DINOSAURS, SPITFIRES, & SEA DRAGONS

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DINOSAURS,
SPITFIRES, and
SEA DRAGONS

Contents

Acknowledgments *ix*

Prologue *1*

1 Material Things *8*

2 Primary Data *22*

3 How the Vertebrate Skeleton Works *40*

4 Reading a Dinosaur Skeleton *53*

5 A Matter of Scale *91*

6 What's Hot and What's Not *129*

7 Brains and Intellect *168*

8 Not Wholly a Fish *185*

9 The Mechanics of Swimming *200*

10 The Sea Dragons *219*

11 The Winged Phantom *257*

12 Out with a Whimper or a Bang? *291*

Epilogue *312*

Notes *321*

References *329*

Credits *351*

Index *355*

Prologue

EIGHT is a golden age. An age of make-believe and wonder. Our Camelot days. Little wonder that eight-year-olds are so enthralled by dinosaurs. They know their names, collect their pictures, and plan dinosaur projects at school. But as they grow older and become wiser to the ways of the world, other interests compete for their attention. They outgrow the dinosaur phase.

Sometimes the muse returns. If the current flood of magazine articles and television specials on dinosaurs is any indicator, she has been unusually busy lately. Not only have dinosaurs become news on the popular front but there has also been a veritable explosion of interest within paleontological circles. When I attended my first meeting of the Society of Vertebrate Paleontology in 1969, the number of North American scientists working on dinosaurs and other Mesozoic reptiles could have been counted on one hand. Now it seems that everyone is working on them—almost a quarter of the two hundred papers presented at the 1989 meeting were on Mesozoic reptiles.

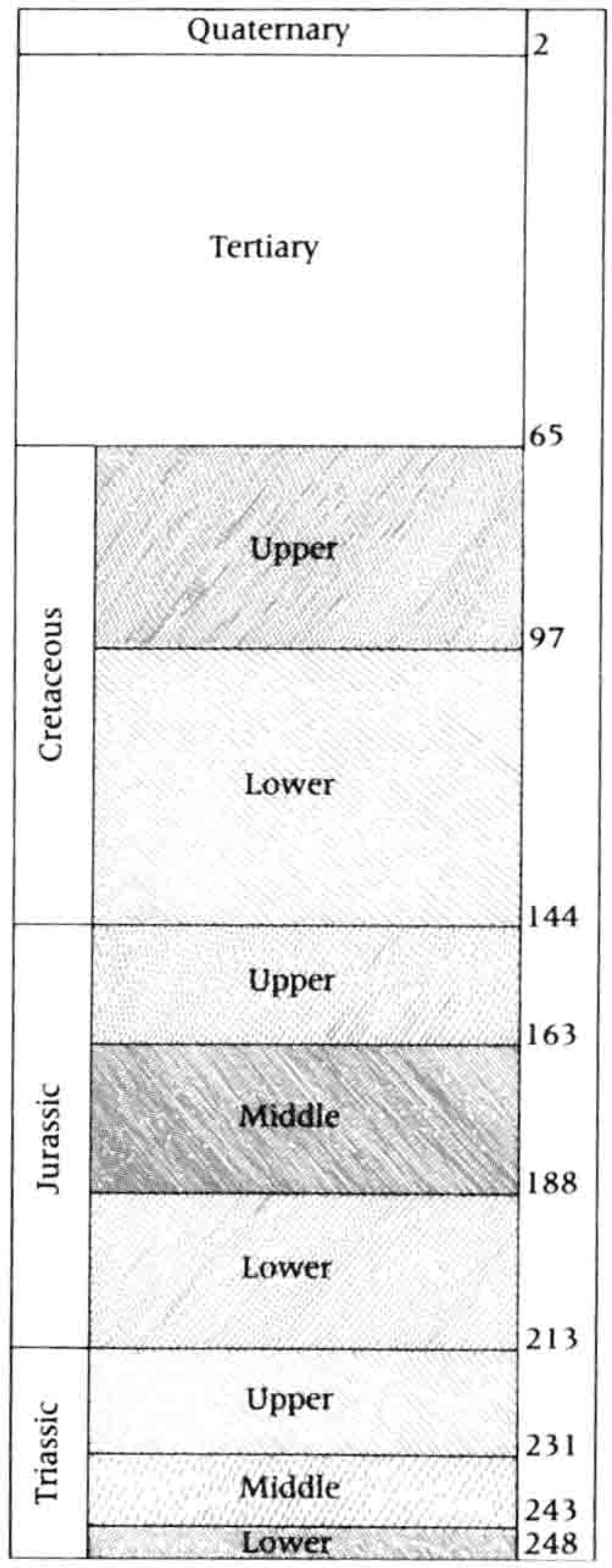
Peter Dodson, a dinosaur specialist himself, estimates that about 40 percent of all the known dinosaurs have been discovered during the last twenty years or so. This statistic is all the more remarkable when it is remembered that the first dinosaur was discovered in the early 1820s. Part of the reason for the rebirth of interest is attributable to renewed collecting activities—primarily in Mongolia, China, Alberta, the western United States, and Argentina and Brazil. Discussions of warm-bloodedness, parental care, and extinction have sparked considerable interest, but some of the accounts have been misleadingly speculative. People often ask me at the Royal Ontario Museum how we know the color of dinosaurs, what sounds they made, how fast they ran, how long they lived, and so forth. When I reply that we simply do not know these things, I sometimes get some odd looks. Surely we know . . . some paleontologist said so on the television . . . I read it in a dinosaur book . . . there was this article in a science magazine.

