows many changes in proportion and many differences in structure as compared with the little animal.

Thus *Allosaurus* had relatively very heavy, strong hind limbs, to carry its great weight. And as a corollary to the strains consequent upon size, the entire pelvis in this animal had become strong and heavy for the attachment of the powerful muscles that moved the hind legs.

The hands of this great meat-eater were armed with hooklike claws, a development in keeping with the size and the violent mode of life which this hunter must have led. Perhaps the greatest difference to be noted between the small carnivore and the large carnivore is to be seen in the huge head that was carried by the giant *Allosaurus*. Here was a large skull which in spite of its size was remarkably light and strong, and possessed a widely gaping mouth armed with dagger-like teeth. This was the business end of the beast. *Allosaurus* was the hunter of big game, and as such he must needs be provided with weapons sufficient for the task—that is, with large, strong jaws and heavy, sharp teeth. He had them.

The culmination of development in the

↑ *Allosaurus,* a large predaceous theropod dinosaur of Jurassic age. It is represented here as devouring the carcass of a brontosaur, one of the large dinosaurs on which it probably preyed

↓ The largest carnivorous land animal that ever lived: *Tyrannosaurus.* This animal represents the culmination of meat-eating adaptations in the dinosaurs. It evidently preyed upon some of the large herbivorous dinosaurs of its day and is here represented as attacking the horned dinosaur, *Triceratops*

Restorations by Charles R. Knight

theropod dinosaurs was attained by the giant Cretaceous form, *Tyrannosaurus* (tye-ran-o-SAWR-us), the "king of the dinosaurs." This was the greatest and most fearful land-living carnivore that has ever dwelt on earth, an animal of magnificent proportions and terrible power, beside which the modern lion and bear would appear as almost harmless dwarfs. *Tyrannosaurus*, standing on his powerful hind limbs, carried his head some 18 or 20 feet above the ground, while the distance from the tip of his nose to the tip of his tail was all of 50 feet. This animal might have weighed some eight or ten tons when he was a living creature of destruction.

The several specializations which characterized the upper Jurassic *Allosaurus* were carried to extremes of development in the Cretaceous *Tyrannosaurus*. Thus, this giant among the carnivores had exceptionally strong legs and a very stout pelvis to serve as a fulcrum between the backbone and the limbs. In *Tyrannosaurus* there was a reduction of the fore limbs so that they had become inordinately small. Correlative with this reduction of the forelimbs there was also a reduction in the hands, which were armed with hooked claws. The reduction affected not only the size but also the number of digits, so that only two claws were functional on each hand; evidently *Tyrannosaurus* had little use for his arms.

That this was so is proved by the extremes to which the head developed in this great dinosaur. The skull of *Tyrannosaurus* was indeed a tremendous structure, powerfully built, with a mouth having a gape of almost unprecedented size and armed with huge, scimitar-like teeth. Such was the offensive weapon for this mighty hunter, a weapon that could be used with effect against other large and tough dinosaurs of that day.

There were other carnivorous theropods living in Cretaceous times, similar to *Tyrannosaurus* but showing lesser degrees of specialization. One of these was the somewhat smaller form, *Gorgosaurus* (gor-go-SAWR-us).

A somewhat different line of theropod specialization is to be seen in the Cretaceous dinosaur, *Struthiomimus* (strooth-ee-o-MIME-us), the "ostrich dinosaur." This evolutionary line, alone among the theropods, departed from the carnivorous mode of life and turned to a vegetarian or perhaps a fruit-eating life.

Struthiomimus was a dinosaur of medium size, and like the other theropods was bipedal, with a long tail to act as a counterbalance to the body. The fore limbs were rather well developed and were provided with long-fingered, grasping hands, something on the order of the hands in *Ornitholestes*.

It is in the structure of the head and neck that the "ostrich dinosaur" shows the greatest departure from the typical theropod adaptations. In this reptile the neck was very long, sinuous, and birdlike, as compared with the rather medium-length or even short neck of most of the theropods, while the head was small, and lightly built. The skull in *Struthiomimus* was remarkable not only for its small size and light construction, but also because of the fact that all of the teeth had been lost, while the jaws were beaklike—again an ostrich-like adaptation. It would seem that *Struthiomimus* lived a harmless and blameless life, eating such fruits or buds or insects that might come its way, with ever a wary eye cocked on the big rapacious carnivores that ranged across the Cretaceous landscape.

Sauropoda

The sauropods (SAWR-o-pods) were the

↑ The Upper Cretaceous theropod, *Struthiomimus.* This dinosaur had gotten away from the active carnivorous habits of its theropod predecessors and become birdlike. The jaws developed as a flat horny beak that might be useful in eating fruits, other green things, insects, and small reptiles

Restoration by Erwin S. Christman

↓ One of the largest dinosaurs, *Brontosaurus,* a creature some 80 feet long and 40 tons in weight. It inhabited the marshes and streams of western North America between 120 and 155 million years ago and fed upon green plants in its tropical environment

Restoration by Charles R. Knight

giants of the dinosaurian world and, so far as land-living animals go, the giants of all time. No other land animals have reached the great bulk attained by some of the sauropod dinosaurs, and only the huge whales in the sea have exceeded them.

The beginnings of sauropod history may be seen well exemplified by the Triassic dinosaur *Plateosaurus* (plat-e-o-SAWR-us), found in Europe and Asia. This was a dinosaur of medium size, some 20 feet in length. It was characterized by its long tail and by its rather long neck, surmounted by a comparatively small head. *Plateosaurus* had, of course, the typical three-pronged or triradiate pelvis of the saurischians, and like its theropod relatives it was at least partially bipedal. In *Plateosaurus* there was some enlargement of the fore limbs, which suggests that while this dinosaur may have tramped across the Triassic landscape on its strong hind limbs, it was nevertheless quite capable of assuming a four-footed posture for the purpose of feeding. The teeth were no longer the sharp blades so typical of the meat-eating theropods; rather they showed a sort of flattening, and a blunting of their points, as if they were becoming adapted to the cropping and cutting of green, leafy plants.

It was in the Jurassic that the sauropod dinosaurs reached the culmination of their evolutionary history. This was the period of the giants, of *Brontosaurus* (bront-o-SAWR-us), *Camarasaurus* (kam-ar-a-SAWR-us), and *Diplodocus* (dip-LAH-do-kus) in North America, of *Cetiosaurus* (seet-ee-o-SAWR-us) in Europe, and of the huge *Brachiosaurus* (brak-e-o-SAWR-us) in Africa. *Brontosaurus* is a typical sauropod and illustrates very well the characters of the group.

This dinosaur was a tremendously long animal, some 70 or 80 feet in length from the nostrils to the tip of the tail, and like all of the typical sauropods it walked on all fours. Much of the length of *Brontosaurus* was taken up by the long tail, which at its end was attenuated and whiplike, and by the correspondingly long neck. Even so, the body was a huge, bulky affair weighing in itself many tons, supported by great, postlike legs. As in almost all of the four-footed dinosaurs, the hind limbs were much larger and more massive than the front limbs, since as already mentioned the four-footed pose in these animals was a secondary development. The feet of *Brontosaurus* were short and broad, as would be necessary to support an animal of such bulk, and they were armed with curved claws—one on each of the fore feet and three on each of the hind feet.

The head of this great reptile was remarkably small compared to the body, and it is difficult to imagine how an animal of such size could take in through such a modestly-proportioned mouth enough green stuff to keep it alive. Yet there is no doubt but that *Brontosaurus* was a plant feeder, and like all plant-eating animals it had to consume a great amount of bulky material in order to get sufficient nourishment to keep it alive and reasonably active. It must be remembered, of course, that these great reptiles must have been rather sluggish, as are the modern cold-blooded vertebrates, so that they would not require as much food to satisfy their needs as we might think would be necessary. At any rate, we know that *Brontosaurus* did live and prosper over a long period of geologic time, so evidently he found his small mouth sufficient for his purposes.

All of the other sauropods represent variations of the pattern seen in *Brontosaurus*.

One well-known form from North America, *Diplodocus,* was remarkably long and tapering, although not so bulky as his cousin, *Brontosaurus.* In this animal the skull was even smaller than in *Brontosaurus,* while the teeth were weak pegs, no bigger in diameter than lead pencils. The nostrils of *Diplodocus* were located on the top of the head, an adaptation for life in the water. Indeed, the evidence would seem to indicate that all of the sauropods spent much of their time in the water, wading around in swamps, and even venturing out into the deeper reaches of lakes or rivers to escape from danger.

The largest of all the sauropods was *Brachiosaurus* which is found on opposite sides of the world, in North America and in east Africa. This dinosaur was not so long as *Brontosaurus* or *Diplodocus* but it was very bulky. In *Brachiosaurus* there was a strange enlargement of the front part of the body, so that the fore limbs were larger than the hind limbs (an exception to the general rule), while the neck was very long and heavy. This caused the back to slope giraffe-fashion to the hind limbs, while the tail was comparatively short. *Brachiosaurus* had the nostrils raised on a sort of dome or eminence on the top of the head, an indication, along with the long neck and raised fore-quarters, that this dinosaur probably waded along the bottom in deep water, where it was enabled by its great size to thrust the top of the head above the surface, periscope fashion, to breathe and to survey the surroundings.

Ornithischia

Ornithopoda

The ornithischian dinosaurs were on the whole more highly evolved than were the saurischian forms. This is a fundamental truth which has its foundations in the basic, diagnostic characters of these two great groups of dinosaurs. It will be remembered that the saurischians were the forms with an essentially triradiate arrangement of the pelvic bones, similar to the arrangement in the ancestral thecodont reptiles, while the ornithischians were those animals in which there was a rotation of the pubic bone so that it came to occupy a position parallel to the ischium. This formation of the pelvis is in itself an indication of the advanced position of the ornithischians as compared with the saurischians.

The argument extends to other parts of the body as well. In particular the ornithischian dinosaurs showed specializations of the head and of the teeth, which went far beyond the specializations to be seen in their more conservative saurischian cousins. It is interesting, too, to see that the Saurischia had gone through the major phases of their evolutionary development during Jurassic times, so that the saurischians of the ensuing Cretaceous period were for the most part continuations of "Jurassic patterns." The Ornithischia, on the other hand, experienced by far the major part of their evolutionary development in Cretaceous times.

The least "advanced" of the ornithischian dinosaurs are to be found among the large group known as the Ornithopoda (orn-i-THO-pod-a), the duck-billed dinosaurs and their relatives. This is not to say that all ornithopods (ORN-i-tho-pods) were of a particularly primitive aspect—indeed, in some of the Cretaceous forms we see highly specialized types. But there was one group of the ornithopods that was relatively unspecialized—the group known as the camptosaurs.

↑ *Camptosaurus:* One of the first of the ornithischian dinosaurs, which lived in late Jurassic and early Cretaceous times. All of the later armored dinosaurs, duck-bills, and horned forms were derived from ancestors something like this five- to eight-foot plant-eating dinosaur

The camptosaurs or iguanodonts appeared about 140 million years ago in the Jurassic period, and they continued their development through Lower Cretaceous times. These dinosaurs were bipedal, although it is an interesting fact that the camptosaurs did not lead a completely two-footed ambulatory existence as did the carnivorous theropods. For the camptosaurs were perfectly capable of coming down on all fours whenever the occasion demanded such a pose, which was probably quite often the case.

In *Camptosaurus* (kamp-to-SAWR-us) the skull was rather long and low, with flattened, bladelike teeth—obviously intended for the cutting and chewing of green plants. In these animals there were no teeth in the front of the mouth, either above or below—a basic pattern that was repeated in virtually all of the ornithischian dinosaurs. Instead, the front of the jaws formed a birdlike beak, which in life was obviously covered by a horny sheath and served as an efficient mechanism for the biting and cutting of plant food. It should be repeated here that all of the ornithischians were strictly herbivorous.

One of the very interesting dinosaurs, which unfortunately is not to be found in any of the American museums, is the European ornithopod, *Iguanodon* (i-GWAN-o-don). *Iguanodon,* a close relative of *Camptosaurus,* is of particular interest not only because it is a well-known animal of which numerous complete skeletons have been discovered, but also because it was the first dinosaur to be scientifically described.

← *Trachodon,* a duck-billed dinosaur of late Cretaceous times. The duck-bills were all aquatic and spent much of their time either in or near the water

Restorations by Charles R. Knight

In 1822 some peculiar teeth were found in Lower Cretaceous rocks in the county of Sussex, England, by the wife of Dr. Gideon Mantell, a famous English paleontologist. Of course nobody at that time had ever heard of a dinosaur, in fact the name "dinosaur" had not yet been invented, so it was indeed a puzzle as to what the strange teeth found by Mrs. Mantell might be. Mantell, unable to identify the teeth to his satisfaction, sought the advice of Sir Charles Lyell, who in turn submitted the specimens to Baron Georges Cuvier, the celebrated French anatomist. Cuvier, after due deliberation, announced that these teeth belonged to a rhinoceros.

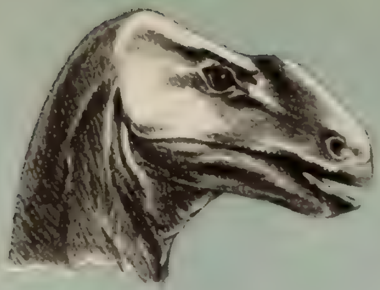
That didn't seem right, so Mantell went back to look for more remains, and found some bones in the quarry where the original discovery was made. There was some more guessing by Cuvier—this time he voted in favor of a hippopotamus—but finally, after diligent comparisons, Mantell himself finally came to the conclusion that here was a new type of reptile, of large size, and with teeth like those of the present-day iguana. Hence the name, *Iguanodon.*

At first Iguanodon was restored as a four-footed reptile, but in later years an unusual series of seventeen skeletons was found in a coal mine in Belgium, and the true nature of this dinosaur was recognized.

The ornithopods reached the height of their development in the Cretaceous hadrosaurs or trachodonts, often called the "duck-billed" dinosaurs. These were large dinosaurs, partially bipedal and partially quadrupedal, and they were obviously water-loving animals. This is shown by the structure of the head, in which the front of the skull and jaw were broadened into a flat "duck bill" (hence the sobriquet) that was most assuredly very handy for grovel-

THE STRANGE HEADS OF SOME DUCK-BILLED DINOSAURS

Restorations by John C. Germann



Kritosaurus

An expansion of the nasal bones gave Kritosaurus a beaked or hook-nosed appearance

Corythosaurus

A large crest, involving the premaxillaries as well as the nasal bones, distinguished Corythosaurus. The long S-shaped curve of the nasal passages formed within the crest an air storage chamber permitting the animal to remain under water longer

Lambeosaurus

The crest projected behind the skull in Lambeosaurus, in addition to forming a sort of hatchet-shaped blade on the top of the skull

Parasaurolophus

In Parasaurolophus the crest, still formed of the nasal and premaxillary bones, reached the extreme development. In this crest, the greatly elongated nasal passage formed an air storage chamber of considerable dimensions

ing in the shallow water and muddy bottoms of streams and ponds. It is also shown by webbing between the toes, revealed in several cases where skin impressions of these animals have been preserved.

The central type is *Hadrosaurus* (had-ro-SAWR-us) or *Trachodon* (TRAK-o-don), found in various parts of western North America and in the eastern portion of the continent, too. Indeed, as already mentioned the first dinosaur skeleton to be found and described in North America was a *Hadrosaurus* skeleton, discovered not in the wilds of the western badlands, but in the town of Haddonfield, New Jersey, a suburb of Philadelphia. A glance will show that *Trachodon* was a camptosaur grown large, in which the skull was flattened, especially in front, to form the broad "duck bill" so characteristic of these dinosaurs.

In late Cretaceous times there were numerous evolutionary variants of this central hadrosaurian theme, developments characterized for the most part by peculiar and bizarre modifications of the skull. One of these was *Kritosaurus* (kritt-o-SAWR-us). Another was *Corythosaurus* (kor-ith-o-SAWR-us). Another was *Lambeosaurus* (lamb-e-o-SAWR-us). Another was *Parasaurolophus* (par-a-sawr-AH-lof-us).

Suffice it at this point to note the strange and wonderful lengths to which evolution carried these fascinating dinosaurs. On page 87 we refer further to the significance of the peculiar skull structure of the several types of hadrosaurian dinosaurs.

A very peculiar group of ornithopod dinosaurs was that of the troödonts (TRO-o-dahnts), small to medium-size dinosaurs, in which the body seemingly was rather similar to the body of other ornithopods, but in which the head was remarkably specialized. In these dinosaurs the roofing bones of the skull became extraordinarily thick, so that there was a dome of solid bone above the brain, while on the nose and at the back of the head there was a fearsome array of nodes, points, and spikes. The extreme was reached in one of the late Cretaceous troödonts, *Pachycephalosaurus* (pak-e-SEF-a-lo-sawr-us), having a solid domed skull roof some nine inches thick. This was, indeed, the original bonehead!

Stegosauria

There were two groups of ornithischian dinosaurs which during the course of their development were distinguished by a "hands off" trend of evolution. These were the so-called armored dinosaurs, the walking fortresses that defied their enemies by the comparative impregnability of their defense—the stegosaurs of the Jurassic and the ankylosaurs of the Cretaceous.

Stegosaurus (steg-o-SAWR-us) was typical of the Jurassic pattern of dinosaurian armor. Here was a rather large ornithischian, completely quadrupedal, but with the fore limbs so much smaller than the hind legs that this animal was a congenital "high-behind." From the tiny camptosaur-like head, carried rather close to the ground, the back arched in a steep curve to the high hips, and then descended again to the tip of the tail. The massive body was supported by strong legs, ending in broad padded feet.

The "armor" of *Stegosaurus* was perhaps the most striking feature of this strange dinosaur, and it contributed much to the strange appearance of the beast. Down the middle of the back there was a series of upright, triangular plates, arranged alternately, while the tip of the tail bore four

***Stegosaurus,* an armored dinosaur of the Jurassic period. Some of the earlier restorations showed this animal with the plates paired, and with six tail-spikes, but the arrangement of alternating plates with four spikes on the tail, shown here, is based upon the most recent evidence**

Restoration by Charles R. Knight, copyright The Chicago Natural History Museum

huge spikes, presumably intended to serve as a pointed reminder to any other dinosaur that might venture closer than was considered proper by Mr. *Stegosaurus.*

Whether the plates along the back served as a really effective protection to the spinal column is a question which at this distant date cannot be very satisfactorily answered. At least they were decorative.

This dinosaur is famous, among other things, for the small size of his brain. Indeed, this was a peanut-headed reptile, if ever there was one,—an animal bigger than an elephant, with a brain about the size of a walnut. It is a remarkable fact that the brain of *Stegosaurus* was actually 20 times smaller than the enlargement of the spinal cord in the hip, which served to control the movements of the heavy hind limbs and the powerful tail. Which has given rise to the quaint, and somewhat fanciful story that this dinosaur had two sets of brains—an idea charmingly perpetuated by the late Bert Leston Taylor, a columnist on the *Chicago Tribune.*

THE DINOSAUR

"Behold the mighty dinosaur,
Famous in prehistoric lore,
Not only for his power and strength
But for his intellectual length.
You will observe by these remains
The creature had two sets of brains—
One in his head (the usual place),
The other at his spinal base.
Thus he could reason 'A priori'
As well as 'A posteriori.'
No problem bothered him à bit
He made both head and tail of it.

"So wise was he, so wise and solemn,
Each thought filled just a spinal column.
If one brain found the pressure strong
It passed a few ideas along.
If something slipped his forward mind
'Twas rescued by the one behind.
And if in error he was caught
He had a saving afterthought.
As he thought twice before he spoke
He had no judgment to revoke.
Thus he could think without congestion
Upon both sides of every question.
Oh, gaze upon this model beast,
Defunct ten million years at least."

—Bert Leston Taylor

It wasn't quite as bad as all that, but at any rate *Stegosaurus* must have been pretty much a walking automaton, without much of what might be called original thought.

Ankylosauria

The Cretaceous armored dinosaurs were the ankylosaurs, somewhat less startling in appearance than the stegosaurs but perhaps somewhat more effectively protected. These

ORNATE ARMOR helped to protect *Palaeoscincus* (center foreground) from other dinosaurs of his time. To the left is *Trachodon,* to the right (middle distance) *Corythosaurus* and (farther away) *Parasaurolophus.* In the center background are two *Struthiomimus*

Restoration by Charles R. Knight, copyright The Chicago Natural History Museum

THE FIRST OF THE HORNED DINOSAURS, *Protoceratops*, from the Cretaceous of Mongolia. In this primitive member of the group the horns were as yet undeveloped

Restoration by Charles R. Knight, copyright The Chicago Natural History Museum

dinosaurs had a real armor plating, an overlapping pavement of bony plates presumably covered with horny sheaths, which encased the entire body, head and tail, armadillo-fashion.

Ankylosaurus (an-kyle-o-SAWR-us) was typical of this group of dinosaurs. A medium-size dinosaur this was, quadrupedal in pose and of heavy build. The skull was broad and strongly protected by the armor plates, while the arched back was completely encased by the articulating scutes. Add to this a heavy, stiff tail, ending in a huge clublike mass of bone and you have a picture of *Ankylosaurus*.

Here was the tank of Cretaceous days, low, squat, and strongly protected by his outer casing. He could blunder along through the world without a great deal of concern about the rapacious carnivores that ranged far and wide, the gigantic *Tyrannosaurus* and his lesser relatives. By seeking refuge within the strength of his shell he was fairly safe from attack, and with the knout on the end of his tail he might lay about him, to create devastation within the arc swept by that mighty club.

Most of the other armored dinosaurs of the Cretaceous were generally similar to *Ankylosaurus*. Of these, *Palaeoscincus* (pale-e-o-SKINK-us) and *Nodosaurus* (node-o-SAWR-us) may be mentioned.

Ceratopsia

Of all the dinosaurs the Ceratopsia (ser-a-TOPS-e-ya) or horned ornithischians were the last to appear. The earliest ceratopsians appear in beds of Cretaceous age, and in the relatively short lapse of geologic time between their rise and their final extinction these animals enjoyed a remarkably varied course of evolutionary adaptation.

The ancestry of the ceratopsians is indicated, if not actually represented, by a small bipedal dinosaur from the Lower Cretaceous of Mongolia, known as *Psittacosaurus* (sit-a-ko-SAWR-us). This little animal was characterized especially by the development of its skull, which was very deep and narrow, so that the front of it formed a large pointed beak, similar to the beak so characteristic of the horned dinosaurs. Indeed, *Psittacosaurus,* as has been shown by Gregory, is an almost ideal ancestor for the ceratopsians, not only with regard to the development of the skull but also because of the characteristic expression of the pelvis, in which the pubic bone was reduced (a typical ceratopsian feature), and because of the form of the limbs and of the feet. A series running from *Psittacosaurus* to *Protoceratops* (prot-o-SER-at-ops) (the first of the "frilled" ceratopsians), and to the later forms, shows how the small two-legged dinosaurs became specialized to give rise to the giant horned dinosaurs of Upper Cretaceous times.

The first of the frilled ceratopsians was a small dinosaur known as *Protoceratops,* discovered a few years ago in the upper Cretaceous Djadochta beds of Mongolia. This little ornithischian was five or six feet in length, and in spite of its comparatively small size it would seem to have been almost entirely quadrupedal. Evidently the four-footed pose was established at a very early stage in this line of dinosaurian development.

The most striking feature of *Protoceratops* was its head, which was relatively very large and deep. The front of the muzzle and the jaws formed a hooked parrot-like beak, and the back of the skull extended back to form a pierced or fenestrated frill that overhung the neck and the shoulder region. Like the other ornithischians, *Protoceratops* lacked teeth in the front of the jaws, *except* for two tiny vestigial teeth on each side near the front of the upper jaws—obviously an evolutionary "hang-over" from a more primitive stage of development. This little animal, although a horned dinosaur, had only the beginnings of a nasal horn, for he was the first of his line and had not developed the specializations that were so characteristic of his large and impressive grandchildren.

Protoceratops is known from a number of skeletons and from a remarkable series of skulls which show the development of this animal from a newly hatched baby to a fully developed adult. These skulls show, for instance that the flat "frill" at the back of the skull was not present in the newly born *Protoceratops,* but that it grew as the animal grew up, so that by the time adulthood was attained, there was a well-developed, fully-formed frill. Incidentally, it is probable that this frill grew as an accommodation for strong neck muscles which controlled the movements of the head, these in turn being made necessary by the great relative increase in the size of the skull.

To make our knowledge of *Protoceratops* really complete, there were discovered with this little dinosaur several nests of its eggs. These were the first dinosaur eggs to be discovered, and as such they became very famous in the public press some years ago. The eggs are similar in shape and in surface texture to the eggs of certain modern turtles. In two of them were found the bones of an unhatched embryo *Protoceratops!*

From the modest beginnings of *Protoceratops,* the giant horned dinosaurs of late Cretaceous times evolved. Of the great

A.M.N.H. photograph

A nest of eggs of *Protoceratops*, the ancestral horned dinosaur, as they were discovered in Mongolia by the Central Asiatic Expedition of the American Museum of Natural History

ceratopsians, *Triceratops* (try-SER-at-ops) is typical and is perhaps the best known genus.