The point I always make is that we do not know everything about living animals, so how can we possibly know so much about animals that disappeared over sixty million years ago? How can we have a complete picture of creatures that left little more than their bones behind? Questions about how fast zebras run, how much elephants weigh, and for how long crocodiles live may sound simple enough, but when we try looking for answers we are often surprised at how few pieces of data are available. Zebras are remarkably uncooperative at running in straight lines for biologists to clock their speeds, and crocodiles are no more conscientious when it comes to keeping family records! Our knowledge of the living world is built on shaky foundations, so why should we be so ready to build dinosaurian sand castles in the air?

All we have are bones, but we usually don't have *all* the bones. When people see a particular dinosaur—say the genus *Diplodocus* or *Tyrannosaurus*—in a museum, they may get the impression that they are seeing a complete skeleton, with many more like it in other museums. Sometimes this is true, but more often than not they are looking at a plaster cast of an original skeleton or at an incomplete skeleton that has been largely restored in plaster. According to Dodson, almost half of the 540 genera of dinosaurs are represented by single specimens and very few specimens comprise complete skeletons.

Firm in the conviction that we can begin to understand extinct animals only by understanding living ones, I have chosen to present my interpretations of Mesozoic life by drawing analogies with relevant examples from the living world. This explains why so much space has been devoted to modern animals. I must also serve warning that I stand at the conservative end of a broad spectrum of opinion on how much can be said of life in the past. The words *may, perhaps,* and *possibly* therefore appear frequently, as I make every attempt to avoid straying beyond the data, but this does not mean that we will not take off on some flights of fancy together, nor avoid having some fun.

The Mesozoic Era, which began about 245 million years ago and ended 65 million years before the present, is often referred to as the Age of Reptiles because they were the predominant land animals. That is not to say that the other major groups of vertebrates were not present at the time. The fishes and amphibians had appeared long before the first dinosaurs, the mammals only a little later; the birds did not appear on the scene until about the middle of the era. Reptiles roamed the land, swam in the sea, and flew in the air. Judged in terms of their diversity, their numbers, and their long tenure on the Earth—over 150 million years—they were a phenomenal success. Modern reptiles—the crocodiles, turtles, lizards, snakes, and *Sphenodon* (sole representative of an ancient group related to lizards)—though successful in their own right, pale into insignificance when compared with reptiles of that former age. Why were the Mesozoic reptiles so successful? Was there anything special about them? The answer to the last question is probably no. The reptiles probably just happened to be at the right place at the right time. Today, it seems to be the turn of man, and tomorrow . . . who knows?



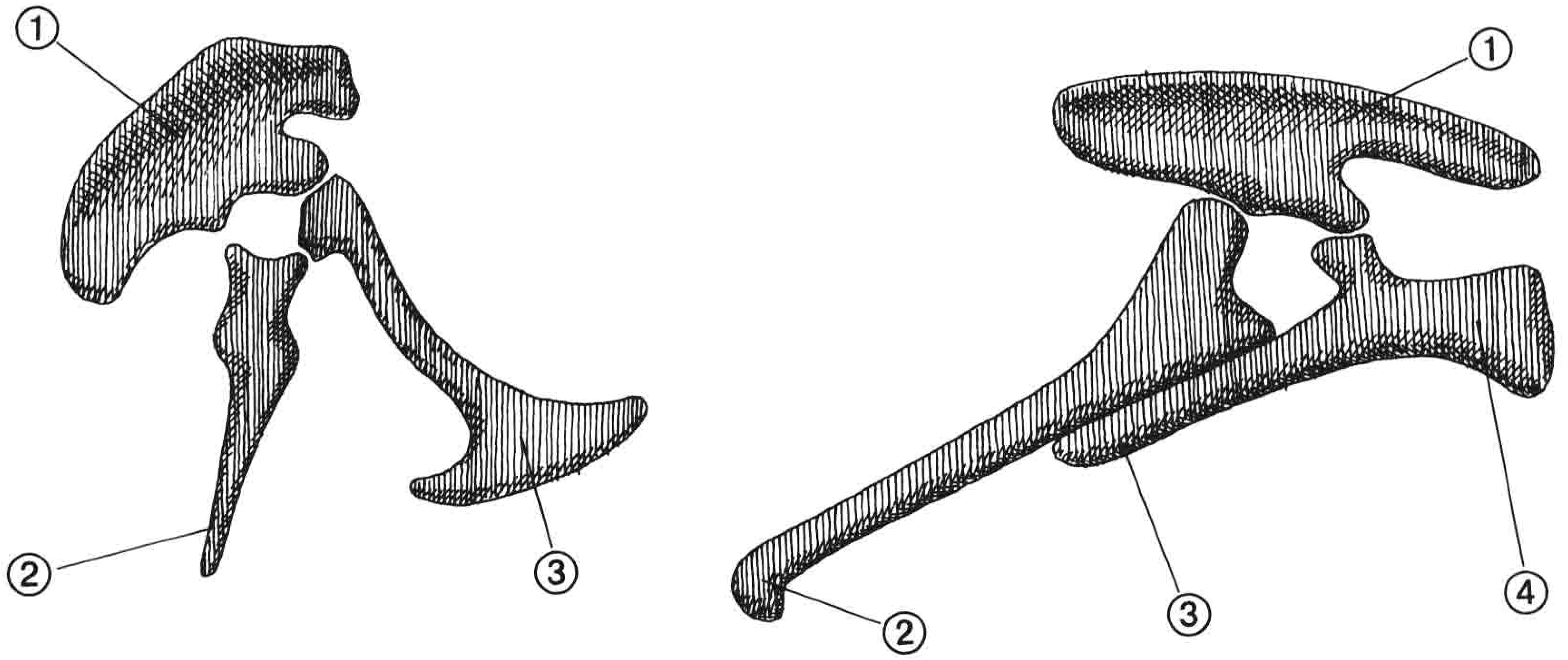
The geological time scale, measured in million years before the present, for the Mesozoic Era—the Age of Reptiles. (Based upon data from Harland et al., 1982.)

Mesozoic reptiles faced similar problems in their world that modern animals face today, and they often resolved them in similar ways. Some of their solutions were unique, though, which is one of the reasons why they are such a fascinating group to study. Little wonder that so many books have been written about them. The purpose of this book is to explore how Mesozoic reptiles lived and functioned and, in so doing, to gain some insights into the underlying reasons of their success. Extinct animals, like living ones, are dominated and constrained by the same physical laws that govern the rest of the world. The same forces that determined the shape of the wing of a Spitfire, or the I-beam used in construction, were operational during the evolution of the pterosaur wing and the bones of sauropods. We can therefore gain insights into the functional significance of biological structures by drawing from the world of the engineer. This not only gives us a better understanding of the mechanics of animals, but also of the properties of the materials from which they are constructed. We will therefore try to view our subjects with the eyes of an engineer. But our knowledge of Mesozoic reptiles is only as good as the fossils upon which they are based. The fossil record, we shall see, has certain pitfalls and shortcomings, and we have to be constantly aware of these in the interpretations we make. No attempt will be made at a comprehensive treatment of all the reptiles of that time—that would require several books. Instead attention will be focused on selected groups and on topics of particular interest. Sauropod ("lizard-footed") dinosaurs, for example, will be used to illustrate the problems of being a giant, and a wide range of Mesozoic reptiles will be used to discuss the great reptilian extinction that occurred at the close of the Cretaceous.

The biological phenomena we encounter will be interpreted within the framework of Darwinian evolution, the unifying concept of the biological sciences. It is true that biologists may disagree on certain aspects of the mechanisms of evolution, and that we are revising our ideas on such problems as the evolution of higher taxa (macroevolution) and the role of natural selection ("survival of the fittest") on large-scale evolutionary change, but few would doubt that evolution has occurred and continues to occur. According to the theory of evolution, organisms that are alive today are similar to, but not identical with, organisms that once lived on the Earth. Today's plants and animals are the modified descendants of organisms that once inhabited the world. The modern horse, for example, evolved from a smaller, horse-like animal that had three toes instead of the single toe that characterizes living horses.

Darwin's theory of evolution by means of natural selection provided a mechanism to explain how evolution may have taken place. His theory is elegant in its simplicity. Offspring are similar to, but not identical with, their parents. Therefore no two individuals are exactly alike. Each species produces far more offspring than can possibly survive and, as the offspring are not exactly alike, it follows that some individuals will have features that give them an advantage over others. These advantages, however slight, give the individual a better chance of surviving. Because advantaged individuals have a better chance of survival, they tend to leave more offspring and, since these offspring inherit some of their parents' favorable features, they too tend to have improved chances of survival. The action of natural selection, operating over long periods of time, would therefore bring about a modification of the species, eventually leading to the appearance of a new species. When we talk of advantageous features, we mean features that are advantageous to an individual in the environment in which it must live. For dinosaurs, this was the Mesozoic world.