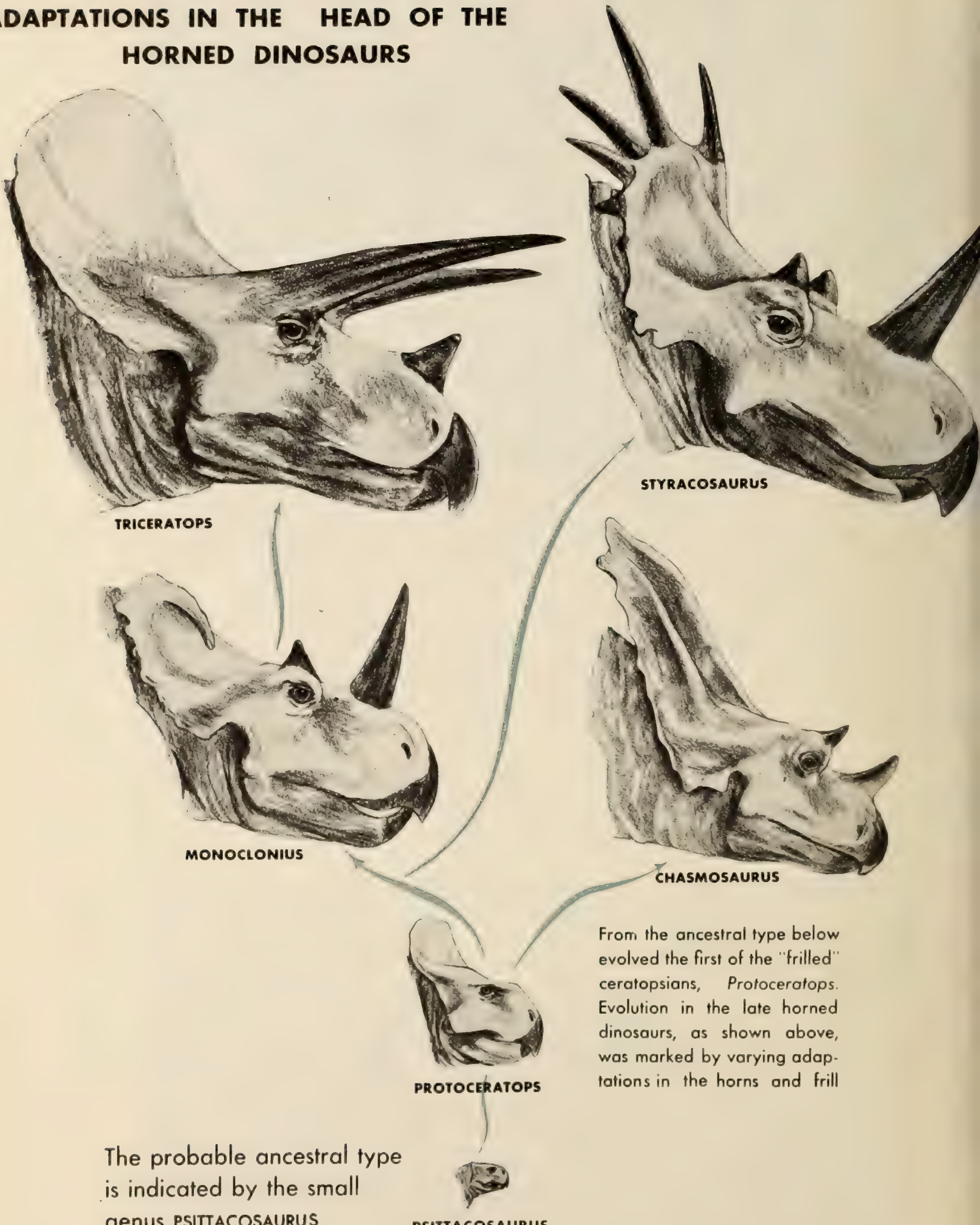
This was an animal about 20 to 30 feet in length, standing some eight feet in height at the hips. Needless to say, *Triceratops* was fully quadrupedal, with strong limbs, and short, broad feet. The remarkable feature of *Triceratops* and of all the large horned dinosaurs was the enormous head, constitut-

The last of the horned dinosaurs: *Triceratops*, a strong animal, admirably equipped for defensive fighting. The seven-foot skull with its flaring "collar" was fully one-third the entire length of the animal. From the Upper Cretaceous of North America

Restoration by Charles R. Knight, copyright The Chicago Natural History Museum

Restorations by John C. Germann

ADAPTATIONS IN THE HEAD OF THE HORNED DINOSAURS



From the ancestral type below evolved the first of the "frilled" ceratopsians, *Protoceratops.* Evolution in the late horned dinosaurs, as shown above, was marked by varying adaptations in the horns and frill

The probable ancestral type is indicated by the small genus PSITTACOSAURUS ing fully one-third of the entire length of the animal—an accentuation of a development that was already apparent in *Protoceratops*. Thus, in a large *Triceratops* the skull was some seven feet in length, of which about one-half was occupied by the great flaring frill that extended back over the neck and shoulders. As in all of the other ceratopsians, the skull and jaws were deepened and narrowed in front to form a hooked parrot-like beak. This animal carried on its nose a stout horn, and over the eyes were two other horns, these latter very long and strong and admirably suited for defensive fighting.

The skull of *Triceratops* was attached to the backbone by a ball-and-socket joint at the back of the brain case, which was at about the middle point of the skull, beneath the front of the frill, so that the skull was virtually balanced upon it. With tremendous neck muscles attached to the bottom of the frill, combined with strong leg muscles, *Triceratops* must have had a remarkable ability for making short powerful lunges with the head down and the two long horns directed forward to impale any luckless antagonist. Such an arrangement was eminently useful to *Triceratops*, for he lived in a land inhabited by *Tyrannosaurus*, than whom there never was in this world a more powerful adversary.

The other giant ceratopsians of late Cretaceous days were variations on the *Triceratops* theme. Their differences were expressed mainly in the development of the horns and the frill.

Thus there was *Chasmosaurus* (kas-mo-SAWR-us), with small horns. And *Monoclonius* (mon-o-KLON-e-us) with a large horn on the nose and small horns over the eyes. And *Styracosaurus* (sty-rak-o-SAWR-us) with a large horn on the nose, no horns of consequence above the eyes, but spikes all around the margin of the frill.

These were the last of the dinosaurs. They came onto the scene of dinosaurian evolution during its final stages and disappeared, along with certain other final survivors, during that great transition between Mesozoic and Cenozoic times, when reptilian dominance gradually yet unequivocally gave way to mammalian dominance on the earth. Their history was relatively short, but while it lasted it was varied, interesting, and successful.

10

Adaptations of the Dinosaurs

TIME FLIES, but the life of the world goes on. Today fat cattle graze across the western prairie where yesterday there were bison. Today the white-faced steers are rounded up by cowboys, to be shipped to market, where yesterday the bison was trailed and hunted by the wolf. Life is a continuous round and an unending struggle between the hunter and the hunted, it is a story of many kinds of plants and animals fitting into their various roles by means of adaptation to the environment.

So it was in the days of the dinosaurs. Then as now there were the plant-eaters, getting their livelihood direct from the green products of Mother Earth. Then as now there were the hunters, feeding upon the inoffensive herbivores. There were the large plant-eaters and the small plant-eaters, the large hunters and the small hunters. There were the upland forms and the animals of the swamps, the rivers, and the lakes. There were the tree climbers and the diggers in the earth. All formed a part of the ecology of the time—that complex relationship between the various forms of life, the "balance of Nature" as we often call it, whereby each plant and each animal is adjusted to the topography, the climate, and the life that surrounds it.

The adaptations of the dinosaurs were numerous, for in Mesozoic days these reptiles filled many of the "ecological niches" that are occupied by the mammals of our own time.

Some of the dinosaurs were large and others were small, as we have already seen. The small dinosaurs, such as the "bird catcher," *Ornitholestes,* retained many of the characters as well as the pose of their thecodont ancestors, while the large dinosaurs, such as the great bipedal carnivore, *Tyrannosaurus,* or the quadrupedal giant, *Brontosaurus,* showed many specializations in form and in pose over their small ancestors.

As has been pointed out on a preceding page, growing big isn't a simple matter of duplicating a small-scale animal on a large scale. The large animal is confronted by many problems of mechanics, of stresses and strains, which never bother the small animal. On the other hand, the large animal is relieved to a certain extent of some problems, of heat loss for instance, that are important in the physiology of the small animal.

As the giant dinosaurs increased, there were many adaptations as a result of the stresses and strains placed upon bone, muscle, and ligament consequent upon the ever-increasing bulk of these animals. Compare the giant *Tyrannosaurus* with the small *Ornitholestes. Tyrannosaurus,* although a two-legged dinosaur like his small cousin, lost the lightness and gracefulness of limb and foot that were so characteristic of *Ornitholestes.* In *Tyrannosaurus* there were several tons of weight to be carried around, so that the legs became very heavy and strong, while the feet broadened to form a good support and to furnish traction against the ground.

In an upright animal of gigantic size, such as *Tyrannosaurus,* the strain on the hips—the fulcrum for the body—must have been enormous. Thus, it can be seen that the connection between the hipbones and the backbone in this animal was strengthened by the lengthening of the sacrum, so that an additional vertebra became attached to the upper hipbones, the ilia. Compare this with the comparatively small attachment between the backbone and the hips in little *Ornitholestes*.

It is in the great sauropods, however, that we see the most advanced adaptations to large size. These huge dinosaurs, 70 or 80 feet in length and weighing 20 or 30 or 40 tons, must have experienced problems in mechanics that have never before or since plagued a land-living animal.

So it is that the limbs in these dinosaurs were heavy and postlike and the individual bones were extraordinarily massive and dense—veritable pillars for the support of the animal. Likewise, the feet of these giant sauropods were short and broad, so that they formed massive, round pediments through which the weight of the body was thrust against the earth.

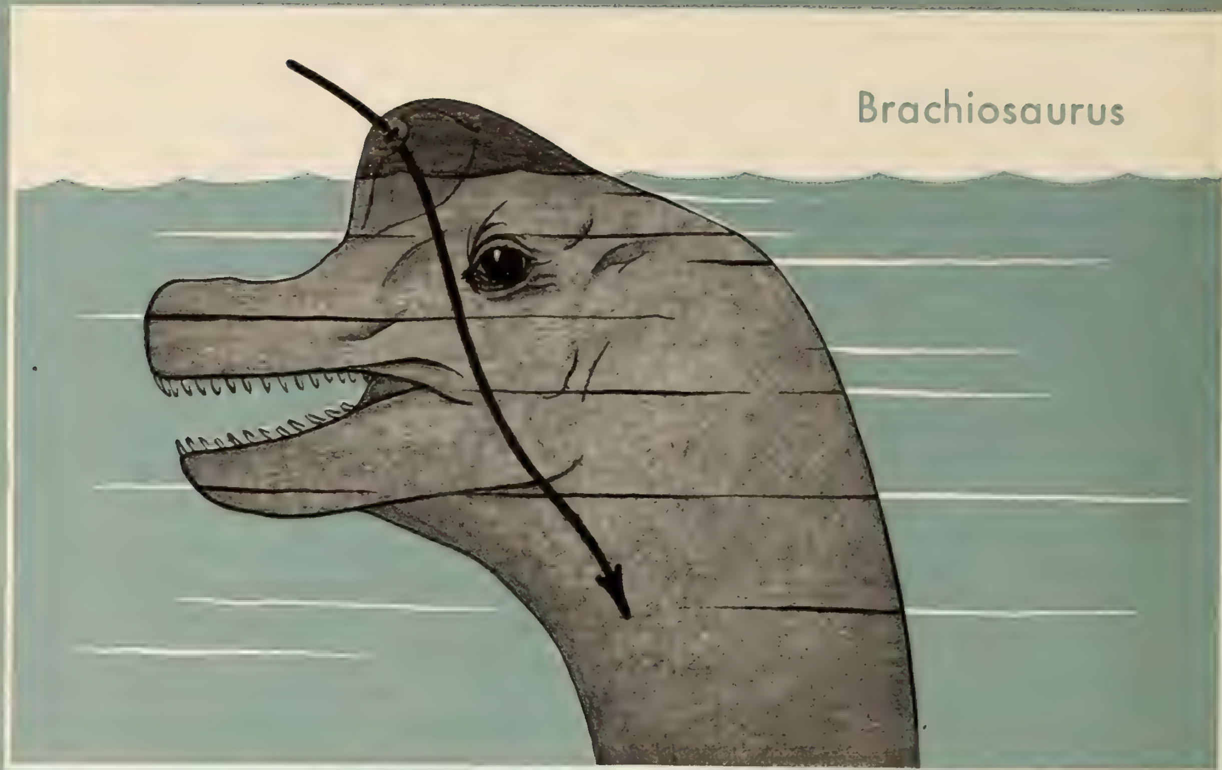
Like the lacy trusses of a cantilever bridge, the backbone of *Brontosaurus* stretched between the strong abutments of the limbs and their girdles, and beyond, to form the neck and the tail. Here was a problem that required for its solution strength combined with lightness; strength upon which to hang the many tons of body, neck, and tail, lightness so that the vertebral column itself, necessarily large because of the needed strength, would not be overburdened by a great amount of "dead weight" of bone. The problem was solved by the inexorable processes of evolution, so that the vertebrae became "excavated" where bone wasn't needed. In other words, bone was formed along the lines where stresses would come and it was taken away from those areas where there were no particular stresses, just as in the trusses of the steel bridge or in the flying buttresses of a Gothic church, strength is achieved without a resort to massiveness. In addition, the spinal column in the sauropods was strengthened by extra articulations between the vertebrae, which gave in effect additional interlocking joints to strengthen the backbone without decreasing its flexibility.

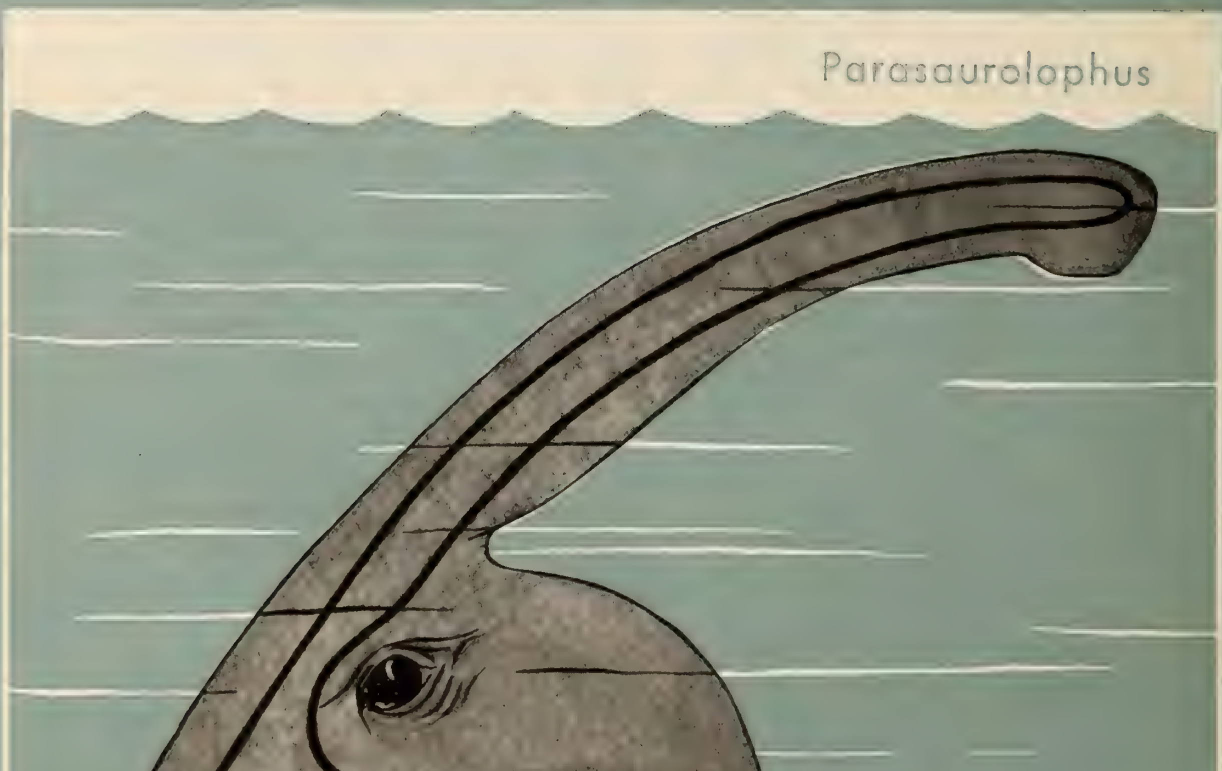
STRENGTH AND LIGHTNESS simultaneously achieved: a bone from the neck of the giant sauropod dinosaur, *Brontosaurus*. Note the concentration of bony material along lines of stress and the formation of hollows in other portions

From Osborn and Mook, 1921

The dinosaurs lived in all kinds of surroundings. Some of them were upland forms, well adapted to fairly rapid progression over hard ground. Such was the case with many of the bipedal theropods, the small carnivores such as *Ornitholestes* and the large carnivores such as *Allosaurus* and *Tyrannosaurus*. Such was also the case with many of the quadrupedal types, particularly the horned dinosaurs of Cretaceous times and many of the armored dinosaurs.

These upland forms were seemingly rather active—at least for reptiles. The bipedal animals were able to run or walk about with some show of speed, by virtue


Brachiosaurus


Parasaurolophus

of their swinging, two-legged stride. The quadrupedal forms, such as the horned dinosaurs, were built as efficient walkers; the limbs were strong and the belly was raised high off the ground.

Other dinosaurs were lowland animals, living in marshy country or along the shores of rivers and lakes. It would seem that these animals spent much of their time in the water, feeding among the lush marsh plants or even venturing out into deeper waters to escape from their traditional enemies, the giant carnivores.

Many of the lowland dinosaurs were probably slow and sluggish. It is likely that *Brontosaurus* and his relatives spent much of their time moving along slowly, feeding upon green plants. Perhaps these giant sauropods passed considerable time in motionless torpor, as do some of the large crocodiles in our own times.

The aquatic habits of the sauropods are attested to by the structure of the skull in some of them. In *Diplodocus*, for instance, the nostrils were placed on the top of the head, as is so often the case in water-living beasts, to facilitate breathing. This development is accentuated in the gigantic *Brachiosaurus* from Africa, in which the nostrils were raised so as to protrude above the top line of the brain case.

The truly aquatic dinosaurs were, however, the trachodonts or hadrosaurians. As mentioned on a previous page, we know that these dinosaurs had webbed feet, from the several "mummies" that have been preserved. In addition, the trachodonts had deep, narrow tails that must have aided in swimming—tails that were curiously strengthened and perhaps stiffened by calcification of the tendons of the back muscles, to form a lattice-work binding the bones of the spinal column.

But the most striking features of the trachodonts were the developments of accessory structures on the top of the skull in many forms, as already described and illustrated. These crests, in such animals as *Corythosaurus*, *Lambeosaurus*, and *Parasaurolophus*, were formed almost entirely by the bones surrounding the nostrils, the premaxillary and nasal bones, and to a small extent by the frontal bones of the forehead. It would seem from dissections that have been made, that the crests in the hadrosaurs were occupied by the nasal passages which were thereby lengthened so that they formed air storage chambers. The usefulness of such an arrangement to an aquatic animal that may have kept the head submerged for considerable periods of time is obvious.

It has even been suggested that certain dinosaurs may have been tree-climbing reptiles, living a life not unlike that of some of our larger tree-climbing mammals of the present day. One form in particular, *Hypsilophodon* (hips-i-LOF-o-don), shows grasping feet that would seem to have been adapted for clasping branches. This was a rather small dinosaur, and there is no reason why it might not have lived in trees.

The ancestral thecodont reptiles were carnivorous, and the carnivorous diet was retained by most of the theropods. As might be expected, the giant theropods, such as

← *Brachiosaurus* could breathe with only a small portion of the head above the surface of the water. The nostrils were on an eminence on top of the head. *Parasaurolophus*, a duck-billed dinosaur, had a greatly elongated nasal passage within the crest. This presumably formed an air storage chamber which enabled the animal to remain under water for a considerable period

Drawings by John C. Germann

Allosaurus and *Tyrannosaurus,* had widely gaping mouths armed with huge, bladelike teeth. Only in the toothless "ostrich dinosaurs" such as *Struthiomimus* was there a departure from this primitive or ancestral carnivorous diet among the theropods.

Most of the dinosaurs were, however, herbivorous, living upon green plants. In this category, we find the sauropods among the Saurischia and all of the dinosaurs belonging to the order Ornithischia. Consequently there were various adaptations for eating plant food in these animals.

In the giant sauropods dental adaptation seemed to be mainly a process of limiting the teeth to the front of the jaws and transforming them into rather weak pegs. How such teeth, mounted in such small jaws, could serve to tear off enough leaves from their stems to keep these huge dinosaurs going, is a problem that baffles the imagination, yet the evidence is there and cannot be refuted. These dinosaurs did live, and very successfully too, for many millions of years.

In the ornithischians the teeth were restricted to the sides of the jaws, the front of the jaw being transformed into a sort of a beak, as mentioned above, consisting of the premaxillary bones in the upper jaw and of a new element, the predentary bone, in the lower jaw. This sharp, birdlike beak must have served these dinosaurs for the purpose of tearing green leaves away from their stems.

When it came to the process of chopping and chewing the plant food into digestible bits, the ornithischians were admirably provided with dental batteries of considerable complexity. In the primitive camptosaurs there was a row of fluted teeth on either side of each jaw, which when worn maintained sharp edges that would serve to chop the food by a scissor-like motion of the jaws.

Modifications of these teeth occurred in the armored dinosaurs and in the ceratopsians or horned dinosaurs, but it was in the aquatic hadrosaurs that the dental battery attained its most specialized form. There was in these dinosaurs a tremendous increase in the number of the teeth so that instead of a relatively few teeth in each jaw, above and below, there were in each jaw some 500 teeth. Thus there was a total of about 2000 teeth in the mouth of a typical duck-billed dinosaur. These teeth, which were small and rather lozenge-shaped, were arranged in several closely packed rows. When worn, the overlapping surfaces of the teeth formed a rough pavement that served to grind the food, mill-fashion, into a pulpy mass. As in a well-organized army, there was a large number

THE MECHANIC
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In the Saurischia, as illustrated by *Allosaurus,* the hinge of the jaw is approximately on a line with the tooth sockets. The jaws were closed by a scissors action, with the upper and lower teeth sliding past each other of "replacements," so that as the teeth in use were worn they were pushed out, until they wore away completely, to be replaced by new teeth. It is a complex structure and a difficult process to describe, but the advantage of such an arrangement is obvious.

Adaptations to diet were not only reflected in the structure of the teeth of the dinosaurs, but also extended to the development and the articulation of the jaws. This follows the principle that biting and chewing among the vertebrates are not alone functions of the teeth, but are dependent upon the structure of the skull, the strength of various muscles, and the movements of the jaws.

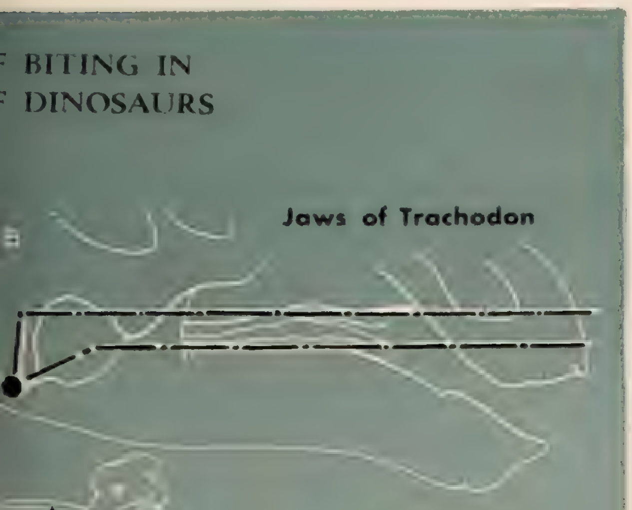
In the Saurischia the jaws worked on what might be called the "scissor principle." This may be explained by saying that the articulation or fulcrum for the jaws was on a line with the edges of the jaws and the teeth, so that the mouth was closed by a scissor-like action, whereby the sharp teeth of the lower jaw were sheared past those of the skull. In this manner, the carnivorous theropods were able to tear and cut their unfortunate victims into sizable chunks that might be swallowed.

It is interesting to see that the giant carnivores had an expansion of the back part of the lower jaw, which afforded increased attachments for the powerful muscles that activated the bite in these fierce hunters. It is interesting to see, also, that in the toothless, fruit-eating "ostrich dinosaurs," such as *Struthiomimus*, the typical theropod method of jaw articulation was retained, even though these animals had departed from the ancestral carnivorous diet.

What about the great sauropods? Here again, the primitive "scissor" articulation of the jaws was retained, even though these huge dinosaurs had turned entirely to a vegetarian diet. The heritage of the ancestor was retained in the descendant.