The early part of the Mesozoic Era was a subtropical world, dominated by evergreens—pines, firs, and other needle-bearing plants. Ferns were abundant, some of them growing as tall as trees. So, too, were cycads, which looked like palm trees with stunted trunks. There were no grasses, shrubs, or other flowering

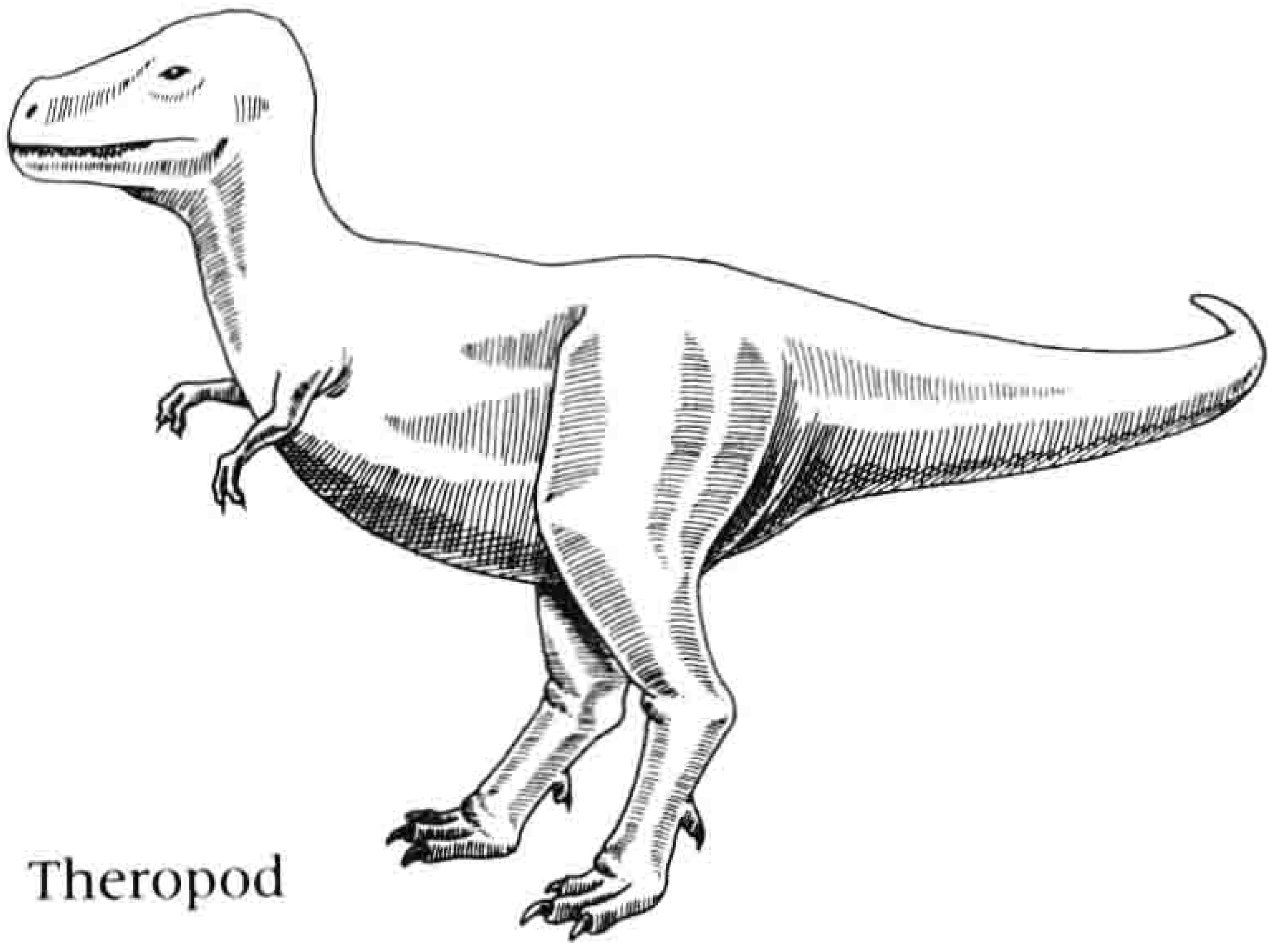


The two major groups of dinosaurs, the Saurischia and Ornithischia, are primarily distinguished on their pelvic girdles. Left, *the saurischians have a simple, three-pronged pelvis comprised of three paired bones. Dorsally (above) there is the ilium (1), which is attached to the vertebral column, and ventrally (below) there is the pubis (3), which is anterior (in front), and the ischium (2), which is posterior (behind).* Right, *the ornithischian pelvis is more complex in that the pubis (3) is directed posteriorly, alongside the ischium (2), and there is an additional anterior process, called the prepubis (4). The ornithischian pelvis is therefore a four-pronged rather than a three-pronged structure.*