The reason for this lack of specialization in the jaws of the sauropods is probably to be found in the fact that these great dinosaurs seemed to have indulged in very little if any chewing of their food. They simply cropped the plants that came within reach of their small front teeth and then swallowed whole the green stuff, to be worked on by the gastric juices of the digestive tract.

In the more highly developed Ornithischia there was a departure from the generalized form and articulation of the saurischian jaws. The Ornithischia, as we know, were herbivorous, and it would seem that they were able to cut and chop and in some cases even to grind their food between their lateral dental batteries. Con-



In the *Ornithischia*, as illustrated by *Trachodon*, the hinge of the jaw is below the line of the tooth sockets, and the jaws are closed by a "nutcracker" action, with the teeth clamping together almost all at the same time

Drawings by John C. Germann

sequently, in these dinosaurs the jaw articulation was depressed so that it was placed on a level much lower than that of the teeth. An analysis of the movements of the jaws in these animals will show that this articulation served to bring all of the upper and lower teeth into contact at about the same time, in what might be called a "nut-cracker" or crushing action. This method of chewing is an obvious advantage to a plant-eating animal, particularly if the animal indulges at all in the pleasure of grinding its food.

The dinosaurs developed many bodily weapons for "defense," whether such defense was of the passive variety, or of the more active and vigorous method of defense by offense and counter-offense. For the world of the dinosaurs was one of unending strife, of a constant struggle between those that would eat and those that would rather not be eaten.

In the carnivorous theropods the teeth constituted the principal means of defense. Needless to say, "defense" in these animals was mainly of the offensive variety; they were able to survive because of their pugnacity.

It is quite possible that these dinosaurs also used the hind feet in fighting, and that they were able to claw and scratch with their hooklike hands.

Many of the dinosaurs sought safety in flight. This was true of the smaller theropods such as *Ornitholestes* and *Struthiomimus*, and in some of the Ornithischia, notably the duck-bills. In the case of the trachodonts, it is likely that running away was directional—in other words, that these animals would make for the water as soon as one of the great carnivores came over the horizon. So with them there would be a dash for the shore, a great deal of splashing about in the

↑ The champion bonehead, *Pachycephalosaurus*, whose name means "the thick-headed reptile." All of the space above the brain is occupied by solid, dense bone

↓ A reconstruction of the head of *Pachycephalosaurus*. Note the ornate nobs

A.M.N.H. photograph

shallows, with water flying up in a high spray, and finally a quiet escape through the friendly deep waters.

Many of the ornithischian dinosaurs were armored in one way or another. In the true "armored dinosaurs," the stegosaurs and ankylosaurs, there were protecting plates and spikes, which reached the climax of their development in such animals as *Ankylosaurus* and *Nodosaurus*. These dinosaurs were the armadillos of their day. When danger threatened, it was necessary only to curl up, or possibly to flatten out against the ground and let the attack rage past. These animals were not, however, merely passive defenders of their rights. Almost all of them had spikes or clubs on the end of the tail, lethal weapons of great value in beating off an attack.

Some of the ornithischian dinosaurs, the troödonts, were remarkable in the protection given to the brain by the skull. In these animals the skull roof became enormously massive, not through the development of sinus cavities as is usual in the vertebrates, but by the actual thickening of the bones. In one of these animals, for instance, there was a protection of some ten inches of solid, dense bone above the brain, although why such a lowly brain should need such vault-like protection is something to wonder about.

The horned dinosaurs, it would seem, indulged in "active defense." These were the "rhinoceroses" of their day, blundering across upland glades and challenging all potential enemies by the power of their

➔ An earlier form of the boneheaded dinosaurs, *Troödon*, an animal only about six feet long but already showing promise of a bonehead to brag about

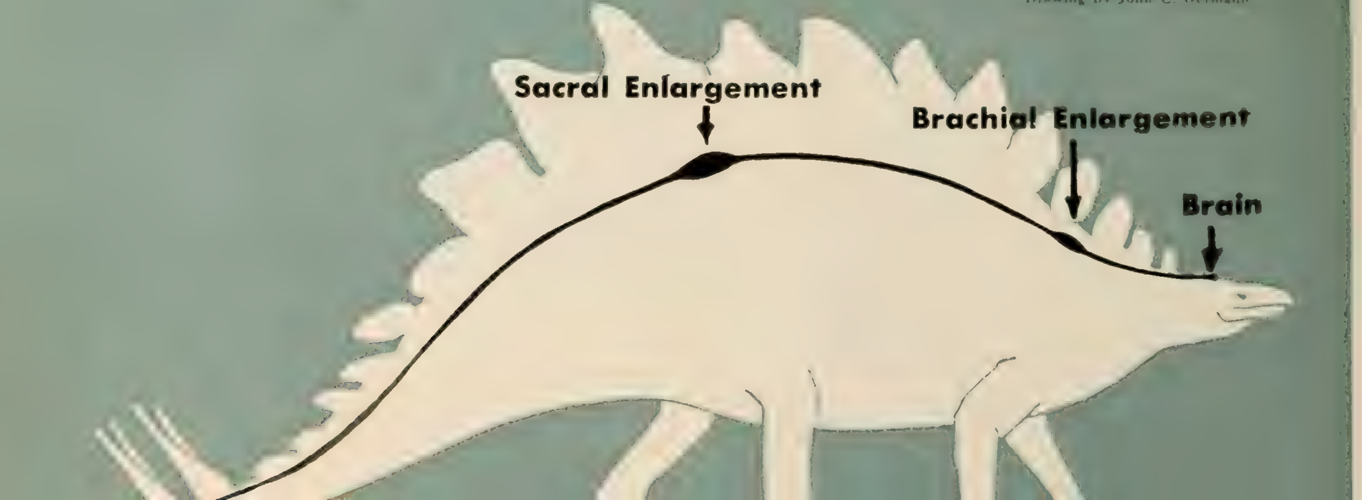
Drawing by John C. Germann

strong bodies and the length of their horns. *Triceratops* might face his adversary with lowered head, the long horns pointing forward to impale his foe, the huge frill, to which were attached the powerful neck muscles, flaring up behind as a protection for his neck and back. With a short rush his attack was one of great power. He needed it, in a world where *Tyrannosaurus* was running rampant.

Finally, some of the dinosaurs were protected, or at least partially protected, by their great size. These were the giant sauropods. They were so large that only the largest of contemporary carnivores even dared to attack them. Perhaps at that the carnivores were forced to limit their depredations to such of the giants as might be injured, or bogged down, or possibly to the little sauropods.

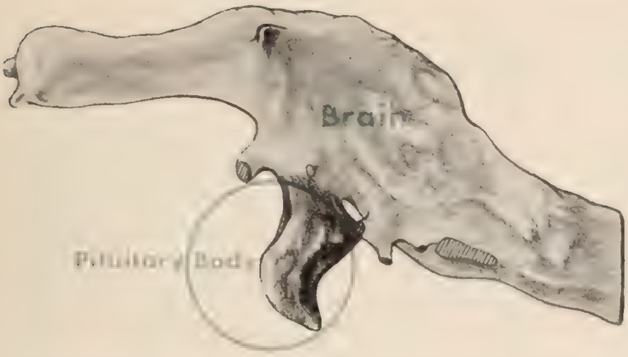
It must always be kept in mind that the dinosaurs were reptiles. Being reptiles, their life was less well organized and less well directed than are the activities of the mammals so familiar to most of us. It is certain that the dinosaurs had a reptilian brain of comparatively lowly form and organization, so these were not what we would call "thinking animals." Their daily round was largely a series of reflex actions, of responses to external stimuli. They muddled through life in a ponderous world.

Not only was the brain of the dinosaurs of lowly form, but it was extraordinarily small, when one considers what huge animals these reptiles were. It is a well-known fact, established many years ago, that large animals have smaller brains in comparison to their size than do small animals. For instance, an elephant weighing six tons has a brain weighing about ten pounds, which is approximately 1/10 of one per cent of the body weight. Compare the latter figures with those for a sheep, in which the body weight is about 75 pounds and the brain weight about three and a half ounces, in a ratio of 3/10 of one per cent of brain to body weight. Or compare the body weight of about seventeen pounds to a brain weight of two and a half ounces in a fox-terrier dog, which gives a ratio of brain to body weight of almost 9/10 of one per cent. From the above figures it is readily seen that the brain of the elephant is much bigger than that of the sheep or the dog even though in relation to body weight it is smaller. Giantism in the ele-



The brain of *Stegosaurus* was only one-twentieth the size of an enlargement in the spinal cord in the hip, which served to control the movements of the hind limbs and tail

Drawing by John C. Germann



The great size of dinosaurs may have been caused by enlargement of the pituitary gland. This illustration shows the relatively large size of the pituitary body in relation to the primitive brain of a troödont dinosaur

Drawing by John C. Germann

phant's body has been accompanied by a certain degree of giantism in the brain, but in the dinosaurs not only was the *relative* size of the brain small, its *actual* size was also very small. Thus in *Stegosaurus*, an animal as heavy as a modern elephant, the brain was no larger than that of a small kitten.

Indeed the diameter of the brain in the large dinosaurs was in many cases less than that of the spinal cord, while in size it was much smaller than the brachial and sacral enlargements of the cord in the shoulders and hips which served to control the movements of the legs and tail. For instance, in *Stegosaurus*, as already mentioned, the sacral enlargement was 20 times as large as the brain. As a matter of fact, the dinosaur brain was probably, in the main, a receptor mechanism—a center where the visual images, the odors, and the sounds coming in from the outside world were received so that the animal's activity might be correlated with the environmental conditions indicated by these outside stimuli.

One interesting development in the dinosaurs was the great enlargement of the pituitary body attached to the base of the brain. In all but the "giants" among recent vertebrates this pituitary body is relatively small. In the dinosaurs it was relatively large, and it is an interesting fact that in the huge sauropods it was very large. There was evidently a correlation between the enlargement of the pituitary body and the size of dinosaurs.

The functions of the pituitary body in recent vertebrates are various, but among other things the anterior lobes of this gland, the very part of the pituitary body which seemingly was enlarged in the dinosaurs, secretes the growth hormone. This means that animals with large, active pituitaries, are large animals. So it is not surprising to see that in those dinosaurs which showed an excessive enlargement of the pituitary, the individual reached gigantic proportions.

Of course giantism in the dinosaurs was closely related to the environment. Those dinosaurs with active growth hormone secretions and enlarged pituitaries became dominant because the climatic and other environmental conditions of later Mesozoic times were favorable to giantism. It is all a part of a correlated and complex picture, the whole of which must always be kept in mind.

11

Dinosaurian Associations

We have had a glimpse at the variety of dinosaurian evolution. We have seen how these dominant reptiles of the Mesozoic land became adapted to numerous environments and to different modes of life. All of this has given us a fairly comprehensive view of the dinosaurs as zoological units—as living mechanisms that have become modified in various fashions, while at the same time they have maintained certain basic relationships to one another as members of two great reptilian orders having a common ancestry. Yet the picture is not complete, because little attention has as yet been given to the "ecological relationships" of the dinosaurs, to those complex interrelationships that are present in any community of animals. Let us look at the dinosaurs as they dwelt together, let us see in the mind's eye how they lived and fought and died.

The dinosaurs, as has been said—perhaps to the point of monotony—persisted over a period of great geological length. They lived in all quarters of the globe. Obviously it is impossible to attempt in a few brief paragraphs to describe all of the dinosaurs of the Mesozoic on all of the continents. Nor is such a procedure necessary. The dinosaurs conformed to certain well-established types, characteristic of each of the Mesozoic periods. A fairly adequate picture of the more specialized dinosaurian assemblages may be had by picking out one dinosaurian association from the Jurassic period and another from the Cretaceous.

Of all the Jurassic dinosaur faunas, none is better known nor more characteristic than the so-called Morrison fauna—the dinosaurs found in the Morrison formation of Wyoming, Colorado, and certain other western states. These dinosaurs are found together, and under such conditions of deposition that there can be no doubt that they all lived at the same time.

In the dim and distant days of the Jurassic the West was not a land of high mountains and broad prairies, a land of clear blue air, as it now is. Indeed, quite the reverse conditions prevailed. It was a land of low-lying tropical swamps, of steamy jungles and marshes where the sun filtered through dense, monotonously green foliage—palms and ferns and water-plants. Here lived the Morrison dinosaurs, an integrated association of animals, the small and the large, the hunted and the hunters. There was a pattern of life, just as there is today on the western plain, but it was a pattern on a giant scale.

Darting back and forth through the dense undergrowth was *Ornitholestes*, the little carnivore, the one dinosaur of the Jurassic that retained to a considerable degree the structure and the habits of its distant Triassic ancestors. *Ornitholestes* was certainly one of the less conspicuous members of the Jurassic fauna, a small animal stalking small prey.

There was nothing shy about *Allosaurus*, the tyrant of the Jurassic scene. Here was a carnivore of gigantic size, stalking across the dry ground between swamps and lakes, hunting giant prey with nothing to fear but other members of his own species.

Dominating the scene in bulk, but not in spirit, were the giant vegetarians *Brontosaurus* and *Diplodocus*. Theirs was a generally peaceful life, a life lived in the swamps and marshes, where they fed on the leaves of lush plants, waded shoulder deep through small lakes, lay for hours in reptilian torpor, engulfed by the damp warmth of the jungle. There were occasional punctuations to this quiet life, intervals of wild alarums, of attacks by *Allosaurus* and his kin, of escape to the deep protective waters of the lakes or to the soft, impassable mire of the swamps where the giants were safe, where they might resume their slow, ponderous round of daily inactivity.

Then there was *Stegosaurus*, the armored dinosaur, living in the uplands, if the high ground between the swamps and marshes may be called uplands, feeding upon green plants, protecting himself from the attacks of *Allosaurus* by a "hedgehog defense," by a passive presentation to the attacker of thick hide and plates, and cruel spikes on the end of a viciously swinging tail. This much can be said for *Stegosaurus*, at least he met aggressive attack with a certain degree of aggressive defense, and thus he was able to survive in a harsh world.

Finally, among the Morrison dinosaurs there was *Camptosaurus*, one of the two-legged ornithopods, a rather small and inoffensive plant-eating animal. *Camptosaurus* was perhaps too large to dart into the undergrowth as did *Ornitholestes*, but it is probable that this little dinosaur had to make himself relatively inconspicuous or even scarce on occasions if he were to survive. At this *Camptosaurus* was eminently successful, for he and his descendants survived into the following geologic period, which is more than can be said for some of the other Jurassic dinosaurs.

Such was life in the Jurassic.

Let us now go forward from the Jurassic to catch a glimpse of the Cretaceous dinosaurs. This time we will choose the fauna which lived in North America in late Cretaceous times and which is found in the Belly River formation, now exposed in certain portions of southern Alberta.

At that stage in the history of the earth conditions were quite different from what they had been in Jurassic times. North America was still a country having a warm, equable climate, but it wasn't the low-lying tropical region that it had been when *Brontosaurus* and *Allosaurus* were alive. It was now more of a semi-tropical region, with palms and ferns along the shores of the rivers, inland seas, and lakes, but with upland regions of some height forested with such familiar trees as oaks and willows, sassafras and hickory. This was the environment in which the late Cretaceous dinosaurs lived.

Of these later dinosaurs *Struthiomimus*, the so-called ostrich dinosaur, played one of the lesser roles in the drama of life. Here was a relatively small and inoffensive animal, occupying much the same position in the Cretaceous scene that *Camptosaurus* had in the Jurassic landscape. *Struthiomimus* lived on succulent plants and perhaps upon such small animal fry as he might be able to catch. He was long of hind limb and slender of build—obviously designed to vanish with great speed the moment any of the ever-dangerous carnivores might appear over the horizon.

Of the carnivores, *Gorgosaurus* was typical. This was a larger and more active cousin of the Jurassic *Allosaurus*, and an animal that was specialized to prey upon the various large herbivorous dinosaurs that inhabited the Cretaceous landscape. It was an advanced member of the line of carnivorous dinosaurs, a line which culminated with the gigantic *Tyrannosaurus*, of uppermost Cretaceous age.

Of the large herbivorous dinosaurs,

there was a great variety of forms. Along the rivers and lake shores were the semi-aquatic duck-bills, *Trachodon* and his crested cousins, *Corythosaurus* and *Parasaurolophus*. These animals fed upon the water-plants of the bank or of the strand, and perhaps upon certain mollusks, too. They were water-lovers and even when on land were ready to dash into the protection of their aquatic environment at an instant's notice. Needless to say, such notice was usually the sudden appearance of *Gorgosourus* or one of his predatory relatives.

Inhabiting the uplands were the armored and the horned dinosaurs, plant-eaters that were well equipped to beat off or withstand the attacks of the fierce carnivores. *Palaeoscincus* was a typical armored form, a veritable dinosaurian tank, or armadillo, completely encased by heavy armor plate, with a spiked tail capable of wreaking havoc on anything that came within reach of its powerful sweep.

Of the horned dinosaurs, *Monoclonius* and *Styracosaurus* were the Belly River representatives. These powerful animals, with their efficient nose horns, were seemingly quite capable of repulsing the attacks of the carnivores under ordinary conditions.

Such was the pattern of life in Cretaceous times, one that repeated the pattern of the Jurassic scene but with the use of different elements, a pattern that is repeated even today on a less grandiose but perhaps on a more efficient scale among our mammals. If we can visualize this pattern, a mélange of interrelated animals running through geologic time, we will be that much better able to appreciate the structural modifications which in the dinosaurs attained such a variety of forms. Let us therefore remember the pattern as it has been pictured here, a pattern of hunter and hunted, of carnivore and herbivore, of large and small, of upland and aquatic, all living together and adjusting themselves to each other. That is the key to the adaptive radiation of the dinosaurs.

12

Flight

In Jurassic times there occurred a new and a very important event in the long and complex history of the vertebrates. This was the development of the power of flight.

The story of the backboned animals throughout their pre-Jurassic history was one of animals living in the waters, or venturing out of this ancestral habitat to try their fortunes on the solid land. During a stretch of geologic time of great immensity, a period measured by the hundreds of millions of years, the vertebrates were restricted to the waters and to the lands, where, as we have already seen, they developed an astonishing variety of forms, adapted to numerous environments and methods of life. But it was not until the advent of Jurassic days, when tropical forests steamed beneath the sun and hordes of dinosaurs ruled the land, that the vertebrates first ventured into the thin air, to soar upon outstretched wings, free from the trammels of an earth-bound or of an aquatic existence.

Strangely enough, two groups of animals took to the air in Jurassic times, and strangely enough, both of these groups were closely related to the dinosaurs. One group was that of the flying reptiles, the pterosaurs, which arose in the Jurassic, reached the culmination of their evolutionary development in Cretaceous times, and then became extinct along with their dinosaurian cousins, during the profound transition between Cretaceous and Cenozoic times. The other group was that of the birds, which likewise arose during the Jurassic, but which successfully weathered the Cretaceous-Cenozoic transition, to inhabit the air of our present-day world.

It would seem almost as if the "time was ripe" in Jurassic days for the appearance of flying vertebrates. Perhaps a more accurate explanation would be to say that in the Jurassic period of Earth History the vertebrates had attained a complexity and perfection of bodily makeup that made it possible for them to overcome, through evolutionary processes, the severe difficulties of flying.

We know from our own acquaintance with the history of the airplane that flight is no simple matter. It was attained by man only after the invention of the internal combustion engine, when there was a combination of power and lightness sufficient to lift the man-made wings off the ground. This evolution of the modern airplane offers an analogy with the evolution of the flying vertebrates. Any backboned animal that attempts flight must:

a. Transform the normal type of front limbs into wings.

b. Become light in the body while retaining a very strong skeleton and powerful muscles.

c. Have a highly developed nervous system, with a particularly fine sense of balance.

Let us see how the two groups of animals which first attempted to fly in Jurassic times solved these problems.

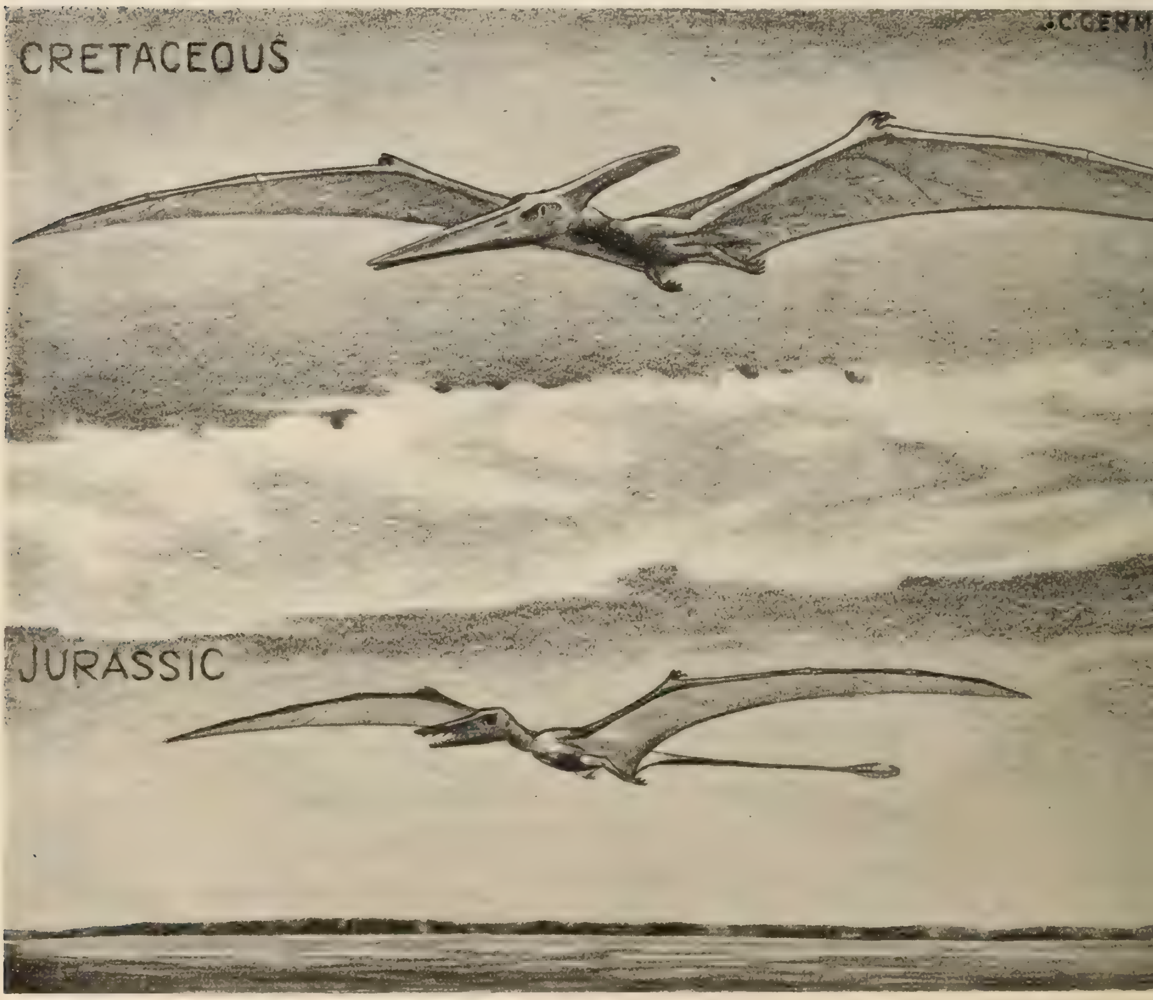
Pterosauria

The pterosaurs (TER-o-sawrs) were diapsid reptiles of basic thecodont ancestry

They were lightly built, with hollow bones which were strong yet at the same time remarkably light. In the skull there was an unusual amount of fusion of the bones, while the back was very short and strong, an adaptation brought about by a reduction of the number of bones making up the spinal column. The pectoral and pelvic girdles to which the limbs are attached were strongly anchored to the backbone. Indeed, there was a new and special attachment, not found in any other animal, that held the shoulder girdle firmly to the backbone, thereby affording a secure anchorage for the long wings. Moreover, the breastbone or sternum, attached to the lower ends of the pectoral girdle and the ribs, was greatly enlarged to provide a

FLYING REPTILES. In the Jurassic form, *Rhamphorhynchus*, there were teeth in the jaws, and a long tail. In the advanced Cretaceous form, *Pteranodon*, the teeth had been lost and the tail reduced

Restorations by John C. Germann



strong attachment for the strong breast muscles that moved the wings. In these highly modified reptiles the fourth finger of the hand was greatly elongated, and this formed the support for a long, membranous wing. The remaining fingers were small, hooklike claws, which evidently were used for hanging onto rocks or limbs. The hind limbs were very weak, so it would seem that these flying reptiles were very poor walkers —in fact, it is doubtful whether they moved around on the level ground to any extent at all.

The flying reptiles of the Jurassic period (155 to 120 million years ago) were for the most part rather small, often no larger than sparrows or robins. They were characterized by the presence of teeth in the skull and lower jaw, and usually although not always by a long, rudder-like tail. The Cretaceous pterosaurs (120 to 60 million years ago) were the giants among nature's "flying machines." *Pteranodon* (ter-AN-o-don), for instance, had a maximum wing-spread of some 27 feet! These large pterosaurs were specialized beyond their Jurassic forebears in that they had lost the teeth and the tail had become very short.

What were the habits of the pterosaurs? These were quite obviously aerial reptiles, but it is doubtful whether they flew as much as they glided, or soared. These animals were lightly built—even the giant form, *Pteranodon,* with a wing-spread of more than 20 feet, had a relatively small body—and it would seem probable that they were living gliders, majestically soaring back and forth on the warm currents of air rising from the tropical landscape beneath them. Certainly they had a less powerful and efficient muscular system for moving the wings than do our modern flying birds.

Whatever may have been the flying habits of the pterosaurs, it is certain that these animals had a less efficient wing than do either the birds or the bats. In the pterosaurs there was a single series of bones, the fourth finger, running along the front edge of the wing as a support. Consequently, if the wing membrane should be torn, these animals must have found flying difficult. Compare this with the several fingers that support the membrane in the bat's wing, or with the feathers than constitute the wing of the bird. The advantages of wing construction in these modern flying vertebrates are obvious.

The brain in the pterosaurs was very large, considering that it was a reptilian brain, and it showed a strongly developed sense of sight and a weakly developed sense of smell. In these respects the pterosaurs were similar to our present-day birds; they soared aloft in search of their food, scanning the landscape and guiding their flight through large and efficient eyes.

Finally, it is barely possible that the pterosaurs were warm-blooded, at least partially so. This is a "scientific guess" but it is based upon the fact that these were specialized flying vertebrates and as such must have had to sustain action over considerable periods of time. Such a feat is difficult, if not impossible, for the cold-blooded reptiles as we know them, but it would have been feasible should these ancient reptiles have independently attained a warm-blooded condition, similar to that of the birds or the mammals.

Such was this first pattern for vertebrate flight—a pattern that was established in Jurassic times and persisted to the end of the Cretaceous. Even though it failed to survive, just as so many other reptilian developmental patterns failed to survive the Cretaceous-Cenozoic transition, it was

WING OF PTEROSAUR, BIRD, AND BAT

Drawings by John C. Germann

nonetheless successful, for it continued over a period of some 50 to 60 millions of years. But it wasn't so successful a pattern for flight as was that of the birds, or of the bats.

The Birds

Birds are little more than "glorified reptiles." True enough, to the average spectator there seems to be nothing in common between the gorgeous blue and white flash of the jay, screaming his indignation through the high branches of the oak tree, and the silent and sinuous menace of the blacksnake gliding through the grass, the object of the bird's imprecations. But underneath the feathers of the bird and the shining scales of the reptile the resemblances are there, and when the ancestries of these two apparently so dissimilar vertebrates are traced back through the fossil record the resemblances become all the more significant—the bird becomes ever more reptilian, so that there can be little doubt as to its earliest orgin.

The birds, although classified as a separate class of the vertebrates, are essentially of basic thecodont ancestry. They are lightly built, with strong, hollow bones. Not only are the bones extraordinarily pneumatic, for the sake of lightness, but also there are a number of air sacs in the body of the bird, which further contributes to its flying ability. The skull shows an unusual amount of fusion of the bones (just as was the case in the pterosaurs). The back is short and strong, while the neck is rather long. The pectoral and pelvic girdles are very strong; the latter is firmly attached to the spinal column by a greatly lengthened and strengthened series of articulations between the vertebrae and the sacral portion of the pelvis. In the typical flying birds the breastbone has become greatly enlarged to afford anchorage for the powerful pectoral muscles that activate the wings. In the large ground-living birds such as the ostrich, no such development of the breastbone is seen, but there is reason to think that in these cases there has been a secondary reduction of this element from a formerly large structure. Thus far in this summary of the characteristics of the birds we see a considerable amount of parallelism with the flying reptiles. This is as might be expected. We have been looking at adaptations imposed by the rigorous restrictions inherent in flying, namely lightness and strength in the skeleton, and provision for the attachment of powerful muscles to move the wings.

In certain ways, however, the birds have followed a line of development quite different from that of the pterosaurs.

In the first place, the birds have feathers, and they have had them since they first arose as but partially modified reptiles in the Jurassic period. It is true that the feathers are nothing more nor less than highly modified scales, but they are nonetheless important and basic in this differentiation of bird from reptile. They afford insulation for the bird, which is a warm-blooded animal. Compare this condition with the naked pterosaurs, which might have been warm-blooded, but at best could have had this character only imperfectly developed. What is more important, the feathers provide the flying surfaces for the bird. Instead of having to depend upon a membranous wing, stretched upon an elongated finger or fingers, the birds have the wing surfaces composed of the long, stiff, hard feathers, attached to the skin that covers the fingers and the lower arm bones. (See illustration.) Here is a mechanism ever so much more efficient than the pterosaurian wing, a mechanism that allows the wing to function even while replacements of feathers are being made. Since the birds depend upon the long wing feathers for the flying surfaces, the finger bones have coalesced and become strengthened, to form a strong base of attachment for these feathers.

Again, the birds may be contrasted with the pterosaurs in the development of their hind limbs. It will be remembered that in the pterosaurs the hind limbs were extraordinarily weak, whereas in the birds the legs are very strong—not unlike the legs in some of the two-legged dinosaurs. (In fact, the similarity of the hind limbs in the birds and the dinosaurs affords one line of evidence pointing to a certain degree of relationship between these different types of vertebrates—a relationship dependent upon their descent from a common thecodont ancestry.) Thus the bird is an efficient animal on the ground, which the pterosaur most decidedly was not, and this may account in part for the survival of the birds and the disappearance of the flying reptiles.

In the bird brain, as in the pterosaur brain, there is a pronounced dominance of the visual areas, for the birds depend chiefly upon sight for the direction of their movements. The sense of smell is greatly reduced. The part of the brain concerned with balance, the cerebellum, is very large in the birds, a development that is not surprising in an animal adapted for rapid and skillful flight.

It might also be mentioned that the birds have a high, constant body temperature, which enables them to sustain their activities over considerable periods of time.

Finally, the birds show a development which can only be guessed at so far as the flying reptiles are concerned. This is the remarkable perfection of nesting and the care of the young. Here is an adaptation which in itself must have been of great importance during past geologic ages in the continuation of the species—an adaptation which is completely lacking or at best only rudimentary in the reptiles that have survived into our present-day world.

The earliest known bird is the famous *Archaeopteryx* (ar-kee-OP-ter-ix), found in the Solenhofen limestones of Jurassic age, in Bavaria. Of this form, two fairly complete specimens are known, one in the Berlin Museum, the other in the British Museum.

Had this early bird not been found with the imprints of its feathers preserved, it is doubtful whether it would now be classified as a bird. For *Archaeopteryx* was indeed very close to its reptilian forebears. It was beginning to show the coalescence of skull elements and the obliteration, so characteristic of the birds, of the temporal openings behind the eye. Yet these developments had not proceeded to such a point that the skull was really "un-reptilian" in appearance. Moreover, there were teeth in the upper and lower jaws of *Archaeopteryx*, teeth that were an heritage from reptilian grandparents.

The fore limbs were wings in *Archaeopteryx*, but there was none of the perfection of adaptation seen in the later birds, for the fingers were long and not coalesced, while the breastbone showed none of the expansion that developed in the powerful flying vertebrates of later times. Moreover, the pelvis was only beginning to show the developments that became so characteristic of the birds, namely the fusion of bones to make it an extremely strong and rigid structure. And there was a long, reptilian-like tail, but a tail with feathers arranged on either side of it.

It is probable that this first stage in the evolution of the birds was a gliding stage, a stage at which true flight had not as yet been attained.

However that may be, it is certain that by Cretaceous times the birds had become pretty good birds. These Cretaceous birds, which may be regarded as representing the second stage in the evolution of the group, were for the most part about as well developed along the lines of avian specialization as are the modern birds, except that teeth were still retained in the jaws. Consequently they must be regarded as a link between the very ancient and imperfect birds of the Jurassic period and the modernized birds of Cenozoic and recent days.

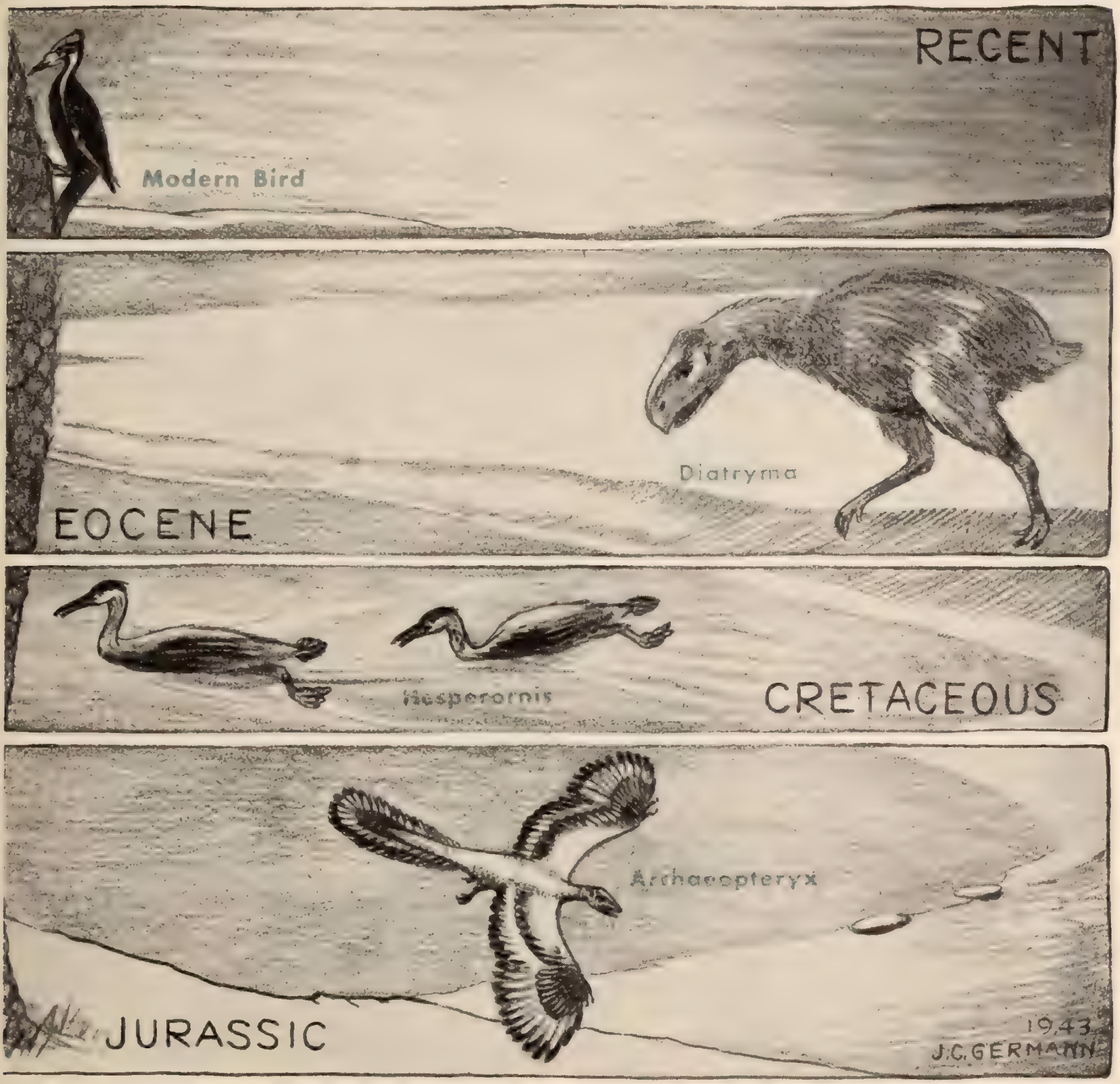
One of the well-known Cretaceous birds was *Hesperornis* (hes-per-ORN-is), a swimming and diving toothed bird, evidently with habits similar to those of our modern loon. In this bird the wings were lost—the result of a *secondary* return to a non-flying mode of life.

Finally, with the opening of Cenozoic times, birds became completely modernized. The teeth were lost and the mouth became a horny beak, adapted to pecking and biting.

In early Cenozoic times there was a considerable development of large, flightless birds, similar in habits to the modern ostriches, rheas, and the like. At that stage of Earth History, the mammals were still in the earlier phases of their development, and it would seem likely that these early flightless bird giants were for a time serious competitors with some of the mammals for dominance of the ground. An exceptionally fine example of one of these early flightless birds was the large form, *Diatryma* (dye-a-

TRY-ma), from the Eocene of Wyoming.

At this same time, however, the birds were developing as tree-living, flying creatures, and it was to be in the air, free from the harsh struggle ever present among the animals of the ground, that the birds were to find the environment best suited to the establishment of their final dominance.



Restorations by John C. Germann

Four stages in the evolution of birds. The primitive bird, *Archaeopteryx,* had feathers and was probably able to fly, but in many details it was essentially reptilian. The Cretaceous aquatic bird, *Hesperornis,* was completely avian in structure, although it still retained the teeth of its reptilian forebears. In the Eocene period, giant ground birds such as *Diatryma* may have competed seriously with the early mammals for dominance on the land. The modern birds are adapted for life in the treetops, on the ground, or in the water.

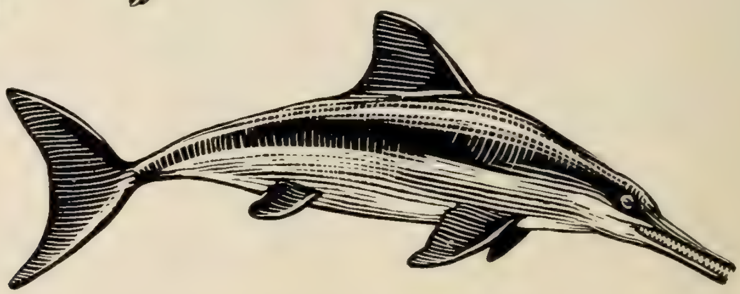
13

Sea Serpents

ALTHOUGH THE DINOSAURS were the undisputed rulers of the land in Mesozoic times, they never extended their sway to dominance of the water. True enough, some dinosaurs were partially aquatic. The great sauropods spent much of their time in the muck and water of swamps and small lakes, while the hadrosaurs (the duck-billed dinosaurs) were obviously rather active swimmers. Yet even these most aquatic dinosaurs showed only partial adaptations to a life in the bounding waves. They were primarily land animals that spent their days along the shores of rivers or lakes, wading about in the shallows, escaping to the deeper waters when danger threatened, but always coming back to the land—the environment to which they were firmly tied by the bonds of their heritage.

True dominance in the waters of Mesozoic times was held by reptiles other than the dinosaurs. These belonged to four groups: the ichthyosaurs, plesiosaurs, mosasaurs, and marine crocodiles. The first two of these groups belonged to the reptilian subclasses Parapsida and Euryapsida, respectively, containing those reptiles having a single upper opening in the skull behind the eye, groups which we have not yet discussed. The other two groups, the mosasaurs and the marine crocodiles, of much less importance as aquatic or marine reptiles, were related to the dinosaurs—either distantly, in the case of the mosasaurs, or by a fairly strong bond, as in the case of the marine crocodiles.

An early aquatic reptile, *Mesosaurus*



The fishlike *ichthyosaur*, a perfectly streamlined and thoroughly aquatic reptile. Its ancestry can be traced back through a form possibly similar to *Mesosaurus*, to a typical land-living primitive cotylosaur like *Seymouria*

Drawings by Margaret M. Colbert

The Ichthyosaurs

The subclass Parapsida consisted essentially of two reptilian orders, the Mesosauria (mes-o-SAWR-e-ya) and the Ichthyosauria (ik-thee-o-SAWR-e-ya). These two orders of reptiles are often designated collectively as the Ichthyopterygia (ik-thee-op-ter-IJ-e-ya).

The Mesosauria were late Carboniferous reptiles of aquatic habits, whose fossils have been found in South Africa and in Brazil. They were rather small reptiles, usually less than two feet in length, and were long of head and body. The length of the skull in these little reptiles, of which *Mesosaurus* is typical, was due in large part to the drawing out of the jaws in front of the eyes. These elongated jaws were armed with a fearsome array of sharp teeth, and the combination of long jaws and pointed teeth suggests the probability that this was a fish-catching animal. There was a tapering, flexible tail, which was evidently deep and narrow—the type of a tail that one might expect to find in a swimming animal. Moreover, the limbs were modified to form paddles, of which the front pair was somewhat smaller than the hind pair. Thus it would seem that *Mesosaurus* lived in the water, and it is indeed doubtful whether this little reptile ever ventured onto the land.

In spite of their adaptations to life in the water, there are certain things about the Mesosauria that point to their descent from thoroughly terrestrial reptiles. For instance, the form of the vertebrae in these little reptiles indicates quite clearly their derivation from cotylosaurian ancestors, from animals similar to *Seymouria*. Therefore it seems probable that at a very early stage in the history of the land vertebrates, certain primitive cotylosaurians abandoned the land life which their labyrinthodont ancestors had so slowly and with such a great struggle attained, and returned to the primal environment of all life—the water. Thus arose the mesosaurs.

Whether the mesosaurs were the ancestors of the ichthyosaurs is a moot point. If they were not the actual ancestors, they certainly paralleled the Mesozoic ichthyosaurs, and for the purposes of reconstructing a picture of the evolution of the Ichthyopterygia they serve very well as a stage intermediate between the typical land-living cotylosaurs and the typical aquatic ichthyosaurs.

The first ichthyosaurs, the fishlike reptiles, appeared in Triassic times, and even at that early state in their evolutionary history they were fully aquatic reptiles. They reached the culmination of their development in the Jurassic and Cretaceous periods, only to become extinct at the end of the Cretaceous, like so many of their Mesozoic contemporaries.

These were reptiles of medium size and of fishlike form, a fact that is well established thanks to the fine sediments in which oftentimes not only the bones but also the contours of the body are preserved. Consequently we know that the ichthyosaurs, like the fast-swimming fishes and porpoises of modern times, were thoroughly streamlined. The body was thickest in its forward part and tapered gracefully to the rear, torpedo fashion. There was a large, two-lobed tail at the back of the body which acted as a scull, driving the animal through the water. The four limbs were modified to form fins, and these undoubtedly performed the same functions as do the paired fins in fishes and porpoises, helping to maintain the balance of the animal and aiding it in

Restoration by Charles R. Knight

Ichthyosaur with its young

turning and stopping. A stabilizer was present in the form of a large, fleshy dorsal fin, quite similar to the fin on the back of modern sharks and some porpoises. This fin kept the animal from rolling from side to side as it swam.

So much for outward appearance. In the ichthyosaurs the skull was elongated, with the jaws pulled out to form a pointed beak or rostrum. These long jaws were armed with numerous sharp teeth—again patently a fish-catching device similar to that of the mesosaurs. It is an interesting fact that the teeth of the ichthyosaurs show a labyrinthine internal structure, quite obviously an inheritance from their cotylosaurian and still more distant labyrinthodont progenitors.

The eye was extraordinarily large. Evidently these animals depended for the most part upon vision to govern their movements. The eye opening of most fossil ichthyosaurs shows a ring of small overlapping bones known as sclerotic plates. The function of these plates is not clear, perhaps they helped to protect the large eyeball.

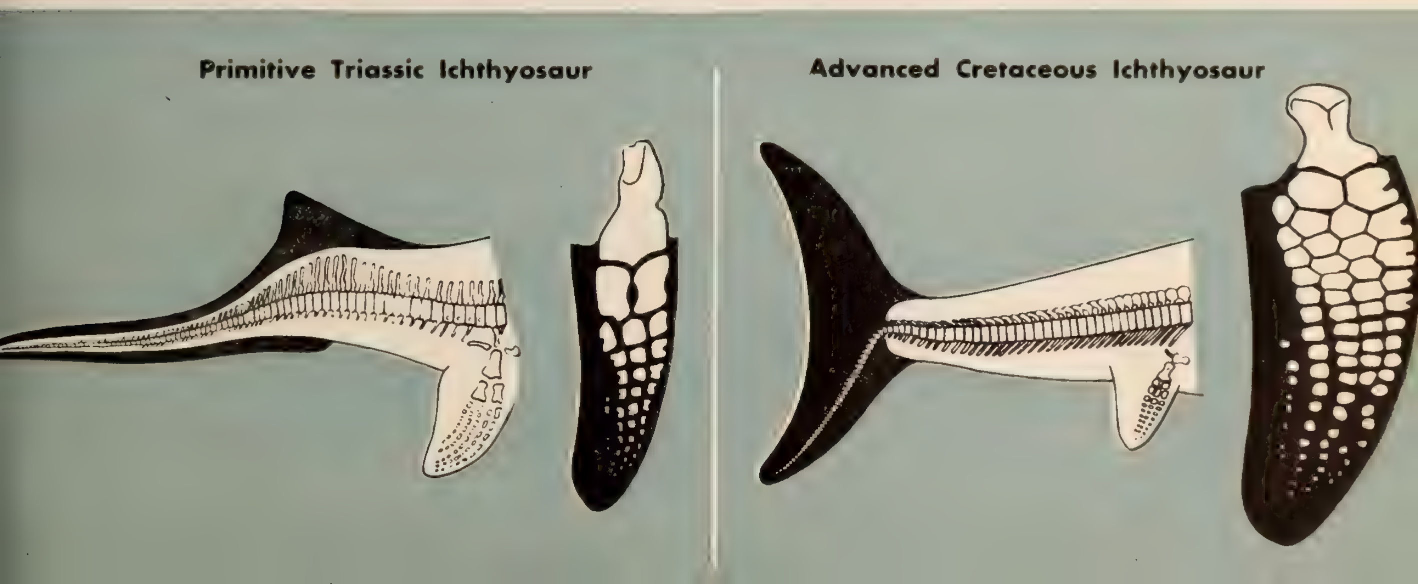
As in all thoroughly streamlined swimmers, the ichthyosaurs had no neck worthy of the name. The head was an integral part of the front of the body, a cutwater or prow that served as the "entering wedge" for an animal moving through a dense medium. The advantage of an immobile, short neck in a fast-swimming animal is obvious.

The body was flexible, for these animals must have propelled themselves in the same fashion as do fish, by a side-to-side flexion of the body, ending with a final push by the tail. Consequently the vertebrae, which in the land-living ancestors of the ichthyosaurs were firmly held together by strong articulating processes, had in these aquatic reptiles become comparatively simple disks, similar in many respects to the vertebrae of fish. For in the ichthyosaurs there was no longer a problem of gravity to be met; the backbone did not have to act as a stiffening element supporting the weight of the body.

The numerous skeletons that have been found show that the backbone in the Jurassic and Cretaceous ichthyosaurs extended down into the lower lobe of the tail. When these fossils were first discovered, it was thought that the sudden downward bend of the tail might have been caused by an injury received during the life of the individual. But as more specimens came to light, always with the same sudden change

The long, pointed tail of the primitive Triassic ichthyosaur (*left*) attained the perfection of a fishlike tail in the advanced Cretaceous ichthyosaur (*right*). The hind fin became smaller, but the front fin (here compared in separate drawings) developed into an effective stabilizing organ, just as it has in the quite unrelated sharks of today

Drawings by John C. Germann



in direction of the tail vertebrae, and as more complete material revealed the fact that this downward bend of the backbone was invariably enclosed within the lower lobe of the fleshy tail, it became apparent that the development was natural. In the modern sharks the backbone bends upward, to enter the upper fleshy lobe of the tail, and this structure has been designated as a *heterocercal* tail. Therefore the downward bending of the backbone in the ichthyosaurs has been termed a *reversed heterocercal* tail.

The reversed heterocercal tail was a specialization peculiar to the later ichthyosaurs, for the earliest of these aquatic reptiles do not show any such structure. In the Triassic ichthyosaurs the tail vertebrae still formed an almost straight line, and the fleshy tail evidently had but barely begun its development along lines that eventually were to form of it a deep scull, similar to the tails in our modern fast-swimming fish.

The limbs of the ichthyosaurs were paddles, and in accordance with this specialization the limb bones had become very short, while the bones of the "hands" and "feet" were flattened hexagons or discs, closely pressed to one another to form a solid internal support for the fins. Here is an outstanding example of transformation in evolution.