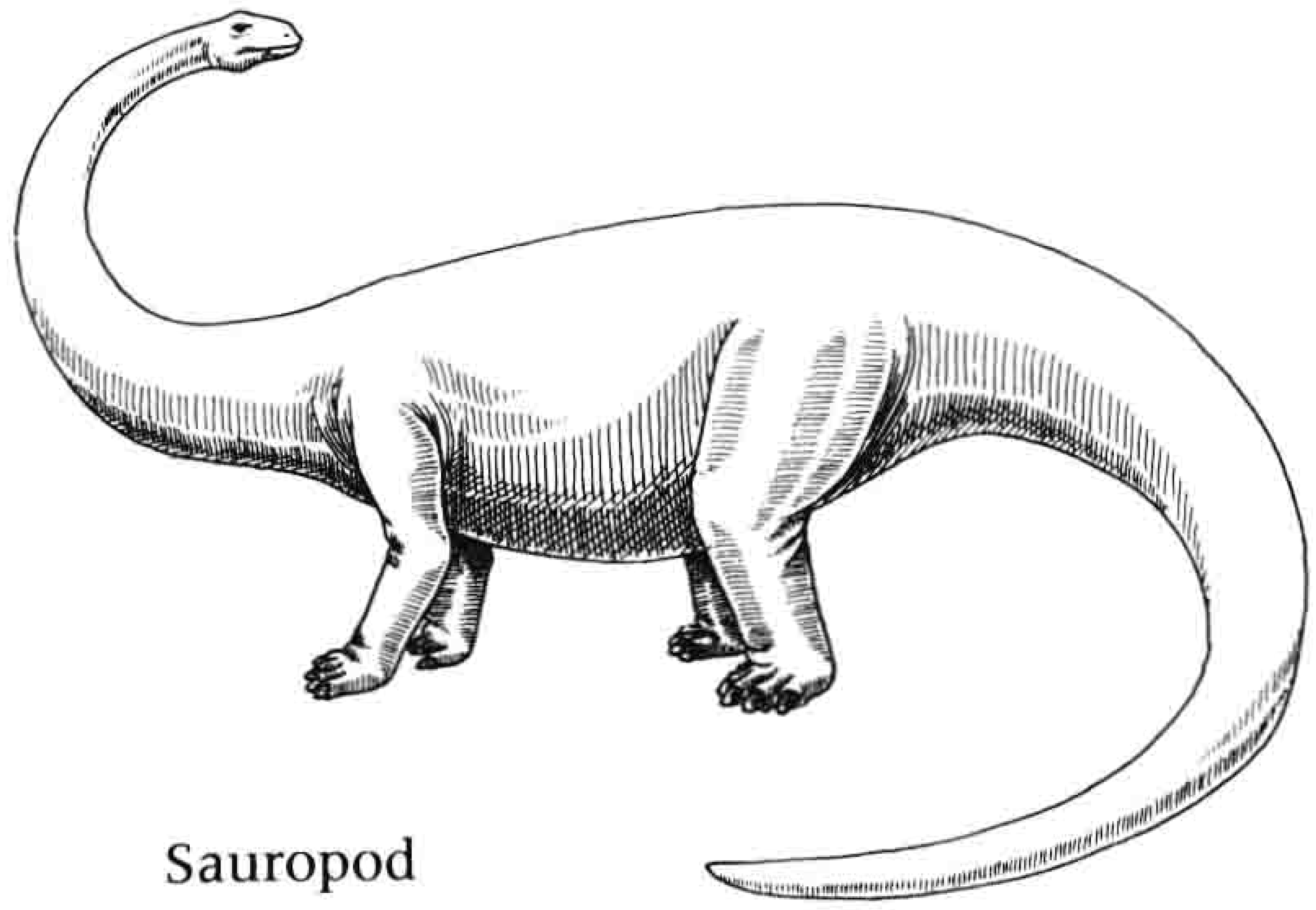
plants, and ground cover was provided by various types of mosses and by horsetails (*Equisetum*). A flora somewhat similar to this may be seen today in New Zealand, New Guinea, Central and South America, and the Caribbean. It was not until Cretaceous times that flowering plants appeared, giving the landscape an appearance like that of the Gulf coast of North America today.

Some of the major groups of reptiles that lived during the Mesozoic Era, and which appear later in the book, are depicted on pages 6 and 7. There are two major groups of dinosaurs, the Saurischia ("lizard-hipped") and the Ornithischia ("bird-hipped"). The appropriate scheme to be used for the classification of the dinosaurs is a subject of considerable debate among specialists and one which is undergoing rapid change. In the interest of simplicity, the conservative system adopted by Carroll (1988) will be followed here.