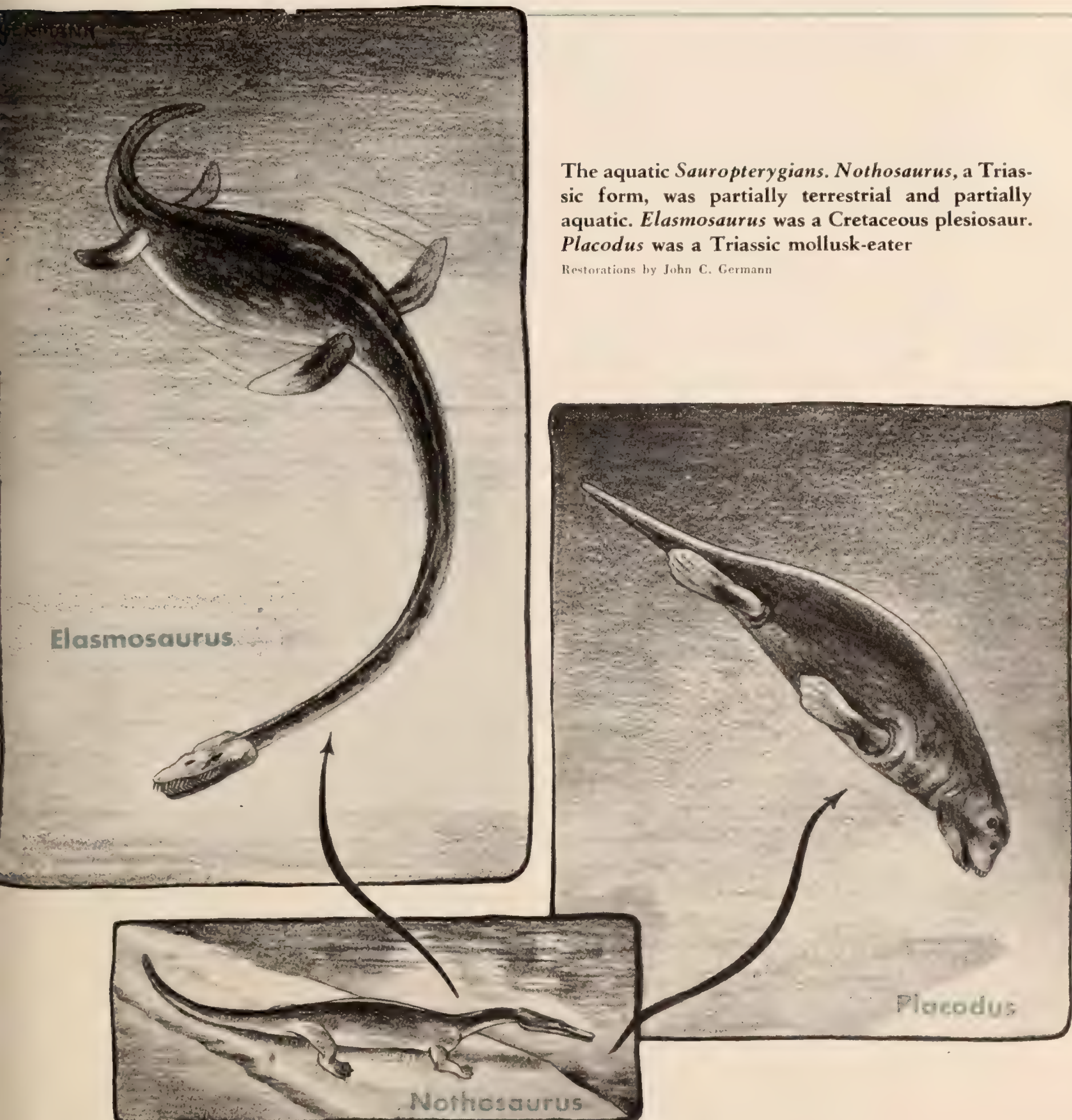
The fore limbs were large and the hind limbs relatively small.

From this review of the anatomy in the ichthyosaurs it is evident that these animals were completely aquatic, living their entire life in the water. In this they were similar to the fishes with which they were contemporaneous and to certain mammals, the modern whales and porpoises. The question arises then as to the manner or method of reproduction in the ichthyosaurs. Reptiles are typically egg-laying animals. How could a marine reptile that never came out on land reproduce by means of eggs? The answer would seem to be that the ichthyosaurs retained the eggs within the body—in other words they were *ovoviviparous* so that the young were born alive. And there is good evidence to support this view. One skeleton of an ichthyosaur in the American Museum of Natural History shows the skulls and partial skeletons of seven baby individuals within the body cavity of the adult. Thus it would seem that we have the record of a mother and her unborn young.

Of course it may be answered that the ichthyosaurs, like so many reptiles, were cannibals that practiced infanticide, and that these seven little ichthyosaurs are merely the remnants of a large Sunday dinner. Naturally there is something to be said for this argument, but the weight of the evidence would seem to be in the other direction. Of particular importance is the fact that one small skull, quite uninjured either by teeth or by the effects of gastric juices, is located between the pelvic bones of the adult in the exact position that might be expected of an infant in the process of being born.

Throughout this description the ichthyosaurs have been compared with fishes and porpoises, and indeed, these animals offer one of the best examples of convergence in evolution—of the similar development of unrelated forms. The modern shark, the Jurassic ichthyosaur, and the modern porpoise are all remarkably alike in external form, because all of them have lived the same kind of life. And the requisites for that type of a life are very strict. Fast movement through the dense watery medium imposes a streamlined design, whether the object be a fish, an ichthyosaur, a porpoise, a torpedo, or a submarine. So it was that the ichthyosaurs became fishlike because they lived like fishes. In a like manner, the modern porpoises are fishlike, even though they are warm-blooded mammals, because they live like fishes.

Yet underneath the skin the animal gives himself away. The ichthyosaur skeleton is reptilian through and through; the porpoise skeleton and the details of its soft anatomy are mammalian through and through. The ichthyosaur came from land-living reptiles, probably certain cotylosaurs. The porpoise has come from land-living mammals, probably from certain carnivorous types. The course of evolution has been reversed; the



The aquatic *Sauropterygians. Nothosaurus,* a Triassic form, was partially terrestrial and partially aquatic. *Elasmosaurus* was a Cretaceous plesiosaur. *Placodus* was a Triassic mollusk-eater

Restorations by John C. Germann

line of development that had its beginnings in the water and emerged onto the land, has finally returned to the water. The course of evolution has been reversed, yet evolution is irreversible. For even though the ichthyosaur returned to the water to live like a fish, it remained a reptile—it merely imitated a fish. No matter how fishlike it might appear on the outside, it had the reptile's structure underneath. It had the reptile's bones and brain, the reptile's heart and lungs. The organization and economy of the fish had been lost, never to be regained; this was an air-breathing reptile, which though fishlike in form, retained in its structure the unmistakable evidences of its terrestrial origin.

The Euryapsida

The most important subdivision of the Euryapsida was that of the Sauropterygia (sawr-op-ter-IJ-e-ya) containing the nothosaurs (NOTH-o-sawrs), plesiosaurs (PLEES-i-o-sawrs), and placodonts (PLAK-o-dahnts), of which groups the plesiosaurs are by far the most numerous and the best known. In these reptiles the diagnostic upper temporal opening or foramen was present, high up on the back of the skull, and bounded below by the postorbital and squamosal bones.

It is probable that these euryapsids developed from a group of Permo-Triassic reptiles known as protorosaurs (PROT-or-o-sawrs), comparatively small, lizard-like animals which show certain skull characteristics that would seem to suggest their position as ancestors of the later sauropterygians. An ancestral stage probably is seen in *Araeoscelis* (air-e-oss-seel-is), from the Permian of North America, a land-living animal, evidently rather lizard-like in its habits. However it was the European Permian form, *Protorosaurus*, seemingly an aquatic reptile, that shows in its development the most definite evolutionary steps toward the plesiosaurs and their relatives.

Thus (as in the case of the ichthyosaurs) the plesiosaurs, which abounded in the waters of the Mesozoic era, were descended from land-living ancestors. Like the ichthyosaurs, the plesiosaurs had completed a cycle of evolutionary development.

The nothosaurs of Triassic age found in Europe were among the first of the sauropterygians to appear. These were aquatic reptiles, but their adaptations to life in the water were not complete. While they had many characteristics that are seen in the later plesiosaurs, it is evident that they were still partially land-living. Like the sea lions of our modern California coast, the long bodied, long necked nothosaurs could use their short, web-footed limbs to haul themselves out onto the rocks. Like the sea lions, they probably lived in and out of the water.

It may be that the nothosaurs were not the actual ancestors of the plesiosaurs, but they were fairly close to such ancestors. So for all practical purposes we may consider the nothosaurs as representing in a general way the stock from which the plesiosaurs developed.

The first plesiosaurs appeared at the end of the Triassic period, and these animals continued their development through the Mesozoic era until, like so many other reptiles, they became extinct during the transition from the Age of Reptiles to the Age of Mammals. But during the long stretch of Jurassic and Cretaceous times the plesiosaurs shared with the ichthyosaurs, mosasaurs, and a few other types the dominance of the water, so theirs was a successful chapter in the long story of vertebrate evolution.

Although the plesiosaurs were thoroughly adapted to life in the water—indeed, it is doubtful that they ever came out upon the land at all—their construction was quite different from that of the ichthyosaurs. Whereas the ichthyosaurs were "pseudo-fish," swimming rapidly in pursuit of prey, and were fishlike in form and habits, the plesiosaurs were "pseudo-marine turtles" that sculled along at a relatively slow pace. The comparison of the plesiosaur with a marine turtle is not exactly accurate, for the plesiosaurs were quite different in many respects from any modern animal whose habits are well known to us. True enough, like the turtle, the plesiosaur had a broad, flattened body equipped with huge rowing paddles. But unlike the turtle it carried its head on the end of a long, snakelike neck, and there was a moderately long tail. In fact, a plesiosaur has been described by one of the earlier writers as "a snake strung through the body of a turtle."

It would seem that the plesiosaurs paddled along the surface or just beneath it, propelling themselves with long, slow strokes of their oarlike limbs. Moving along in this fashion they were able to dart the head from side to side to capture the fishes that probably constituted the bulk of their diet.

The skull in the plesiosaurs was either small and short, or elongated with a sharp beak in front of the eyes. The plesiosaurs with short skulls had an extraordinarily long and flexible neck, which enabled them to flash the head this way or that for catching the ever elusive fishes upon which they fed. Those plesiosaurs usually called pliosaurs, with elongated skulls, had comparatively short necks, but it would seem probable that the long rostrum or beak and its greater gape of the jaws compensated for the lesser reach and flexibility of the neck.

That the plesiosaur mouth was a fish trap, whether short or long, seems obvious, for it was armed with many long, sharply-pointed teeth—ideally shaped and arranged for holding onto such slippery objects as wet fish.

In the limbs and feet of the plesiosaurs we see adaptations parallel to, yet quite different from, those in the ichthyosaurs. In both groups of reptiles these members formed paddles, but it would seem probable that the ichthyosaur paddles were balancing planes, like the fins of fish, whereas the paddles of the plesiosaurs were rowing paddles or oars. Consequently the limbs in the plesiosaurs were never shortened to the degree that is seen in the ichthyosaurs; rather they were elongated like oars, to give the necessary leverage for rowing. The finger bones, though multiplied in number and compressed, were always long—never the flattened discs that are seen in the ichthyosaurs.

An interesting development in the plesiosaurs is to be seen in the form of the shoulder and hip girdles, which were very heavy and strong. These structures afforded attachments for powerful muscles that moved the oarlike limbs back and forth. Moreover, provision for equally strong muscles both in front of and behind the fulcra for the limbs enabled the plesiosaurs to "back water" as well as row forward. Whatever their actions may have been, they must have been interesting to watch. However, there was no one to watch them except other plesiosaurs or ichthyosaurs, whose powers of comprehension would hardly permit them to puzzle about the mechanics of plesiosaurian locomotion.

Related to the plesiosaurs were the Triassic placodonts, typified by the European genus, *Placodus*. These were thoroughly aquatic reptiles, adapted to a diet of mollusks and other shellfish, for their skulls and jaws were equipped with broad, flat crushing teeth. The paddles were relatively weak, so these animals must have been slow swimmers. Why should they need to swim rapidly, since their days were spent coasting along the bottom of shallow waters, picking up the Mesozoic brethren of our modern oysters, which were virtually stationary? There may have been some aquatic enemies to bother *Placodus* and his relatives; if so these predators would find the placodonts rather tough eating. For *Placodus* had heavy dorsal ribs and a strong "basket" of abdominal ribs that offered considerable protection to the body, while a related form, *Placochelys* (plak-o-KEEL-is), was covered turtle-fashion with a strong shell.

The Mosasaurs

The ichthyosaurs, plesiosaurs, and their relatives were the inhabitants of the waters in Mesozoic times. They ruled the open seas and the large lakes, where fish and mollusks abounded and where the great land-living dinosaurs were curious objects to be seen upon a distant shore. Yet abundant as they were, the parapsids and euryapsids had to share their dominance of the water with certain other Mesozoic reptiles. Of these, the most numerous and

The giant mosasaur *Tylosaurus*, of the Cretaceous seas of western North America

Restoration by Charles R. Knight

aggressive were the mosasaurs (MOSE-a-sawrs)—the "sea-lizards" of Cretaceous times. They were literally sea-lizards, for they were nothing more nor less than lizards that became completely adapted to an aquatic life, and in doing so grew to great size.

The lizards and their close cousins, the snakes, are specialized members of the diapsid subclass of reptiles, and in their modern, and to us their more ordinary, manifestations they will be considered upon a later page. They appeared in late Mesozoic times, approximately 130 million years ago, and early in their history one family of lizards, the mosasaurs, separated from their land-living relatives and returned to an aquatic mode of life. And like the other groups of aquatic reptiles that we have already examined, the mosasaurs became highly specialized in body design for their life in the open sea. Like the other aquatic reptiles, they show their true relationships, for beneath the elongated, fish-like form, with all of the various adaptations that go with this great transformation from a land-living to water-living vertebrate, the mosasaurs were lizards—lizards related to the varanids, the large "monitors," which live at the present time in the Old World.

The mosasaurs were all sizable animals, and some of them were truly gigantic. *Tylosaurus* (tile-o-SAWR-us), for instance, from the Cretaceous of Kansas, was more than twenty feet in length—as large as a medium-size whale and equal in bulk to many of the dinosaurs of the day. In this increase in size over their land-living forefathers, the mosasaurs demonstrated very nicely the relationship between design, environment, and size. All the land-living lizards were and are small- to moderate-sized reptiles. But the mosasaurs, which went down to the sea, left behind them that problem of gravity that is ever present to plague and limit the land-living vertebrates; therefore they were able to grow big with impunity, and a good thing too, for they lived in a world of giants.

The skull suffered few changes in the transition from a land lizard to a sea-going type. In fact, it was for the most part a lizard skull grown large, with a pair of dorsally located nostrils (always an advantage to a swimming animal) as about the only concession to a life in the ocean wave.

The body was elongated and flexible, and the tail, especially, was very long. The presence of long spines on the tail vertebrae indicates that the tail in the mosasaurs was narrow and deep, obviously well adapted for propelling the animal through the water. Thus it is evident that the mosasaurs, like the ichthyosaurs, imitated the fish in their movements, using the body and tail for propulsion and depending upon the paired limbs for balance. The mosasaurs never went quite so far as did the ichthyosaurs. They never attained a truly fishlike form in body and tail; they were sea serpents, long and sinuous.

The paired limbs, as is usual among aquatic vertebrates, were paddles, with the limb bones shortened and finger bones flattened to form the internal support for the thin and flexible fins.

The mosasaurs lived about 75 million years ago in Upper Cretaceous times, at a period of general submergence, when shallow inland seas encroached upon the continental areas. For instance, the American mosasaurs are found in the Niobrara formation, an extensive deposit of shallow-water marine beds covering great areas of our western states. This encroachment of shallow seas over much of western North America was, geologically speaking, a fairly rapid and brief event. Likewise, the rise and dominance of the mosasaurs was relatively rapid and short-lived. As compared with the evolution of their Mesozoic contemporaries, the mosasaurs were almost ephemeral. But while they lived they lived well.

The name mosasaur comes from the scientific name of one of the first described members of this group of aquatic lizards, *Mosasaurus*. And this name in turn is based in part upon the Meuse River where the first of these fossils was discovered.

Incidentally, there is an interesting story connected with the discovery of the first mosasaur, and its subsequent fate. The skeleton was found in 1780 in a subterranean gallery of the large sandstone quarries of Pietersberg near Maastricht, Holland, and of course it immediately aroused a great deal of interest among the quarrymen who were working there. When it was realized that an important scientific specimen had come to light the quarrying operations were suspended, and Doctor Hofmann, a French Army surgeon who had previously collected fossils in this quarry, was notified of the discovery. Doctor Hofmann soon arrived, and immediately took charge of the fossil, directing its excavation with such skill that the entire skeleton was removed in a single block of stone.

At this point in the proceedings a certain canon of Maastricht, a Doctor Goddin, decided that the fossil should belong to him, since he owned the lands above the quarry. So he claimed it, but Doctor Hofmann naturally refused to surrender the treasure. The matter went to court, where the judge decided against Doctor Hofmann, not only making him hand the specimen over to Doctor Goddin, but also imposing upon him the costs of the court action.

Doctor Goddin's victory was, however, rather short-lived. During the French invasion of Holland in 1794, Maastricht was bombarded, but the suburb in which Doctor Goddin lived was mysteriously spared. He suspected that the French had orders to capture the mosasaur skeleton, so he hid it in a vault where the conquerors were unable to find it after the surrender. The search became intense, and finally a reward of 600 bottles of wine was offered for the much sought after fossil skeleton. This had its effect. In short order a group of French grenadiers appeared with the fossil, and it was carted away to Paris, to be installed in the Jardin des Plantes. The name *Mosasaurus* was given to the specimen by the English paleontologist, Conybeare, in 1828.

The Marine Crocodiles

The crocodiles will be discussed on a succeeding page, so it is not necessary to go into detail here. It should not be forgotten, however, that some of the crocodiles of Mesozoic times took to the open water and became truly marine reptiles. They shared the dominance of the Mesozoic seas with the ichthyosaurs and the plesiosaurs—although it is probable that they never existed in such numbers as did these others.

Like all of the other marine reptiles we have seen, the marine crocodiles, or geosaurs (JEE-o-sawrs), became specialized along certain characteristic lines. The body became long and flexible. Curiously enough, there developed a downward bend of the spinal column in the tail region, so that the tail assumed the "reversed heterocercal" condition that was so popular with the ichthyosaurs. The limbs, as might be expected, developed into flattened paddles.

14

Decline of the Dinosaurs

WHY DID THE DINOSAURS become extinct? This is a question to which there are many answers.

It is a complex question because the extinction of the dinosaurs was a complex process involving many different but related factors. Consequently, a short and simple answer to the question of why the dinosaurs should all have become extinct is not to be had. Rather it is necessary to examine the problem from several angles—to try to visualize, if possible, those factors which may have contributed to the disappearance of a once mighty line.

Perhaps the most general explanation for the extinction of the dinosaurs would be that these great animals were unable to adapt themselves to changing conditions. They were too fixed in their organization to change in a changing world, so they were left behind in the long race of animals through geologic time. They could only succumb to other more progressive animals; their reign upon the land was at an end.

Now this is all very fine, but after the explanation has been stated in this way it still hasn't told us much; we are left with many questions in our mind. So it is necessary to go into the problem still further.

One factor that may have contributed to the downfall of the dinosaurs is something that is often called "racial senescence," or racial old age. The dinosaurs died out because as a group they were old and had reached the end of their rope. In looking through the pages of geologic history we see frequent instances where animals seemed to perish because they were senescent, because they had reached the end of their natural evolutionary development. The dinosaurs are a case in point.

So-called racial senescence in evolution is usually accompanied by overspecialization—by the production of bizarre forms which appear to be in no way well suited to their environment. It may be that the chromosomes, those carriers of heredity, get "out of control" just before the extinction of a group—indeed, overspecializations due to chromosomal upsets may have been instrumental in causing the disappearance of many particular evolutionary lines.

Some such factor might have been operative in the decline of certain lines of dinosaurs, especially those that died out before the end of Mesozoic times. For instance, some of the armored dinosaurs developed peculiar projections and excrescences over the body and then became extinct before the end of the Age of Dinosaurs.

On the other hand, most of the dinosaurs lived on until, or near, the end of Cretaceous times, and among these late forms were some of the most bizarre and remarkable of all the strange beasts we know by this name. So the factor of "racial senescence" cannot be called upon as an explanation for the extinction of more than a few of the lines of dinosaurian evolution. This is all the more true when we remember that most of the dinosaurs disappeared rather suddenly, geologically speaking, near, or at, the end of Cretaceous times. We must look to other causes for our explanation of this interesting phenomenon.

It may be that the relationship between the very small and lowly organized brain and the great bulk of body was one factor operating to bring about the disappearance of these great reptiles. In late Cretaceous times the mammals were developing at a rapid rate, and these animals, although insignificant in comparison with the dinosaurs so far as size is concerned, were nevertheless large-brained, active forms. As contrasted to the mammals, the dinosaurs were virtual walking automatons. Consequently there may have been a triumph of "brain over brawn."

Again, the dinosaurs, being reptiles, were probably cold-blooded animals, just as our modern reptiles, while the mammals, becoming of ever-increasing importance in late Cretaceous days, were warm-blooded beasts. This means that the dinosaurs were ponderous, sluggish giants as compared with the small but very active mammals. Moreover, the dinosaurs, being cold-blooded, would fatigue easily, just as modern reptiles soon tire under stress of continued activity. Such animals would obviously be at a great disadvantage in the struggle for dominance with their warm-blooded mammalian competitors, because a warm-blooded animal can maintain its activity over protracted periods of time.

All of this adds up to the fact that the small-brained, cold-blooded dinosaurs were competing with the large-brained, warm-blooded mammals, and the more efficiently organized animals won out in the end.

In this connection, the idea has been frequently advanced that the destruction of the dinosaurs was brought about in part by small mammals that preyed upon the eggs of the huge reptiles—that the extinction of the dinosaurs was hastened because increasingly great numbers of them were never born. It is quite probable that such may have been the case, but how important this factor may have been in causing the ultimate complete decline of the dinosaurs is a question of considerable uncertainty.

Another factor that must be taken into account is that of internal causes. For instance, the downfall of the dinosaurs may have been brought about in part by upsets in their glandular secretions. As an example, many of these animals had extraordinarily large pituitary bodies at the base of the brain. It has been found that in modern animals the pituitary body secretes the growth hormone, so that the large size of the pituitaries and the general development of giantism in the dinosaurs went hand-in-hand. The dinosaurs were large because they had over-developed pituitary glands—but what caused the over-development of the pituitaries is something else to speculate about. Perhaps we might blame *that* on the chromosomal disarrangements, mentioned above, but to do so merely pushes the explanation back another step. At any rate, it is quite possible that in the dinosaurs with such large pituitaries there may have been common disturbances of the hormone secretions with resultant deleterious effects upon the animal. It is doubtful, however, whether such a factor was very important in causing the disappearance of the dinosaurs. Moreover, not all of the dinosaurs were giants.

Again, it is possible that epidemics may have been a contributory cause, in some cases. This is something that can only be guessed at.

Thus we are able to speculate along various lines of thought, and by so doing we can find numerous causes which, working together, may have contributed to the extinction of the dinosaurs. No one of them alone would seem to be sufficient to explain it, but a combination of them might offer sufficient reasons for the disappearance of these animals from the face of the earth.

However, there is one line of evidence that is quite out of the realm of speculation. At the end of the Cretaceous and the beginning of the Paleocene periods occurred a new series of events of profound importance to the more recent stages of Earth History. For this was when our modern mountain systems were born—when the young Rockies began to thrust themselves up into the blue sky out of a land that had been low and flat.

This isn't to say that there was a sudden eruption of Wagnerian fireworks, with hot lava spouting all over the place and earthquakes rocking a patient and suffering landscape. Indeed, quite the reverse. To our modern eyes, accustomed to the contrasts of blistering summers and frigid winters, of flat plains and jagged mountains, it was a period of great tranquillity. It would have seemed like a time of perpetual mellow summer amid gentle scenery. Yet the changes were taking place, slowly but inexorably. No individual animal would have noticed them, nor several generations. But the cumulative effect was there, generation after generation and millennium after millennium. The tropical lowlands gave way to rolling uplands. Palms retreated before the hardwood forests. The warm, equable temperatures of the tropics were gradually replaced by the fluctuating temperatures of more temperate climes. In fact, the worldwide tropical climate of Mesozoic days began to be replaced by the zonal climates of the Cenozoic.

And these were changes to which the dinosaurs could not adapt themselves. The great plant-eating dinosaurs seemingly were unable in a relatively short geological space of time to make the change in diet that would have enabled them to live on in a modern world. And with the herbivores went the carnivores. Moreover, all of the dinosaurs, it would seem, were unable to adapt themselves to the temperature changes that were taking place. So they became extinct.

But why did they all become extinct? Why didn't a few of them survive and persist through the Age of Mammals, even to our own day? Their close cousins, the crocodiles, did persist, and it would seem reasonable to think that some few of the lines of dinosaurian evolution might have survived. Maybe there is something in the idea of racial senescence after all!

It is an interesting fact that the dinosaurs weren't the only reptiles that failed to survive the Cretaceous-Eocene transition. Although many of the crocodiles were able to weather this great break in geologic history, certain crocodilians disappeared like the dinosaurs, at the end of Cretaceous times. So did the pterosaurs, the flying reptiles so closely related to certain dinosaurian lines of evolution. So did the aquatic plesiosaurs and the giant aquatic lizards, the mosasaurs. The ichthyosaurs became extinct even before the end of the Cretaceous period.

Thus the Cretaceous-Eocene transition was a period of general reptilian extinction. It was a period when the giant reptiles on land and in the sea—the dominant animals of the Mesozoic scene—gave way to the oncoming mammals. Their day was over, and so far as reptiles were concerned, the future was to belong in the main to the relatively small animals that we know today, the lizards and snakes and turtles, although a limited number of the large crocodiles persisted.

15

The Survivors

Crocodiles, Ancient and Modern

To us, living in the age of steel and airplanes, the Age of Dinosaurs seems very distant indeed, yet even in the modern world, where man flies to the remotest corners of the continents and the oceanic islands, and where he cuts his way into the densest and most primitive of tropical jungles with complex machinery, there still live some survivors from that dim, past era of Earth History. These are the crocodiles and their relatives. Crocodiles were contemporaries of the dinosaurs, and they have persisted into modern times with but little change in form or habits. And by studying the crocodiles, especially their habits and their several modes of life, we can get some inkling as to the mode of life of the dinosaurs, because the modern crocodiles have preserved a Mesozoic manner of living in what continues to be an essentially Mesozoic environment.

To get a full and comprehensive picture of the crocodiles it is necessary to go back to the Triassic, the period when the ruling hierarchies of Mesozoic reptiles were first arising, because the crocodiles, like the dinosaurs, the Mesozoic marine reptiles, and other rulers of the middle period of Earth History first appeared in their most primitive manifestations at that time.

The earliest known animal that we may call a crocodile was an upper Triassic or lower Jurassic reptile found near Cameron, Arizona, represented by a remarkably well preserved skeleton, with virtually the entire bony structure present and in addition much of the dermal armor which covered the back and the belly. This crocodilian forebear has been named *Protosuchus* (prot-o-SOOK-us).

Protosuchus was relatively small, no larger than a medium-size lizard. It was a diapsid reptile, related closely to the thecodonts, the little bipedal animals which, it will be remembered, were ancestral to the dinosaurs. But in spite of its ancestral heritage, *Protosuchus* was already on the way to becoming a crocodile, as is shown by various features of the skull and skeleton. It had a rather short head, with comparatively large eyes and a pointed nose. The limbs were typically crocodilian, even in this ancestral beast, and it is interesting to see that the hind limbs were much larger than the fore limbs, a reminder of its two-legged thecodont ancestry. Perhaps the most striking feature of this little reptile was the heavy armor with which it was protected—large rectangular plates, or scutes, on the back, on the belly, and surrounding the tail.

This grandfather of the crocodiles needed his armor, for he lived in a region that was inhabited by the large phytosaurs—those specialized thecodonts which, it will be remembered, anticipated and paralleled in Triassic times the later true crocodiles. Here was an interesting situation—the ancestor of the real crocodiles, a small, lizard-like armored reptile, living a precarious existence in the continued presence of the giant "precrocodiles," the phytosaurs—the scaly, toothy, stream-living monsters of those distant days. It was a life-and-death race, in which the hunter came out second best, for his kind soon became extinct, while strangely enough, the little, inoffensive victim was the progenitor of a line that eventually became remarkably like his phytosaurian nemesis, the line of the crocodiles.

The real deployment of the crocodiles began in the Jurassic period, and from that time to the present these reptiles have inhabited the tropical streams and swamps of the earth. Generally speaking, the crocodiles may be described as large elongated, armored, meat-eating reptiles, spending most of their time in the water, but capable of active and aggressive movements upon land. The crocodiles float down streams, with only the eyes and the nostrils protruding above the surface of the water, ready to snap up instantly any hapless animal that may come within range of their widely gaping and powerful jaws. It has been a highly successful pattern for existence, for the crocodiles have watched the dinosaurs arise and decline, they have seen the mammals evolve almost from their first beginnings through the early stages of their radiation, to the present high point in their development. As a last and fleeting incident in their long existence upon the earth, the crocodiles have seen man develop from his primate forebears, to go through thousands of years of primitive cultural existence and finally to attain his present state as the creator of a highly complex civilization.

The evolution of the crocodiles was twofold. There was first a Mesozoic radiation of these animals, the Mesosuchians (mes-o-SOOK-e-yans), beginning with the Triassic ancestors like *Protosuchus* and extending through Jurassic and Cretaceous times to

Ancestor of the crocodiles, *Protosuchus*. It was a primitive reptile, but many of its features show that it was already on the way to becoming a crocodile

Restoration by John C. Germann from a model by Louise Waller Germann

produce a great variety of crocodilian adaptations suited for life in differing environments.

The first real crocodiles, as contrasted with the ancestral crocodiles of the Triassic, appeared in Jurassic times. These ancient members of the order lived along streams and in lakes, as do our modern crocodilians, and many of them would seem to have been inhabitants of the seashore, or even of the open ocean. As in modern times, there were long-snouted crocodiles and short-snouted crocodiles. They were all active hunters that prowled along the banks and the strand, or even ventured out into the open waters, constantly in search of any reptiles or fish that might serve to alleviate in part their insatiable appetites. Like the modern crocodiles, these ancient saurians were active predators, a constant threat to all of their contemporaries that might frequent watery places. *Teleosaurus* (teel-ee-o-SAWR-us) was typical of these early crocodilians.

One interesting development already mentioned on page 114, which has never been repeated by later members of the group, took place among the Jurassic crocodiles. This was an adaptation to a purely marine type of life, characterizing the crocodilians known as the geosaurs. These metriorhynchids (met-ree-o-RINK-ids) were long-snouted, long-bodied crocodilians, with the feet modified as paddles and the tail a fishlike scull that served to propel the animal through the water.

Some of the Mesozoic crocodiles failed to survive from the Jurassic into the Cretaceous; others were characteristically Cretaceous in their development and failed to survive into the Cenozoic.

Then there appeared in Cretaceous times the second great deployment of the crocodiles, in which animals derived from some of the typical Jurassic types gave rise to the modern crocodilians or Eusuchians (yoo-SOOK-e-yans) ("True-Crocodiles"). The first eusuchians were small, but they were the progenitors of a successful line of large, active reptiles. By the end of the Cretaceous the three groups of modern crocodilians had appeared, namely the pointed-snouted crocodiles, the broad-snouted alligators, and the very narrow-snouted gavials. Indeed, the eusuchian pattern was well set in the Cretaceous, for there has been very little significant change in the crocodilians since that date.

Of the modern crocodilians, the long-snouted gavials (*Gavialis*) (gave-e-AL-is) of India, Borneo, and Sumatra are the largest. There are records of gavials having a length of 30 feet, which makes them the giants among modern reptiles, and indeed, reptiles of no mean dimensions when compared with some of the large dinosaurs.

Of almost comparable size are some of the present-day pointed-snouted crocodiles, such as the great salt-water crocodile (*Crocodilus*) (krock-o-DILE-us) of India. These crocodiles, using the term in its narrow sense, are found in a variety of forms and sizes in tropical regions around the world in Africa and the Orient, in Australia, and in North and South America.

Among the crocodilians, perhaps the giant of all time was the Cretaceous crocodile, *Phobosuchus* (fobe-o-SOOK-us). This gigantic animal, not unlike the salt-water crocodile and other members of the genus *Crocodilus* in form, had an enormous skull more than six feet in length. The entire animal must have been some 50 feet long, which made it one of the most dangerous and feared predators of Mesozoic times.

The alligators are perhaps the most

highly developed of the modern crocodilians. These reptiles are represented at the present time by the alligator (*Alligator*) in North America and China, and by the caimans in South America. The fossil evidence indicates that alligators once were common residents over much of North America and Eurasia.

The Long-Persistent Rhynchocephalians

Living along the high, rocky coasts of New Zealand is a small, lizard-like reptile which is a lonely survivor from the distant Age of Reptiles. This is the little tuatara, known scientifically as *Sphenodon* (SFEN-o-don), which in spite of its outward resemblance to the lizards is in truth a distinct type of diapsid reptile.

Sphenodon is the final survivor of a very ancient order of reptiles, that group known as the Rhynchocephalia (rink-o-sef-AY-le-ya) ("Beak-Heads"), so named because of the rather deep, beaklike construction of the front of the skull. The first rhynchocephalians made their appearance early in the history of the diapsid or two-arched reptiles—in Triassic times—and from that ancient date they established a line of evolution which, if not particularly important, at least had the virtue of a long life.

Although related to the dinosaurs, the Rhynchocephalia were never large reptiles. They were the modest members in a tribe that was generally characterized by size and impressiveness, and were outwardly more or less lizardlike, from their beginnings to the present single survivor, the tuatara.

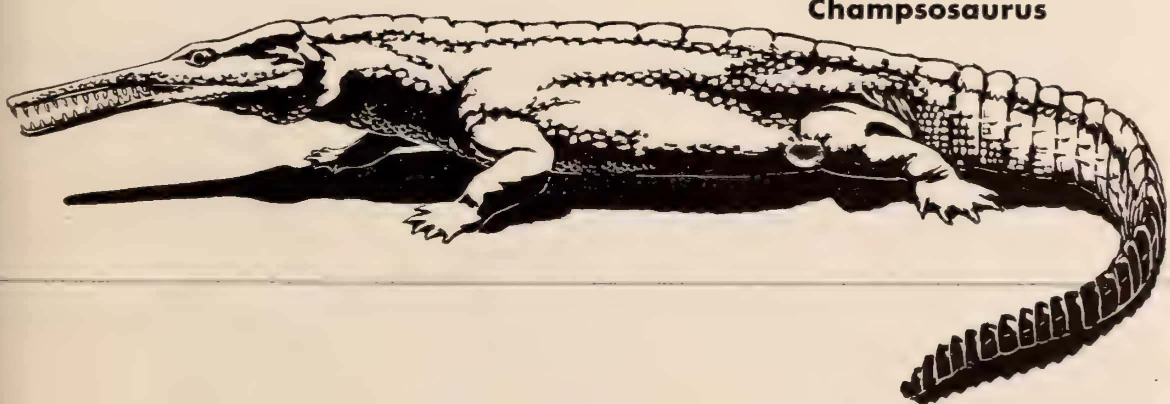
In late Mesozoic and early Cenozoic times there lived an eosuchian, the genus *Champsosaurus* (camp-so-SAWR-us). This reptile, related in a general way to the rhynchocephalians, was some four or five feet in length, and was characterized by

Sphenodon

A survivor from the distant age of reptiles, the tuatara of New Zealand, and his ancient relative, *Champsosaurus*. Although related to the dinosaurs, the Rhynchocephalia and the Eosuchia, to which these reptiles belong, were never very large

Restorations by John C. Germann

Champsosaurus



the long, gavial-like compressed pointed snout.

The Lizards and Snakes

To many of us the word "reptile" means one thing, and that thing is a snake. To some of us it may mean two things, a snake and a lizard. Certainly snakes and lizards are the commonest and the most widely distributed of modern reptiles, known to almost all people except perhaps Eskimos and Irishmen, and commonly regarded with mixed feelings of disdain and horror, quite undeserved on the part of the poor reptiles.

These reptiles belong to the order Squamata (skwa-MAH-ta), in which are included the extinct Mesozoic marine reptiles, the mosasaurs (described in Chapter thirteen). The Squamata are essentially modified diapsid reptiles, in which the bony border of the lower opening behind the eye, the lateral temporal fenestra, has been lost.

The lizards are the more primitive of the Squamata. We know them well, so there is little needed in the way of description. Typically the lizards are elongated, sprawling reptiles, living close to the earth and hunting their prey there. The monitors of the Old World, of which the genus *Varanus* (var-AN-us) is characteristic, are typical lizards, and it was from forms such as these that the gigantic Cretaceous mosasaurs evolved. Indeed, the mosasaurs were nothing more nor less than monitors grown large and specialized for an aquatic existence. At the present time the lizards show a variety of forms, the results of specializations that have taken place since their first appearance in Cretaceous times. There are the iguanids, living in deserts and along seashores, the agamids, the various skinks, the geckos that live in houses of the tropical east, and the peculiar tree-living chameleons. Even though the lizards are now spread far and wide over the tropical and temperate reaches of the globe, they are not particularly important paleontologically.

The snakes are nothing more than highly specialized lizards—lizards in which the legs have been lost and the skull highly modified. Like the lizards, the snakes would seem to have made their appearance in Cretaceous times, since which time they have spread over the earth and become specialized in a variety of ways.

Unfortunately the fossil record of the snakes is extremely scanty. These reptiles lived in environments such that their bones were rarely preserved, and when they were, they were scattered so that isolated vertebrae usually form the only records available to us. The skull in the snakes has been from the beginning such a specialized and fragile apparatus that it is rarely found as a fossil.

Putting the fossil evidence together and combining it with our knowledge of recent snakes, it would seem that the most primitive of these strange vertebrates are the boids, the large constrictors including the boas and pythons of the tropics. In these snakes there are numerous teeth, and the skull more nearly approximates the lizard skull than in most other snakes. The most highly developed of the snakes are the poisonous ones. In these snakes the skull has been greatly modified, and the teeth reduced, except for the large, specialized fangs, which are used to inject poison into the intended victim. Terrifying as these poisonous snakes may be, they are nonetheless objects for admiration, for they demonstrate most beautifully the high degree of specialization that may be reached through the processes of evolution.

Like the lizards, the snakes are of little paleontological importance.

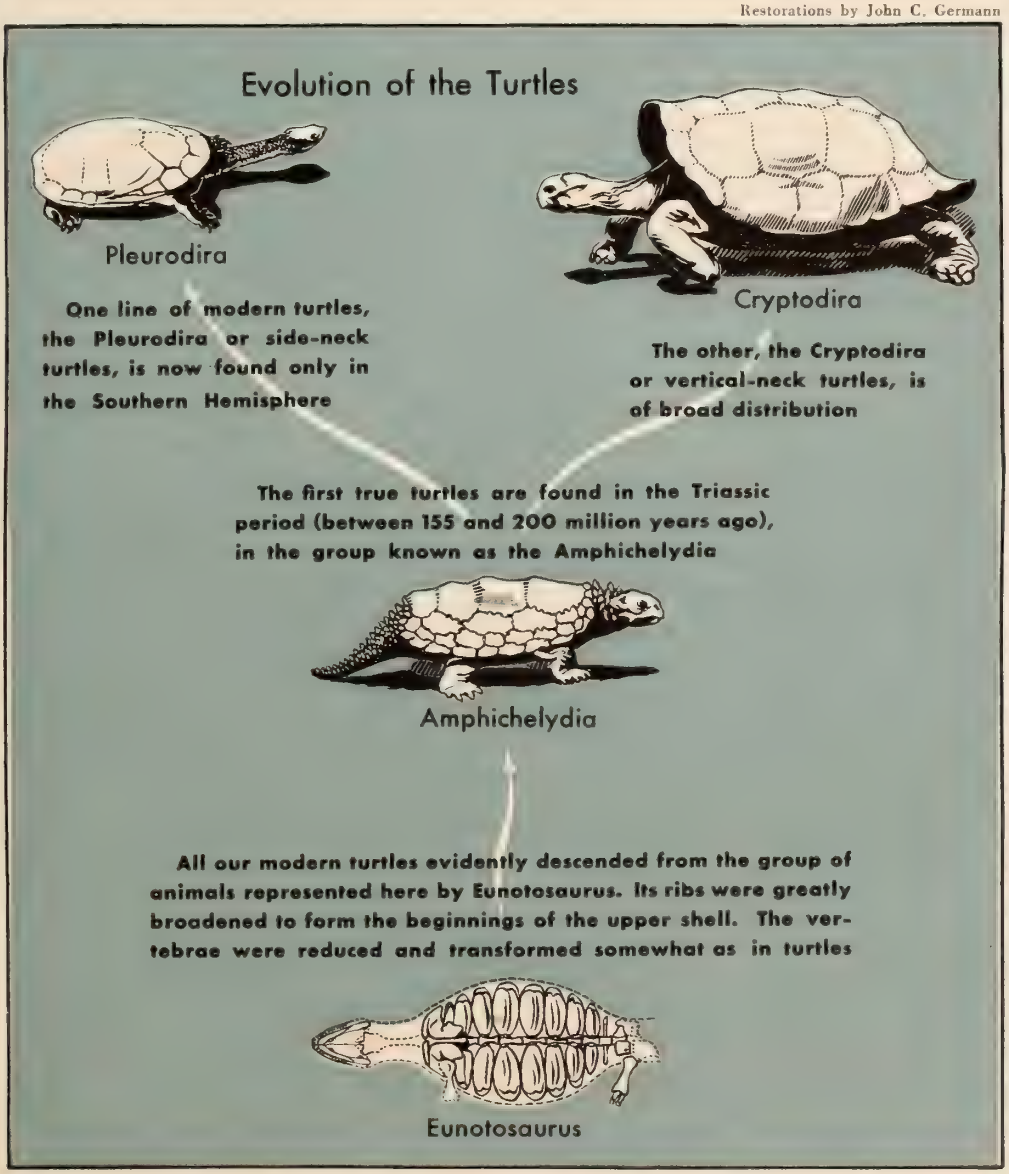
The Turtles

One group of reptiles, which seemingly belongs to the Anapsida, has persisted into our own times. This is the group known as the Chelonia (kel-OWN-e-ya) or Testudinata (tes-TOOD-e-na-ta), the animals which we commonly call turtles.

True enough, the turtles don't look much like the primitive anapsids that inhabited the world in Permian and Triassic times. The reason for this dissimilarity is that the turtles have become highly modified reptiles and it is by the very reason of these modifications that the turtles have been able to live their lives down through the ages, while so many of their former contemporaries became extinct.

The ancestry of the turtles is obscured in the mists of geologic antiquity, but it is probable that they were descended from certain generalized anapsid reptiles. There is preserved, albeit all too imperfectly, the remains of a reptile known as *Eunotosaurus* (yoo-note-o-SAWR-us), from South Africa, a reptile that would seem in many ways to fulfill the role of ancestor to the turtles.

Restorations by John C. Germann



Eunotosaurus had a limited number of elongated bones in the spinal column very similar to the vertebrae of the turtles. And what is more significant, *Eunotosaurus* had expanded ribs that touched one another, ribs that appear to be the beginnings of the shell which is so characteristic of the turtles.

Certainly by Triassic times (perhaps 175 million years ago) the turtles had become established upon the earth, for in the Triassic of Europe is found a full-fledged turtle, *Triassochelys* (try-as-o-KEEL-is), an animal in which the pattern for turtle survival already had become well set. From *Triassochelys* to the present, the story of the turtles has been a relatively static one, a story of some reptiles that were able to pull in their necks and their legs and their tails and within the protection of their hard shells to survive the vicissitudes of life through long periods of geologic time.

The turtle skull is seemingly an anapsid skull modified by the loss of many bones and by the marginal notching of the back of the skull. In accordance with this general trend of reduction in the turtle skull, the teeth have been completely suppressed, and their function has been taken over by a horny beak that encloses the bones of the jaws. The turtle limbs seemingly are modified anapsid limbs, and it may be that in the peculiar right-angle pose of these limbs we see a retention of the pose that characterized the primitive reptiles.

It is the turtle shell, however, that shows most completely the lengths to which evolutionary transformation has gone in these peculiar reptiles. The upper shell, or carapace, of the turtle is formed of modified ribs that have grown together to form a housing for the body. Now in normal vertebrates the limbs and their girdles (the pectoral and pelvic girdles) are *outside* the ribs, but in the turtles, the limb girdles and the limbs themselves are under the shell, in other words, they are *inside* the highly modified ribs. The method whereby this evolutionary hocus-pocus has taken place is shown by the development of the modern turtle within the egg. It is evident that at a certain stage of turtle development the transverse or side-to-side growth of the animal is very rapid, and takes place in such a fashion that the ribs actually grow out and over the limb girdles.

Add to this upper shell, or carapace, of transformed ribs the lower shell, or plastron, and you have the pattern of turtle survival.

From the primitive turtle ancestors such as *Triassochelys,* modern turtles have developed along two main lines. One is that of our northern turtles belonging to the group *Cryptodira* (KRIP-tow-dire-a), in which the neck is withdrawn into the shell by a vertical flexure. The other is the group of Pleurodira (PLUR-o-dire-a), living in the southern hemisphere; in these the neck is withdrawn into the skull by a side-to-side flexure.

16

Why Study Fossils?

OUR STORY IS ENDED. We have seen in brief review the manner in which the first land-living vertebrates arose; we have surveyed the development of the early reptiles and have seen how from them those of Mesozoic creation, the dinosaurs, began, became dominant and then disappeared forever from the face of the earth; we have looked at the pitifully few survivors that live on as a link with past reptilian dominance.

Having done all of this, we may pause to ask a question—what does this study lead to? Why paleontology? Why devote the time and energy and the money to a science that is so far removed from our contemporary world as is the study of fossils? In these days of great world-shaking events, why should we bother with the bones of beasts long vanished?

It is a good question. In our modern world so troubled by the complications of machine-age wars and involved economic situations, the study of fossils may appear at first glance to be rather distantly removed from the realities of life, and it is true that much of paleontology has little direct economic significance. Of course some aspects of paleontology are very important in industry. For instance the study of microscopic fossils, by which many layers in the earth's crust may be identified, is of the utmost importance to the petroleum industry. Without the help of the "economic paleontologist" a great deal of the exploratory work for oil would be blind "wildcatting" rather than the well-planned, coordinated effort that it is. Certain other aspects of economic geology, too, depend to some extent upon the identification of earth strata as interpreted by the study of various types of fossils. Yet even taking these aspects of paleontology into account, it can still be said that much of the study of fossils yields no direct economic returns. So the question still stands.

The answer to the question is simply found, and it is this—man is a curious animal. In fact, if man were not so curious, if he were not so interested in everything about him, he wouldn't be man. It is the very definite primate trait of poking into everything under the sun that has put us where we are. We have arisen to the heights of our mental development, and correlatively to the present degree of our dominance in the world, through the trait of wanting to know something about everything and thereby gaining such an understanding of the world about us as to enable us to achieve our position of unparalleled superiority over the rest of the animal kingdom. To put it more simply, we are great because we understand our world, and we understand our world because we are curious about it.

The proper understanding of our world depends in part on the proper understanding of its past history, and for a proper understanding of the past history of the earth the subject of paleontology looms large.

For instance, most people read newspapers, not because of any monetary profit that they may derive from the reading, but because they want to know what is going on in the world about them. The dissemination of news and information is the primary justification for a newspaper. Similarly, people do not study history because of any definite predictable economic gains that may be made by such a study, but rather because a knowledge of history is an aid to the shaping of present-day conduct. We wish to know what happened in the past, partly for the pure pleasure of knowing how our ancestors behaved and partly for the ability that it gives us to interpret present-day events. In the same way, a knowledge of prehistory, carrying the story back even to the beginnings of life on the earth, gives us an increased understanding of the world in which we now live. That is the function of paleontology. It is a science of interpretation. It is a "cultural science" if you please, the knowledge of which gives to its possessor a magnificently broad view of the world.

The student of paleontology is the man with a long view of things. "His field of vision embraces the whole of life. His time scale is so gigantic that it dwarfs to insignificance the centuries of human endeavor. And the laws and principles which he studies are those which control the whole great stream of life, upon which the happenings of our daily existence appear but as little surface ripples."[1]

The world of primitive man is a world filled with fears of the unknown, a world in which the individual is surrounded by "gorgons, and hydras, and chimaeras dire." Such was the fantastic world that gripped and bound the mentality of medieval man. And it was only through the rebirth of knowledge and learning, by the free expression once more of man's natural wish to learn about everything that he saw, or felt, or heard, that the mists of medieval superstition cleared away. After the Renaissance, man's cultural progress was rapid, because he was allowed to be curious.

This pursuit of knowledge inevitably and finally produced the evolutionary concept —a mode of thought which grew through the years, to be suddenly and gloriously crystallized by Darwin in his great work, *The Origin of Species*. In the entire history of man, the year 1859, the year in which Darwin's work was first published, will always be outstanding. The entire history of life on the earth was from then on interpreted as an orderly process, subjected to the laws of nature, rather than as a series of disjointed, catastrophic, and often contradictory events.

Thus was introduced a revolution in human thought which has gradually spread until today it forms a basic portion of our cultural background. Indeed, the development of the evolutionary concept has profoundly revolutionized man's manner of thinking, just as in earlier days the discovery by Copernicus that the planets revolve about the sun opened the eyes of his contemporaries to new horizons around them. Darwin, like Copernicus, gave to man a new and objective view of man's position in the world about him and in the universe.

So it is that paleontology needs no defense—it needs no justification. As long as man is interested in the world about him, as long as he wants to know the past history of this world, so long will he study fossils. Paleontology is a part of our modern cultural environment, it is a part of the great pattern of science and literature and art which has enabled us to know nature as it has never been known before, and thus has made of us the "Modern Men" that we are.

[1] Matthew, William D. "The Value of Palaeontology." *Natural History Magazine,* XXV (1925), No. 2, p. 167.

17

Where the Dinosaurs and Their Relatives are Found

The dinosaurs, the dominant land animals of Mesozoic times, were of world-wide distribution. They roamed through the tropical jungles and waded through the low-lying swamplands that stretched across the continental land masses in those distant days of world-wide climatic uniformity. They were the ubiquitous inhabitants of the earth, just as today the warm-blooded, furry mammals are the dominant land-living animals, around the world and almost from pole to pole.

We know this because their fossil remains have been found on all of the continental land masses and in widely separated degrees of latitude. They are found in North and South America, ranging from the northern plains of Alberta to the southern plains of Patagonia. Dinosaur bones have long been known from various parts of Europe, and in recent years they have been found in Africa and in Asia. In fact, we find them in so distant and seemingly isolated a land as Australia.