Many other reptilian groups shared the Mesozoic world with the dinosaurs, but we will be concerned with only two of these: the pterosaurs ("winged lizards") and the ichthyosaurs ("fish liz-

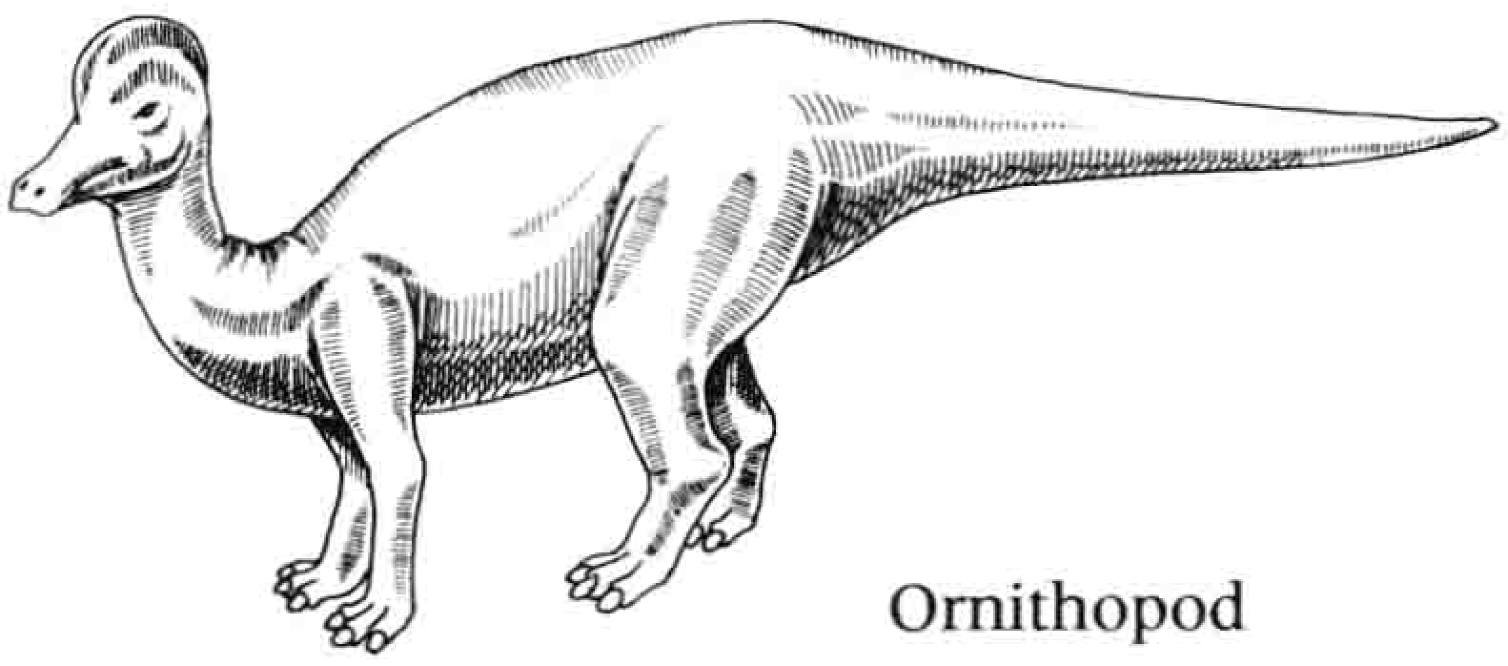


Theropod

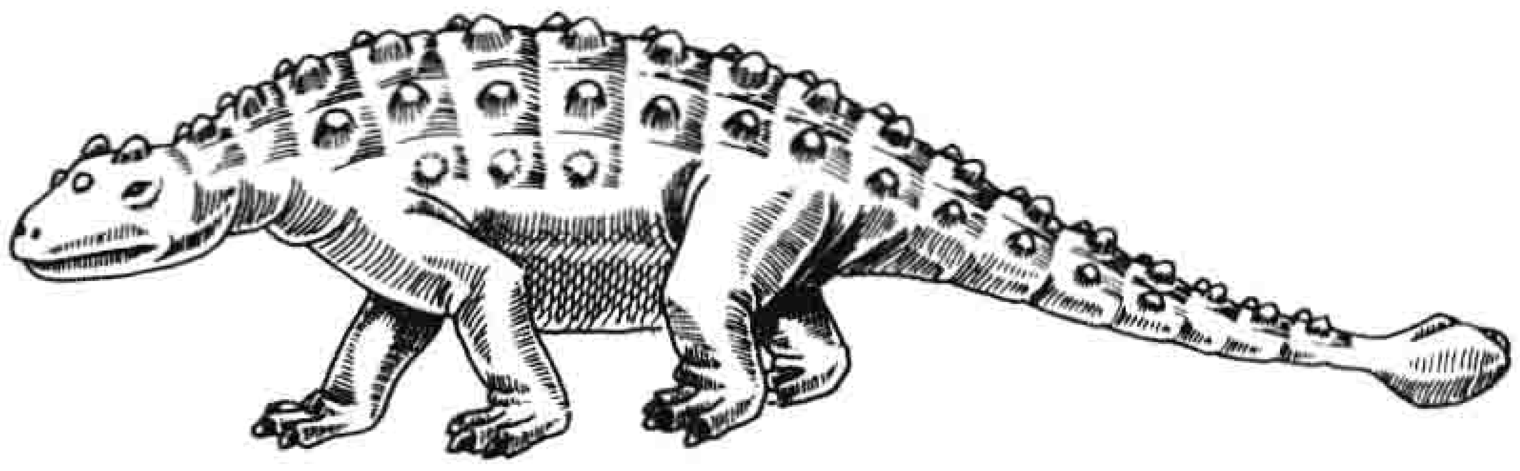


Sauropod

There are two main types, or suborders, of saurischian dinosaurs: theropods and sauropods. The theropods were mainly bipedal and carnivorous. The sauropods were mainly quadrupedal, herbivorous, and often of gigantic size. The ornithischians, probably all of them herbivorous, were of five main types: the unarmored ornithopods; the ankylosaurs, which were armored with flat, bony plates; the pachycephalosaurs, which had a thick dome of solid bone on top of their skulls; the stegosaurs, which had a series of vertical plates along the back; and the ceratopsians, which had horns. The dinosaurs were land animals, whereas pterosaurs were creatures of the air and ichthyosaurs and plesiosaurs lived in the seas.