From this it is evident that during Mesozoic times not only the climate but also the geographic conditions were different from what they are today. Not only were climates uniformly tropical and subtropical, thereby providing conditions of temperature that allowed the reptiles to spread over most of the continental land areas of the globe, but also there were connections between continents which do not exist at the present time, whereby animal and plant life in those distant days could cross from one region to another. What was the earth like during the long geologic periods when reptiles were dominant on the land?

This is not an easy question to answer, for the answer must be based upon many lines of evidence that are difficult of interpretation. In short, the answer must be found in a study of paleogeography, the interpretation of the face of the earth as it was in past geologic ages.

The study of paleogeography is founded to a large extent upon a study of sediments, the rock materials such as limestones, sandstones, and shales which were deposited at the bottoms of seas, lakes, rivers, and on the dry land, originally in the form of limes, sands, and muds. These sediments are the pages of the geologic record in which are contained many facts as to the past history of the earth. In them are preserved the fossils which show us what life was like in former ages of the earth's history.

It is evident that if all of the sediments that were deposited since the beginning of time were preserved, we would have a relatively complete history of the earth. Such is not the case, for during the long existence of our planet sediments have been subjected to the many vicissitudes of erosion by water and wind, to deformation by the uplift of mountains, and to transformation by earth processes of movement, pressure, and heat. So the pages in the book of Earth History are not nice, orderly, complete pages, but rather are they torn and crumpled, and many of them are missing altogether. Therefore any attempt to reconstruct the past history of the earth, the extent of former continents, the extent of former seas, and the distribution of the animals and plants that lived on these ancient continents and in these ancient seas, involves the problem of piecing together many separate items to tell a logical story. It is here that the factor of interpretation enters, a factor that is determined by the mass of accumulated knowledge plus the individual ability of the interpreter. Therefore it is easy to see that the subject of paleogeography, the interpretation of the former extent of land masses and ocean surfaces, is one in which there are bound to be differing opinions.

This is particularly evident with regard to the stretch of some 160 or 180 million years, from the Pennsylvanian period through the Cretaceous period, which we may call the Age of Reptiles. That great portion of Earth History is so far away from us in time that certain of its details have been obscured by the geologic events occurring since then. It is much easier to come to reasonably sound conclusions as to the manner in which the surface of the earth was divided between oceans and lands during the Age of Mammals, than during the more distant Age of Reptiles.

As a result various opinions have been reached as to the paleogeography of Permian and Mesozoic times. In a general way, these opinions may be grouped into three schools of thought. One school, favored by most American geologists, considers that during the past history of the earth the continental land masses have retained much the same form and position they have today. According to the followers of this theory, the differences in the actual land and water areas between the present and past geologic periods can be explained by the up and down movements of broad continental blocks. This resulted during periods of submergence in the periodic flooding of continental areas by shallow seas, similar to the Mediterranean Sea of our own time, or by narrow oceanic arms extending into deepening troughs. It also resulted in the retreat of the marine waters during periods of uplift, so that the shallow continental shelves, now under water, were frequently high and dry. Also, during periods of uplift, there would be connections between continental areas at places where the seas are now shallow. This would involve connections between North America and Asia in the Bering Straits region, between North America and South America in the Isthmian region, possibly between North America and Europe across Greenland and Iceland, between Eurasia and Africa across the Mediterranean region, and between Asia and Australia across the region now occupied by the East Indies.

A second group of paleogeographers, including many European authorities, considers that in past geologic ages, especially in periods so distant as those of the Mesozoic era, the continents, though in general located as they are at the present time, were nevertheless quite different in their relationships to each other. According to this idea, there were broad transverse connections between the continents, so that the land masses of the earth were arranged more or less along east to west axes. There was a northern land mass including northern Eurasia ("Palaearctis") and North America ("North Atlantis"). Separated from this by an equatorial sea, "Tethys," there was a great southern continent, "Gondwana land," including the eastern portion of South America, southern Africa, peninsular India, and perhaps Australia. According to the adherents to this theory, the relationships as outlined above differed from time to time, sometimes these great land masses existed—at others they were broken up by marine incursions.

Finally, there may be mentioned the followers of the theory of "continental drift," numbered for the most part among some of the European geologists. According to this theory, the land masses were at one time contiguous, and animals roamed freely over one large continental area. Then there was a fragmentation of this great land mass and the continents drifted apart to their present positions.

This is not the place to go into the relative merits of these contrasting theories. Suffice it to say at this point that the present and past distribution of land-living animals can on the whole be very satisfactorily explained upon the basis of the first of the three theories outlined above, namely that of continental permanence. It may be that there was a southern continent of "Gondwanaland" during Permian and Mesozoic times, but it is not necessary to explain the distribution of the reptiles of those times.

The important fact is that during Permian and Mesozoic times there were certain periods when intercommunications existed between the continental areas, so reptiles were able to spread from one great region to another. That is why we find similar reptiles in North America and Eurasia, or in Europe and South Africa, or in Africa and South America. Even the slowest and most sedentary of the reptiles and amphibians were able to cover great areas because of the uniformity of climate, the lack of geographical barriers, and the great length of time involved.

It must not be thought from this that fossil dinosaurs or other reptiles are to be found wherever they once lived. Indeed fossil localities are generally scattered in their occurrence. This is due to the many qualifying factors that enter the picture between the death of an animal, say a dinosaur, and its ultimate discovery as a fossil.

In the first place, a great majority of animals that have died in past geologic ages were never fossilized. Conditions had to be just right for a skeleton to be preserved—it had to be buried soon after the death of the animal, and the conditions of burial had to be favorable in order that the original bone would be transformed into rock. Thus, an overwhelming proportion of the animals that lived in past ages were eliminated from the record at this stage of the process.

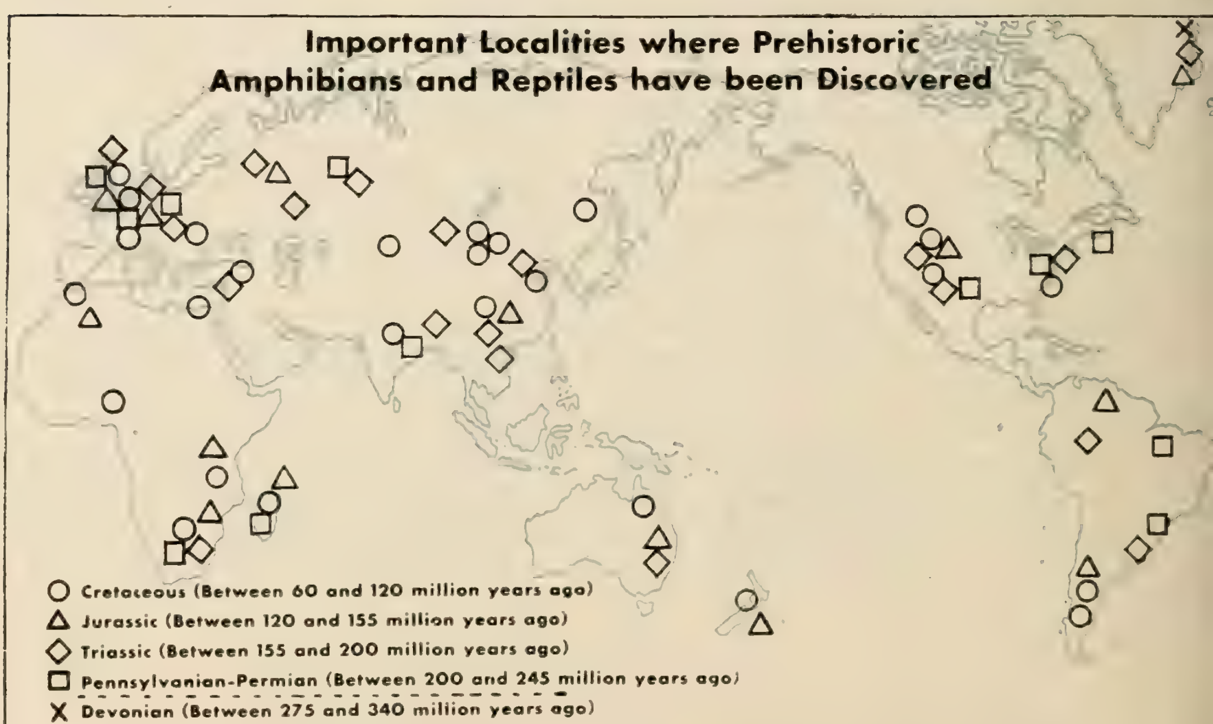
Then, for fossils to come down to us, it was necessary for the sediments containing them to be preserved. As we have seen, sediments are frequently destroyed by erosion, or transformed in various ways by different powerful earth forces. Many potential fossils have been destroyed by events such as these.

Finally, in those sediments which are preserved, we find only the fossils that happen to be near the surface—that have been sufficiently exposed by processes of weathering and erosion that we are able to find them. Here again, the proportion of the known to the whole is greatly reduced, for the fossils contained in the cubic content of any one geologic formation are vastly greater in number than those exposed at the surface where they will be found.

So it is evident that the fossils upon which our knowledge of past life is based are but a tiny fraction of the whole of that life. Even so, we may be sure that the picture we get from them is reasonably accurate, for small as may be the part to the whole, it is nevertheless a random sample, which according to the probabilities of statistics is a rather accurate indication of the true situation. In other words, the fossils are a kind of prehistoric "Gallup poll" of life as it existed on the earth in former ages.

Perhaps this may explain in part why dinosaurs and other fossil reptiles are not found anywhere and everywhere, why they are found in certain restricted localities. Dinosaurs are found for instance, in Wyoming and Colorado, because sediments in which their remains have been preserved are exposed at the surface of the earth in those states. Dinosaurs are not found in Illinois because any sediments which might have contained dinosaur bones have long since disappeared, due to the erosive processes of water and wind, and even of ice. Dinosaurs are but seldom found in New Jersey, even though sedimentary beds of the proper age are exposed in certain localities of that state. This is because conditions during the Age of Dinosaurs were not particularly favorable for the accumulation and fossilization of animal bones. Therefore the sediments in which dinosaurs ought to occur are barren.

To get back to a statement made at the beginning of this chapter, dinosaurs, their reptilian relatives, contemporaries, and predecessors have been found in various localities all over the world, mainly as a result of the studies made by geologists and paleontologists during the past one hundred years. Much of the earth's surface is by now reasonably well known to the students of Earth History, and in the better known areas it is probable that discoveries of new fossil localities will in the future be less frequent than has been the case in the past. Even so, new discoveries will be made, even in the most thoroughly combed areas. This has been and always will be one of the virtues and one of the interesting aspects of the science of paleontology. In the regions less well-known geologically (and there are still great areas falling within this category), there are still many great discoveries to be made. So it is that in a world shrinking geographically, owing to modern methods of transportation and communication, there is much room for paleontological exploration, particularly



The Fossil Record of the Dinosaurs and Their Relatives throughout the World

	South America	Greenland	Eastern North America	Western North America	Northern Asia	Southern Asia - India	Australian Region New Zealand	Eastern Europe - Russia	Western Europe - England	Africa
Labyrinthodonts	Triassic	Devonian, Triassic	Carboniferous —Permian	Carboniferous —Triassic		Permian —Triassic	Triassic	Permian —Triassic	Carboniferous —Triassic	Permian —Triassic
Frogs, toads, salamanders			Cenozoic —Recent	Cenozoic —Recent	Cenozoic —Recent	Cenozoic —Recent	Recent	Cenozoic —Recent	Jurassic —Recent	Triassic —Recent
Cotylosaurs	Triassic		Carboniferous Triassic	Carboniferous —Permian				Permian	Carboniferous —Triassic	Permian —Triassic
Turtles	Cretaceous —Recent		Cretaceous —Recent	Jurassic —Recent	Cretaceous —Recent	Cretaceous —Recent	Cretaceous —Recent	Cenozoic —Recent	Triassic —Recent	Permian —Recent
Pelycosaurs			Permian	Carboniferous —Permian				Permian	Permian	Permian
Mammal-like reptiles	Triassic		Triassic	Triassic	Triassic	Triassic		Permian	Permian Jurassic	Permian —Triassic
Ichthyosaurs	Jurassic—Cretaceous	Jurassic		Triassic—Cretaceous		Cretaceous	Cretaceous	Cretaceous	Triassic—Cretaceous	
Plesiosaurs	Jurassic—Cretaceous	Jurassic	Cretaceous	Jurassic—Cretaceous			Cretaceous	Jurassic—Cretaceous	Triassic—Cretaceous	Jurassic
Primitive diapsids				Triassic					Permian	Permian —Triassic
Rhynchocephalians	Triassic			Jurassic—Cenozoic		Triassic	Recent		Triassic —Jurassic	Triassic
Lizards, snakes	Cretaceous —Recent		Cretaceous —Recent	Cretaceous —Recent	Cretaceous —Recent	Cenozoic —Recent	Recent	Cenozoic —Recent	Cretaceous —Recent	Cenozoic —Recent
Mosasaurs			Cretaceous	Cretaceous			Cretaceous	Cretaceous	Cretaceous	Cretaceous
Phytosaurs			Triassic	Triassic		Triassic			Triassic	
Theropod dinosaurs	Cretaceous		Triassic, Cretaceous	Triassic—Cretaceous	Cretaceous	Triassic, Cretaceous	Cretaceous		Triassic—Cretaceous	Triassic—Cretaceous
Sauropod dinosaurs	Cretaceous			Jurassic—Cretaceous	Cretaceous	Cretaceous	Jurassic—Cretaceous		Jurassic—Cretaceous	Jurassic—Cretaceous
Ornithopod dinosaurs			Cretaceous	Jurassic—Cretaceous	Cretaceous				Jurassic—Cretaceous	Jurassic—Cretaceous
Stegosaurian dinosaurs				Jurassic—Cretaceous					Jurassic—Cretaceous	Jurassic
Ankylosaurian dinosaurs	Cretaceous			Cretaceous	Cretaceous				Cretaceous	Cretaceous
Ceratopsian dinosaurs				Cretaceous	Cretaceous					
Flying reptiles				Cretaceous					Jurassic—Cretaceous	Jurassic
Crocodilians	Jurassic —Recent		Cretaceous —Recent	Triassic—Cenozoic	Cretaceous —Recent	Cenozoic —Recent	Recent		Jurassic —Cenozoic	Cretaceous —Recent

that of a detailed nature. Indeed, this is one subject that will never be enclosed or bounded within a circumscribed horizon beyond which the law of diminishing returns will make work impracticable. There will always be something new in the world of fossils, because even in the best known regions erosion goes on, continually and inexorably, and thus there is a constant exposure of new materials.

Let us now make a brief survey of the places in which the dinosaurs and their relatives have been found.

The greatest and most numerous discoveries of dinosaurs have been made in western North America, particularly in Utah, Wyoming, Colorado, New Mexico, Montana, and Alberta. Dinosaurs have also been found in southern England and in France, Belgium, and Germany. They are also found in Mongolia, and in recent years, in various Chinese localities. Fragmentary remains have been found in India. Some very important materials have come from British East Africa, and the presence of these reptiles is indicated in Madagascar. They are found also in South America, especially Patagonia, and in Australia.

Naturally, the same sediments that have yielded dinosaurs have also been productive of their contemporaries, especially crocodiles and turtles.

The flying reptiles are found most abundantly in the Jurassic deposits of central Europe and southern England, and in the Cretaceous chalk beds of Kansas.

The aquatic contemporaries of the dinosaurs (especially the ichthyosaurs, plesiosaurs, and mosasaurs) are found in sediments of marine origin correlative in age with the continental deposits in which the dinosaurs occur. Because marine animals are able to roam over vast distances, the fossils of these aquatic reptiles are very broadly distributed, as might be expected. Fine ichthyosaurs and plesiosaurs come from central Europe and southern England, from western North America, from Russia, India, Australia, New Zealand, South America, and Spitsbergen. Mosasaurs are found especially well preserved in western and central Europe and in North America, particularly in western Kansas.

The Triassic thecodont reptiles, of which the most widely known are the phytosaurs, are found in North America, especially in southwestern United States and along the eastern seaboard, in Scotland, Central Europe, and South Africa.

Of the "mammal-like reptiles," the great center for the discovery of pelycosaurs is in north central Texas, although these animals are found additionally in Russia. The therapsids show a wide distribution, being especially abundant in South Africa, Russia, western China, and Brazil.

The primitive cotylosaurs are found in Texas, Russia, and South Africa.

The labyrinthodont amphibians, from some of which the reptiles evolved, occur in Permian and Triassic beds in Texas and southwestern United States, in England, central Europe, Russia, India, Greenland, and South Africa.

As for the surviving types of amphibians and reptiles, these are often found in the same localities and sediments as their extinct relatives. In addition crocodilians, turtles, snakes, lizards, and amphibians are found in various Cenozoic sediments throughout the world. They are, however, of so much less importance from the paleontological viewpoint than the mammals with which they were contemporaneous that the post-Cretaceous localities will not be listed or discussed here.

18

How the Dinosaurs and Their Relatives are Classified and Named

THREE HUNDRED YEARS AGO man's knowledge of nature was limited and unorganized. People were familiar to some extent with the animals and the plants around them, but this familiarity was what we might call an "anecdotal knowledge" of nature. Men knew in a superficial sort of way something of the habits of the common birds and beasts, they had a practical knowledge of the medicinal herbs, the domesticated plants, and the trees. But this knowledge was not organized, it was a hodgepodge of unassorted facts.

Then, in the first part of the eighteenth century, there lived in Sweden a man who was destined to bring order out of chaos, a man who changed the course of thought in the natural sciences from haphazard observations and speculations to a systematic and integrated plan whereby all of nature took on a new meaning. It was as if a curtain had been lifted on the world of nature, revealing the life of the earth in orderly aspects which hitherto had been quite unsuspected.

The name of this man was Carl von Linné, usually known as Linnaeus, one of the great figures in the history of science. Every now and then in the course of human events a great man appears, a man who takes the labors of his predecessors and of his fellow men, and shapes them into something—a method of thinking or a way of life—which has a profound effect upon the entire course of human history and endeavor for generations afterwards.

These rare men are the geniuses of our world, and of such stuff was Linnaeus. Linnaeus, who was in his day a distinguished botanist, conceived the idea of naming all of the living things on earth—the plants and the animals—and this he did to the limits of his knowledge in his great work, the *Systema Naturae,* one of the most important publications in the history of the written word. Now this seems simple, yet no man, before the time of Linnaeus had had either the vision or the ability to attempt such a thing. True enough, people had names for plants and animals, but they were vernacular names, in Latin or Greek, or English, or Spanish, or a thousand and one other tongues. It was Linnaeus who had the conception of a logical and systematic manner of naming the plants and animals of the world with names that would be applicable everywhere and by everybody.

So he invented the "binomial system of nomenclature," which may at first sound like a mouthful, but which is in reality a simple and logical plan for distinguishing the vast multitude of living things one from the other. According to the Linnaean system, every distinct type of animal and plant was to have two names, one known as the *generic* name, the other as the *trivial* name. The generic name may be compared with a human family name such as Smith or Brown. It denotes a comparatively small group of related forms belonging to a single *genus,* and, Chinese fashion, it always precedes the specific or trivial name. The trivial name may be compared with a human given name, such as John or Henry or Mary. It denotes a certain *species* contained within the genus. These two names in the Linnaean system indicate the basic relationships of any particular type of animal or plant. Linnaeus used Latin or latinized Greek names when he first began his tremendous and epochal labor of naming all the living things known to him, and it is still the general practice to use such forms, although by modern authors "barbarous" names are also frequently utilized. The important feature of the Linnaean system is that it affords a convenient "handle" for designating animals and plants, no matter what may be the nationality and language of the person who may be studying a particular form.

For instance, the horse in the Linnaean system of nomenclature is *Equus caballus*, and by this name it is known to scientists all over the world, whether they be natives of France, Russia, China, or Timbuktu. The advantage of such a system is at once obvious when one considers that, while an Englishman or an American may speak of a "horse," this same animal is known to the Frenchman as a "cheval," to the Spaniard as a "caballo," to the German as a "Pferd," and so on, almost ad infinitum.

But even beyond the advantage of making animals and plants uniformly distinguishable to men everywhere, the Linnaean system is valuable in that it expresses the relationships of the various forms of life to one another; it has made of natural history a formalized and logical science, rather than a collection of curious facts. By an international agreement, this system dates from the year 1758, when the tenth edition of Linnaeus' *Systema Naturae* was published. That is the *official* beginning of all scientific classifications of animal life.

Ordinarily generic and specific names are italicized. The generic name is always spelled with the initial letter capitalized; it is preferable that the initial letter should not be capitalized in the trivial name. In scientific work it is common to cite the name of the author of a genus or species—the name of the person who first described the form according to the Linnaean binomial system, thus: *Crotalus adamanteus* Beauvais. But commonly the name of the author is not cited. In many general discussions, only the generic names are used, and such has been the case in much of this book.

Which brings us to a common complaint among those who would become acquainted with fossils. "Why do we have to learn so many long-winded and difficult names?" The answer is that most fossils do not have any other names besides their scientific ones. For instance, horses were known to generations of English-speaking people before Linnaeus first designated them scientifically as *Equus caballus*. But most fossils have been made known only through the labors of the scientific student of life, and so it is that the dinosaurs, the phytosaurs, the pterosaurs, and the host of other extinct reptiles discussed in this book have no names other than their scientific ones. Of course it might be possible to invent "common" names for all of the dinosaurs and the other extinct animals that are known to us and are being made known by new discoveries every year. But this would only introduce complications in the long run, and would inevitably lead to endless confusion. For instance, isn't it easier to buckle down and learn *Triceratops, Protoceratops, Styracosaurus*, and the like, than to deal with such voluminous circumlocutions as "three-horned dinosaur," "ancestral horned dinosaur," "horned dinosaur with spikes around the frill," and so on?

Moreover, scientific names aren't so difficult if one will look at them carefully, refusing to be frightened by their seeming length and complexity. The important thing is to analyze each name the first time it is seen. If this is done, the name will have a meaning, and, moreover, it will thereafter be remembered. Perhaps a few remarks as to the manner in which scientific names are formed will be of help in analyzing and learning these names.

As mentioned above, the generic name is commonly latinized Greek, or Latin, and as such it may be a simple or a compounded single word that expresses some real or fancied attribute of the animal to which it applies. For instance, the first recognizable bird, *Archaeopteryx,* was named by combining two Greek terms, *archaios* = ancient or old, and *pteryx* = wing. Thus the combination means "ancient wing," or to translate more freely, "the ancient winged creature." However, the name may be a "barbarous" word or a combination of barbarous and classic, such as *Lambeosaurus,* from *Lambe* = Lawrence Lambe, a Canadian paleontologist, and *sauros* = lizard.

The trivial name, like the generic name, may be classic or barbarous. It may be an adjective, agreeing with the generic name grammatically, it may be a substantive in the nominative standing in apposition with the generic name, or it may be a substantive in the genitive, in which case it usually expresses a locality from which the species was first described, or some person in whose honor it is named.

For instance, as an example of the adjectival specific name, there is *Camerasaurus supremus:*

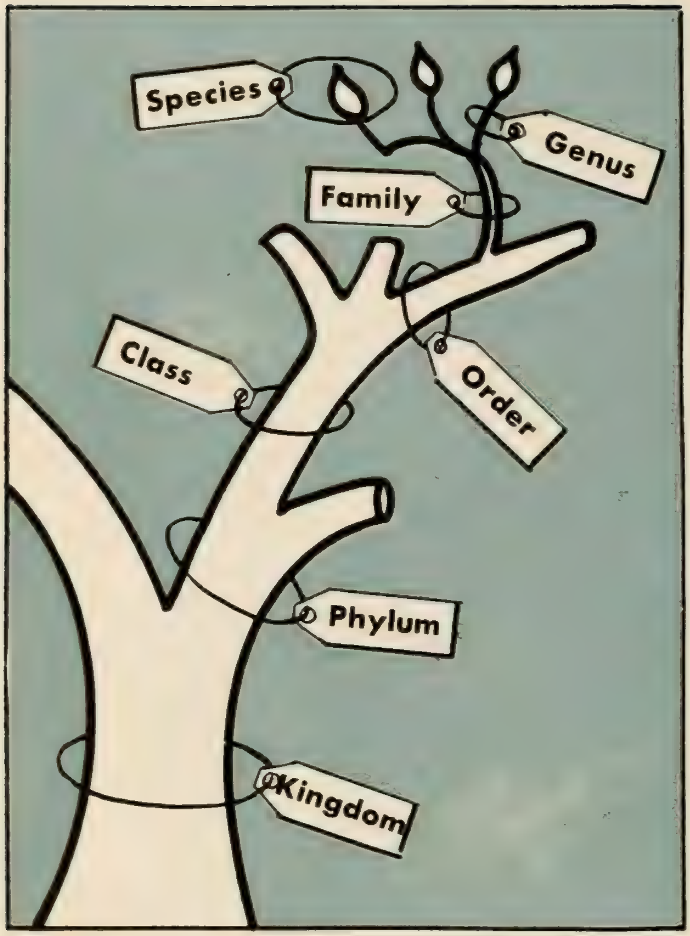
Camera = a chamber, *sauros* = lizard, *supremus* = highest. "Supreme chambered reptile" (in allusion to the structure of the vertebrae).

An example of a substantive in apposition would be *Tyrannosaurus rex: Tyrannos* = tyrant, *sauros* = lizard, *rex* = king. "King of the tyrant dinosaurs."

An example of a substantive in the genitive, formed in this case by adding "i" to a proper name would be *Ornitholestes hermanni: Ornithos* = bird, *lestes* = robber, *hermanni* = A. Hermann, a famous paleontological preparator. "Bird robber (dinosaur) in honor of Adam Hermann."

Perhaps this may serve to give some idea of the manner in which zoological names are composed. Perhaps it is all very confusing, and the reader is certain to become completely enraged when he learns that some whopping big animal is named *parvus* = small, or some small animal is named *grandis* = big, owing to original misconceptions on the part of the person who first described the beasts.

Moreover, some of the authors who have christened strange, new beasts, have, like Shakespeare, known "little Latin and less Greek," so that the names coming from their non-classic pens have been in some cases etymological monstrosities. And in addition, some authors who should know better have at times been just plain careless. The result is that try as we may, names sometimes don't work out very well in translation, nor do they always make much sense. But according to the rules, once a name is given it must stand, no matter how inappropriate it may be, otherwise there would be a complete lack of permanence. The important thing to remember is that the name is a name, a tag to identify the animal, and not a description.



The system under which all animals and plants are classified

PHYLUM	SUPERCLASS	CLASS
CHORDATA	PISCES	AGNATHA (Jawless vertebrates)
		PLACODERMI (Certain primitive "fishes")
		CHONDRICHTHYES (The sharks)
		OSTEICHTHYES (The bony fishes)
	TETRAPODA	AMPHIBIA (The amphibians)
		REPTILIA (The reptiles)
		AVES (The birds)
		MAMMALIA (The mammals)

The classification of animals and plants, taken as a whole, involves more than just the binomial designations of *genera* and *species*. It is extended to include increasingly comprehensive categories; thus genera are combined into *families*, families are grouped into *orders*, orders are combined into the higher category of *classes*, while various classes make up *phyla*. The arrangement may be expressed, from the higher to the lower categories (or to put it another way, from the greater to the lesser divisions) as follows:

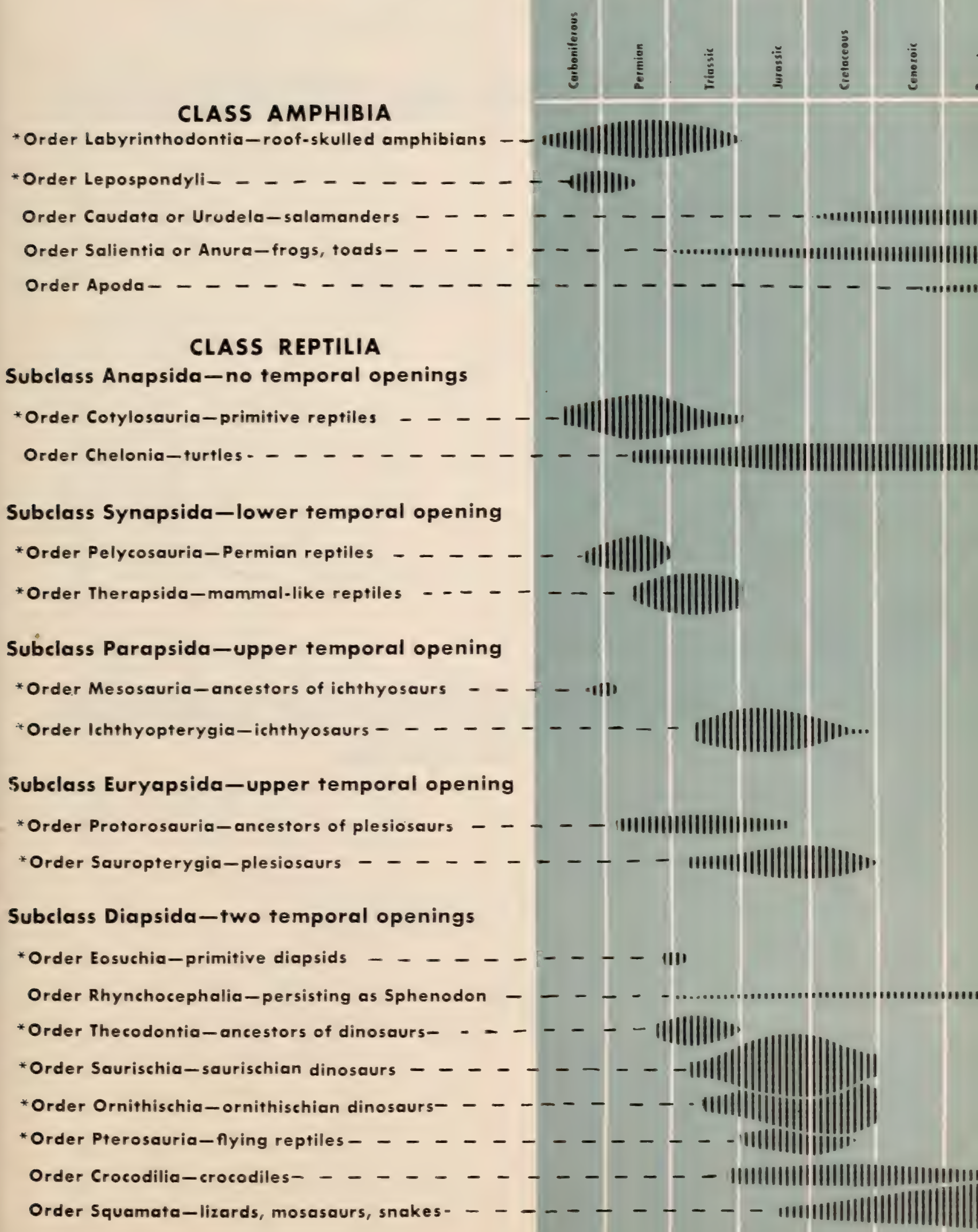
Suppose we wish to express the position of a modern reptile, the rattlesnake, by the system of Linnaean Nomenclature.

Kingdom—Animal (animals as opposed to plants)
Phylum—Chordata (animals with backbones)
Class—Reptilia (the reptiles)
Order—Squamata (the lizards, snakes, and their relatives)
Family—Crotalidae (the pit vipers)
Genus—*Crotalus* (rattlesnakes)
Species—*adamanteus* (the diamond-back rattler)

The great primary divisions of the animal kingdom are the phyla. For instance there is a Phylum Protozoa for all single-celled animals, so many of which are unpleasantly known to us as diseases. Then there is a Phylum Porifera for the sponges, a Phylum Coelenterata for the corals, a Phylum Arthropoda for the insects, spiders, and crustaceans, and so on. All the animals with backbones are contained within a single phylum, known as the Vertebrata or Chordata. This phylum may be subdivided as shown opposite.

Two classes, Amphibia and Reptilia, especially concern us in this present work.

The Main Groups of Amphibians and Reptiles, and Their Span in Geologic History



*—Extinct

SYNOPTIC TABLE OF THE AMPHIBIA AND REPTILIA, INCLUDING THE GENERA MENTIONED IN THIS BOOK

Class Amphibia

ORDER LABYRINTHODONTIA
(The dominant amphibians of late Paleozoic and early Mesozoic times. Devonian-Triassic.)

Suborder Ichthyostegalia
(The first labyrinthodonts. Devonian-Pennsylvanian; North America, Europe.)

Genus *Ichthyostega*
(Devonian; Greenland)

Suborder Rhachitomi
(The culmination of labyrinthodont development. Pennsylvanian-Permian; Europe, North America.)

Genus *Eryops*
(Permian; North America.)

Suborder Stereospondyli
("Degenerate" labyrinthodonts. Triassic; Europe, North America, Asia, Africa, Australia.)

Genus *Buettneria*
(Triassic; North America.)

Suborder Embolomeri
(Early labyrinthodonts. Devonian-Permian; Europe, North America.)

Genus *Diplovertebron*
(Pennsylvanian; Europe.)

ORDER SALIENTIA (ANURA)
(The frogs and toads. Triassic-Recent; Europe, North America, Asia, Africa, South America, Australia.)

ORDER LEPOSPONDYLI
(A group of early amphibians. Pennsylvanian-Permian; Europe, North America.)

Genus *Diplocaulus*
(Permian; North America.)

ORDER CAUDATA (URODELA)
(The salamanders. Cenozoic-Recent; Europe, North America, Asia, Africa, South America, Australia.)

ORDER GYMNOPHIONA
(Tropical legless amphibians. Recent; Asia, Africa, South America.)

Class Reptilia

Subclass Anapsida

ORDER COTYLOSAURIA
(Primitive reptiles. Pennsylvanian-Triassic; Europe, North America, Africa.)

Suborder Seymouriamorpha
(The first reptiles. Pennsylvanian-Permian; Europe, North America.)

Genus *Seymouria*
(Permian; North America.)

Suborder Captorhinomorpha
(Small primitive reptiles. Permian; North America.)

Genus *Labidosaurus*
(Permian; North America.)

Suborder Diadectomorpha
(Primitive reptiles. Pennsylvanian-Triassic; Europe, North America, Africa.)

Genus *Diadectes*
(Permian; North America.)

Genus *Pariasaurus*
(Permian; Africa.)

Genus *Scutosaurus*
(Permian; Europe.)

Genus *Procolophon*
(Triassic; Africa)

Genus *Hypsognathus*
(Triassic; North America.)

ORDER CHELONIA

(Turtles. Permian-Recent; Europe, North America, Asia, Africa, South America, Australia.)

Suborder Eunotosauria

(Turtle ancestors. Permian; Africa.)

Genus *Eunotosaurus*

(Permian; Africa.)

Suborder Amphichelydia

(Primitive turtles. Triassic-Eocene; Europe, North America.)

Genus *Triassochelys*

(Triassic; Europe.)

Suborder Pleurodira

(Side-neck turtles. Cretaceous-Recent; Europe, North America, Asia, South America, Australia.)

Suborder Cryptodira

(Vertical-neck turtles. Cretaceous-Recent; Europe, North America, Asia, Africa, South America.)

Subclass Synapsida

ORDER PELYCOSAURIA

(Aberrant mammal-like reptiles. Pennsylvanian-Permian; Europe, North America.)

Suborder Ophiacodontia

(Primitive types. Pennsylvanian-Permian; North America, Europe.)

Genus *Varanosaurus*

(Permian; North America.)

Genus *Ophiacodon*

(Permian; North America.)

Suborder Sphenacodontia

(Carnivorous forms. Permian; North America, Europe, Africa.)

Genus *Dimetrodon*

(Permian; North America.)

Suborder Edaphosauria

(Specialized types. Pennsylvanian-Permian; North America, Europe, Africa.)

Genus *Edaphosaurus*

(Permian; North America.)

ORDER THERAPSIDA

(Mammal-like reptiles. Permian-Triassic; Europe, North America, Asia, Africa, South America.)

Suborder Dinocephalia

(Large, heavy-headed forms. Permian; Europe, Africa.)

Genus *Moschops*

(Permian; Africa.)

Genus *Titanosuchus*

(Permian; Africa.)

Suborder Dicynodontia

(Tusked forms. Permian-Triassic; Europe, North America, Asia, Africa, South America.)

Genus *Dicynodon*

(Permian; Europe, Africa.)

Genus *Stahlekeria*

(Triassic; South America.)

Suborder Theriodontia

(True mammal-like reptiles. Permian-Triassic; Europe, Africa.)

Genus *Bauria*

(Triassic; Africa.)

Genus *Cynognathus*

(Triassic; Africa.)

ORDER ICTIDOSAURIA

(Transitional to mammals. Triassic; Africa, Asia, Europe.)

Subclass Parapsida

ORDER MESOSAURIA

(Early aquatic reptiles. Pennsylvanian; Africa, South America.)

Genus *Mesosaurus*

(Pennsylvanian; Africa.)

ORDER ICHTHYOSAURIA

(Fishlike reptiles. Triassic-Cretaceous; Europe, North America, Asia, South America, Australia.)

Genus *Ichthyosaurus*

(Jurassic; Europe.)

Subclass Euryapsida

ORDER PROTOROSAURIA

(Permian-Jurassic; Ancestral types. Europe, North America, Africa.)

Genus *Aracoscelis*

(Permian; North America.)

Genus *Protorosaurus*

(Permian; Europe.)

ORDER SAUROPTERYGIA

(Aquatic paddlers. Triassic-Cretaceous; Europe, North America, Asia, Australia.)

Suborder Nothosauria

(Strand dwellers. Triassic; Europe.)

Genus *Nothosaurus*

(Triassic; Europe.)

Suborder Plesiosauria

(Open-sea paddlers. Triassic-Cretaceous; Europe, North America, Asia, Australia.)

Genus *Plesiosaurus*

(Jurassic; Europe.)

Genus *Elasmosaurus*

(Cretaceous; North America.)

Suborder Placodontia

(Shallow-water paddlers. Triassic; Europe.)

Genus *Placodus*

(Triassic; Europe.)

Genus *Placochelys*

(Triassic; Europe.)

Subclass Diapsida

ORDER EOSUCHIA

(Primitive diapsids. Permian-Jurassic; Europe, North America, Africa.)

Genus *Youngina*

(Permian; Africa.)

Genus *Youngoides*

(Permian; Africa)

Genus *Champsosaurus*

(Cretaceous-Eocene; North America.)

ORDER RHYNCHOCEPHALIA

(Small, persisting diapsids. Triassic-Recent; Europe, North America, Asia, Africa, South America, New Zealand.)

Genus *Sphenodon*

(Recent; New Zealand.)

ORDER THECODONTIA

(Stem diapsids. Triassic; Europe, North America, Asia, Africa.)

Suborder Pseudosuchia

(Ancestral bipedal thecodonts. Triassic; Europe, North America, Africa.)

Genus *Euparkeria*

(Triassic; Africa.)

Genus *Ornithosuchus*

(Triassic; Europe.)

Genus *Saltoposuchus*

(Triassic; Europe.)

Suborder Phytosauria

(Quadrupedal crocodile-like thecodonts. Triassic; Europe, North America, Asia, Africa.)

Genus *Machaeroprosopus*

(Triassic; North America.)

Genus *Clepsysaurus*

(Triassic; North America.)

Genus *Rutiodon*

(Triassic; North America.)

ORDER SAURISCHIA

(Dinosaurs. Triassic-Cretaceous; Europe, North America, Asia, Africa, South America, Australia.)

Suborder Theropoda

(Bipedal, carnivorous dinosaurs. Triassic-Cretaceous; Europe, North America, Asia, Africa, South America, Australia.)

Genus *Ornitholestes*

(Jurassic; North America.)

Genus *Struthiomimus*

(Cretaceous; North America.)

Genus *Allosaurus*

(Jurassic; North America.)

Genus *Gorgosaurus*

(Cretaceous; North America.)

Genus *Tyrannosaurus*
(Cretaceous; North America.)

Suborder Sauropoda
(Giant quadrupedal herbivores. Triassic-Cretaceous; Europe, North America, Asia, Africa, South America, Australia.)

Genus *Plateosaurus*
(Triassic; Europe, Asia.)

Genus *Brontosaurus*
(Jurassic; North America.)

Genus *Camarasaurus*
(Jurassic; North America.)

Genus *Diplodocus*
(Jurassic; North America.)

Genus *Cetiosaurus*
(Jurassic; Europe.)

Genus *Brachiosaurus*
(Jurassic; North America, Africa.)

ORDER ORNITHISCHIA
(Dinosaurs. Jurassic-Cretaceous; Europe, North America, Asia, Africa, South America.)

Suborder Ornithopoda
(Duck-billed dinosaurs. Jurassic-Cretaceous; Europe, North America, Asia, Africa, South America.)

Genus *Hypsilophodon*
(Jurassic; Europe.)

Genus *Camptosaurus*
(Jurassic-Cretaceous; North America.)

Genus *Iguanodon*
(Cretaceous; Europe.)

Genus *Hadrosaurus* or *Trachodon*
(Cretaceous; North America.)

Genus *Kritosaurus*
(Cretaceous; North America.)

Genus *Corythosaurus*
(Cretaceous; North America.)

Genus *Lambeosaurus*
(Cretaceous; North America.)

Genus *Parasaurolophus*
(Cretaceous; North America.)

Genus *Troödon*
(Cretaceous; North America.)

Genus *Pachycephalosaurus*
(Cretaceous; North America.)

Suborder Stegosauria
(Armored dinosaurs. Jurassic; Europe, North America, Africa.)

Genus *Stegosaurus*
(Jurassic; North America.)

Suborder Ankylosauria
(Armored dinosaurs. Cretaceous; Europe, North America, South America, Asia.)

Genus *Ankylosaurus*
(Cretaceous; North America.)

Genus *Palaeoscincus*
(Cretaceous; North America.)

Genus *Nodosaurus*
(Cretaceous; North America.)

Suborder Ceratopsia
(Horned dinosaurs. Cretaceous; Asia, North America.)

Genus *Psittacosaurus*
(Cretaceous; Asia.)

Genus *Protoceratops*
(Cretaceous; Asia.)

Genus *Chasmosaurus*
(Cretaceous; North America.)

Genus *Monoclonius*
(Cretaceous; North America.)

Genus *Styracosaurus*
(Cretaceous; North America.)

Genus *Triceratops*
(Cretaceous; North America.)

ORDER PTEROSAURIA
(Flying reptiles. Jurassic-Cretaceous; Europe, North America, Africa.)

Suborder Rhamphorhynchoidea
(Long tails. Jurassic; Europe.)

Genus *Rhamphorhynchus*
(Jurassic; Europe.)

Suborder Pterodactyloidea
(Short tails. Jurassic-Cretaceous; Europe, North America, Africa.)

Genus *Pteranodon*
(Cretaceous; North America.)

ORDER CROCODILIA
(Crocodiles. Triassic-Recent; Europe, North America, Asia, Africa, South America, Australia.)

Suborder Protosuchia
(Ancestral crocodiles. Triassic; North America, Africa.)

Genus *Protosuchus*
(Triassic; North America.)

Suborder Mesosuchia
(Mesozoic crocodiles. Jurassic-Cretaceous; Europe, North America, Africa, South America.)

Genus *Teleosaurus*
(Jurassic; Europe.)

Suborder Thalattosuchia

(Marine crocodiles. Jurassic; Europe, North America, South America.)

Genus *Geosaurus*

(Jurassic; Europe.)

Genus *Metriorhynchus*

(Jurassic; Europe.)

Suborder Eusuchia

(Modern crocodiles. Cretaceous-Recent; Europe, North America, Asia, Africa, South America, Australia.)

Genus *Phobosuchus*

(Cretaceous; North America.)

Genus *Crocodilus*

(Cenozoic-Recent; Europe, Asia, Africa.)

Genus *Gavialis*

(Cenozoic-Recent; Asia.)

Genus *Alligator*

(Cenozoic-Recent; Asia, North America.)

ORDER SQUAMATA

(Lizards and snakes. Cretaceous-Recent; Europe, North America, Asia, Africa, South America, Australia.)

Suborder Lacertilia

(Lizards. Cretaceous-Recent; Europe, North America, Asia, Africa, South America, Australia.)

Genus *Varanus*

(Cenozoic-Recent; Asia.)

Genus *Mosasaurus*

(Cretaceous; Europe.)

Genus *Tylosaurus*

(Cretaceous; North America.)

Suborder Ophidia

(Snakes. Cretaceous-Recent; Europe, North America, Asia, Africa, South America, Australia.)

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Other Sources of Information

THE LITERATURE on the subject of fossil amphibians and reptiles is considerable and is confined for the most part to technical papers and monographs published in numerous scientific journals throughout the world. To make a list of only the most "important" of the technical papers on the subject would be to append a bibliography of such length onto this little book as to give the reader visions of libraries, catalogues, and stacks without end. Therefore only a selected list of general or comprehensive works will be given for the reader who is interested in going further into this subject of ancient tetrapods. In this connection, several excellent bibliographies on fossil vertebrates—mostly by American authors—have been or are in the process of being published. With these at hand, it is possible to find virtually every paper that has ever been published on the subject of vertebrate paleontology.

General Works

GILMORE, CHARLES W. In *Cold Blooded Vertebrates.* Part II, Chapter I, pages 161-172 (fossil amphibians); Part III, Chapters I-VI, pages 211-290 (fossil reptiles, particularly dinosaurs, swimming and flying reptiles.) Smithsonian Scientific Series, Volume 8. Smithsonian Institution Series, Inc. New York, 1930.

A comprehensive and very readable account by an outstanding authority.

HUTCHINSON, H. N. *Extinct Monsters and Creatures of Other Days.* London: Chapman and Hall, 1910.

An account mainly of reptilian and mammalian evolution. Some of the figures are out of date.

LUCAS, FREDERIC A. *Animals of the Past.* American Museum Handbook Series, No. 4, 7th Edition, 3rd Printing, 1929.

A deservedly popular book. It deals with selected forms of extinct vertebrates and does not pretend to be comprehensive.

LULL, RICHARD SWANN. *Organic Evolution.* Second Edition. New York: Macmillan, 1929.

A textbook on adaptation in the animal kingdom. Portions of it are concerned with certain evolutionary lines among the reptiles.

MARSH, O. C. *The Dinosaurs of North America.* Sixteenth Annual Report, U. S. Geological Survey, 1896. Pp. 133-244, 84 plates.

A valuable work, even though somewhat out of date.

MATTHEW, W. D. *Dinosaurs.* American Museum Handbook Series, No. 5, 1915.

An excellent succinct book on the dinosaurs. Out of print and difficult to obtain.

MATTHEW, W. D. *Outline and General Principles of the History of Life.* Synopsis of Lectures in Paleontology 1. University of California Syllabus Series, Syllabus No. 213. 1928.

A short general textbook of paleontology by a great authority. Parts of it are concerned with amphibian and reptilian evolution.

OWEN, RICHARD. *A History of British Fossil Reptilia.* Reprinted from publications of the Palaeontographical Society, London. 1849-1884.

Romer, Alfred S. *Vertebrate Paleontology.* Second Edition. Chicago: University of Chicago Press, 1945.

The most comprehensive modern textbook on the subject. A "must" item for all serious students.

Romer, Alfred S. *Man and the Vertebrates.* Third Edition. Chicago: University of Chicago Press, 1941.

An excellent semi-popular book, of which only a part deals with fossil amphibians and reptiles.

Swinton, W. E. *The Dinosaurs.* London: Thomas Murby and Company, 1934.

The most recent general text devoted exclusively to dinosaurs. Important.

Watson, D. M. S. Article "Reptiles" in the Encyclopaedia Britannica, 14th Edition, Vol. 19, 1928. Pp. 180-200.

A concise account with emphasis upon the fossils.

Williston, S. W. *American Permian Vertebrates.* Chicago: University of Chicago Press, 1911.

Williston, S. W. *Water Reptiles of the Past and Present.* Chicago: University of Chicago Press, 1914.

Williston, S. W. *The Osteology of the Reptiles.* (Edited by W. K. Gregory) Cambridge: Harvard University Press, 1925.

Especially valuable for the student of fossil reptiles.

von Zittel, Karl A. *Text-Book of Palaeontology.* Vol. II. Second English edition, revised by A. S. Woodward from the translation by Charles R. Eastman. London: Macmillan and Company, 1932.

The standard reference book on fossils. Volume II deals with fishes, amphibians, reptiles, and birds.

Bibliographies

Nopcsa, F. *Osteologia reptilium fossilium et recentium.* Fossilium catalogus, Pars 27. Berlin. 1926. "Supplement" *ibid.* Pars 50. 1931.

Lists to that date almost every paper of importance on fossil amphibians and reptiles.

Hay, O. P. *Bibliography and Catalogue of the Fossil Vertebrates of North America.* Bulletin U. S. Geological Survey, 179. 1902. *Second Bibliography and Catalogue of the Fossil Vertebrata of North America.* Carnegie Institution of Washington, Publication No. 390, Vol. I. 1929. *Idem,* Vol. II. 1930.

These publications furnish a complete bibliography of all literature on North American fossil vertebrates from the beginnings of the science on this continent to the year 1928.

Camp, C. L. and V. L. VanderHoof. *Bibliography of Fossil Vertebrates.* 1928-1933. Geological Society of America, Special Papers, No. 27. 1940

Camp, C. L., D. N. Taylor, and S. P. Welles. *Bibliography of Fossil Vertebrates 1934-1938.* Geological Society of America, Special Papers, No. 42. 1942.

These two papers carry on where Hay left off, and in addition list all of the literature for the rest of the world during the years indicated. The series is to be continued.

Camp, C. L., S. P. Welles, and Morton Green. *Bibliography of Fossil Vertebrates* 1939-1943. Geological Society of America, Memoir 37, 1949.

Romer, Alfred S., Nelda Wright, and Tilly Edinger. A bibliography is now in preparation which will deal with all of the literature on fossil vertebrates outside of North America prior to the year 1928. It will be published by the Geological Society of America.

Index, Glossary, and Guide to Pronunciation

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