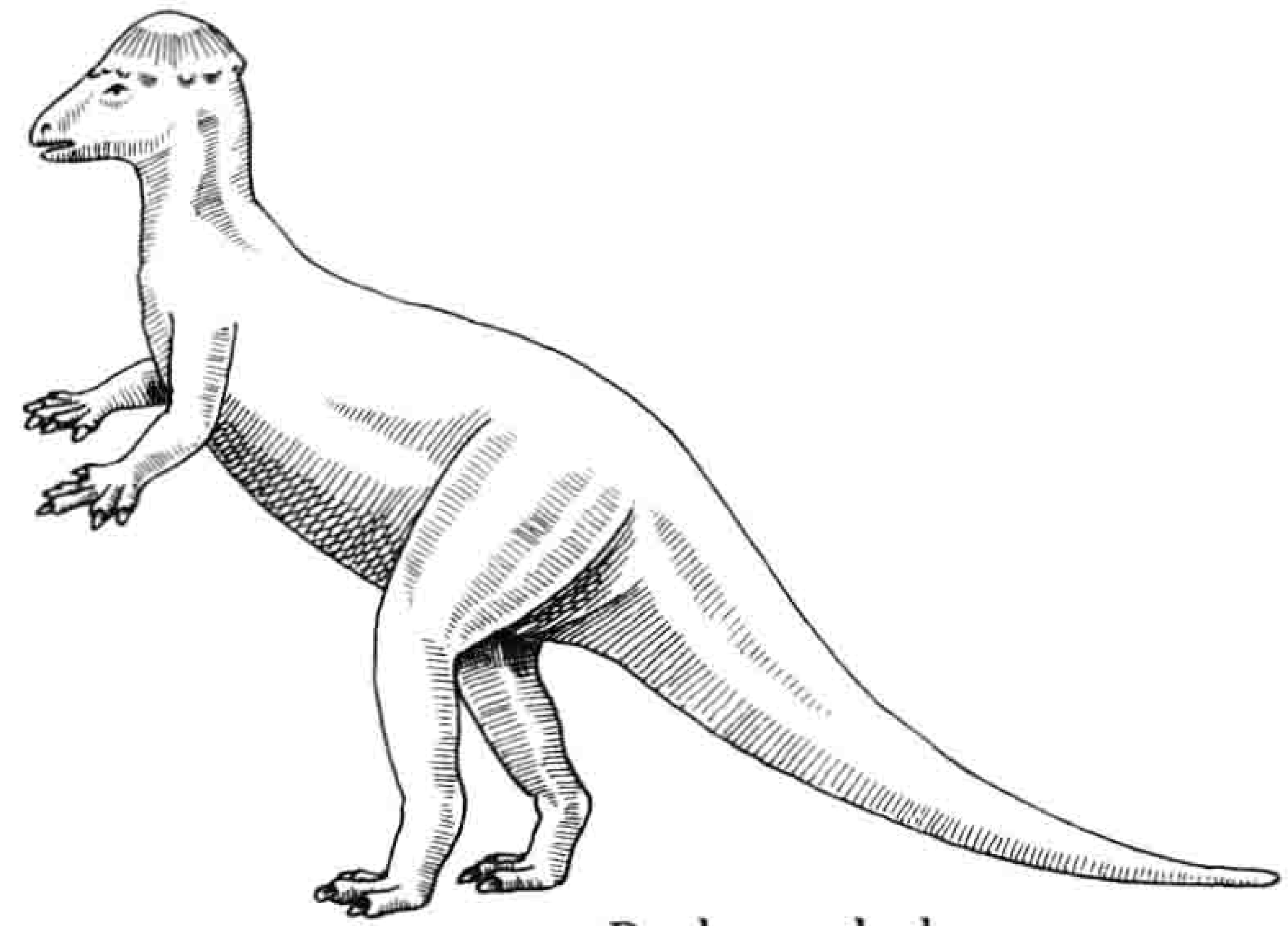
Ornithopod



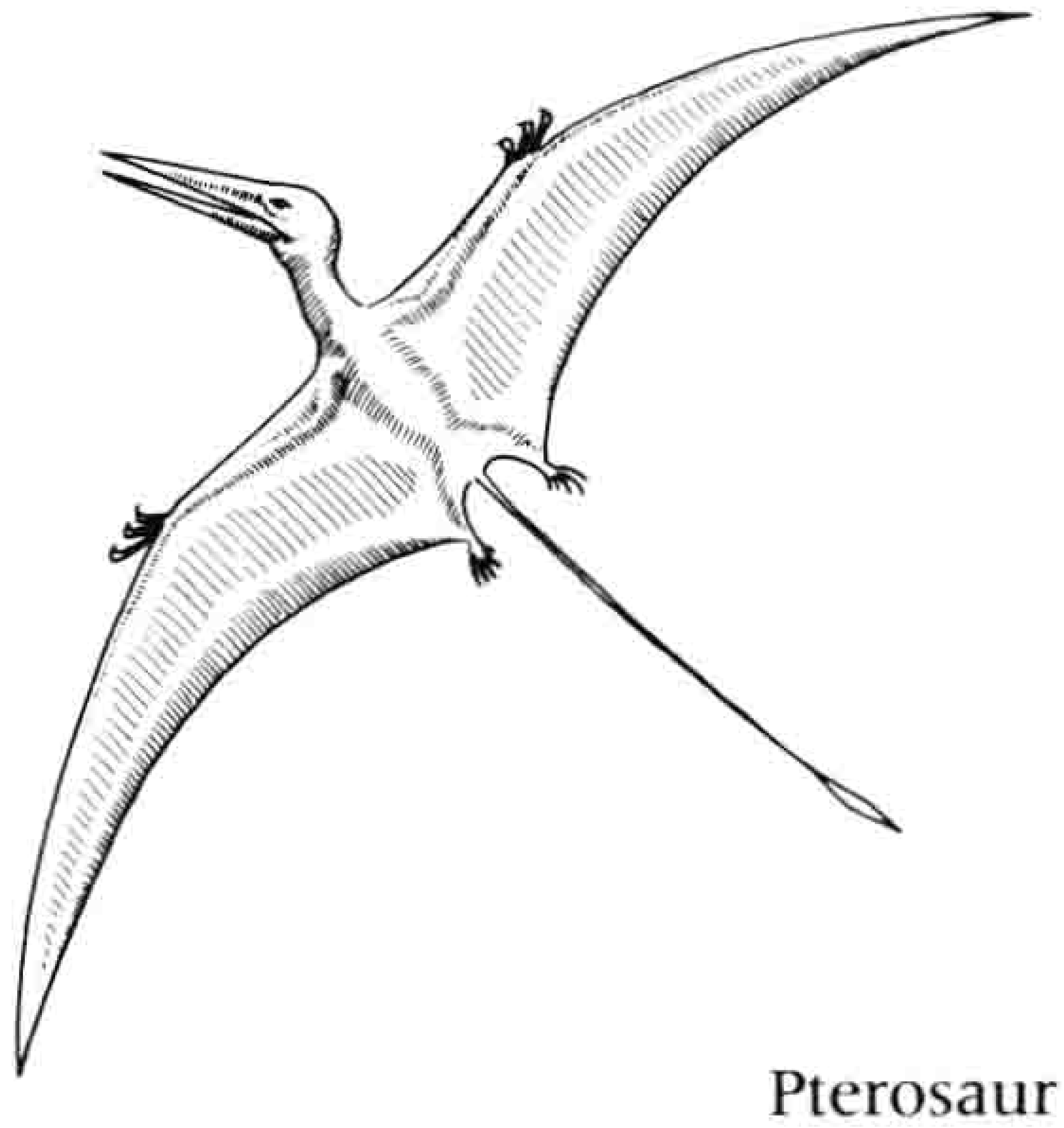
Ankylosaur

ards"). As there exists no comprehensive account of ichthyosaurs in any other nonspecialist book, and as they are of particular interest to me, three chapters are devoted to them. Passing reference will also be made to a second marine group, the plesiosaurs ("near lizards"), which have been likened to a snake strung through the body of a turtle.

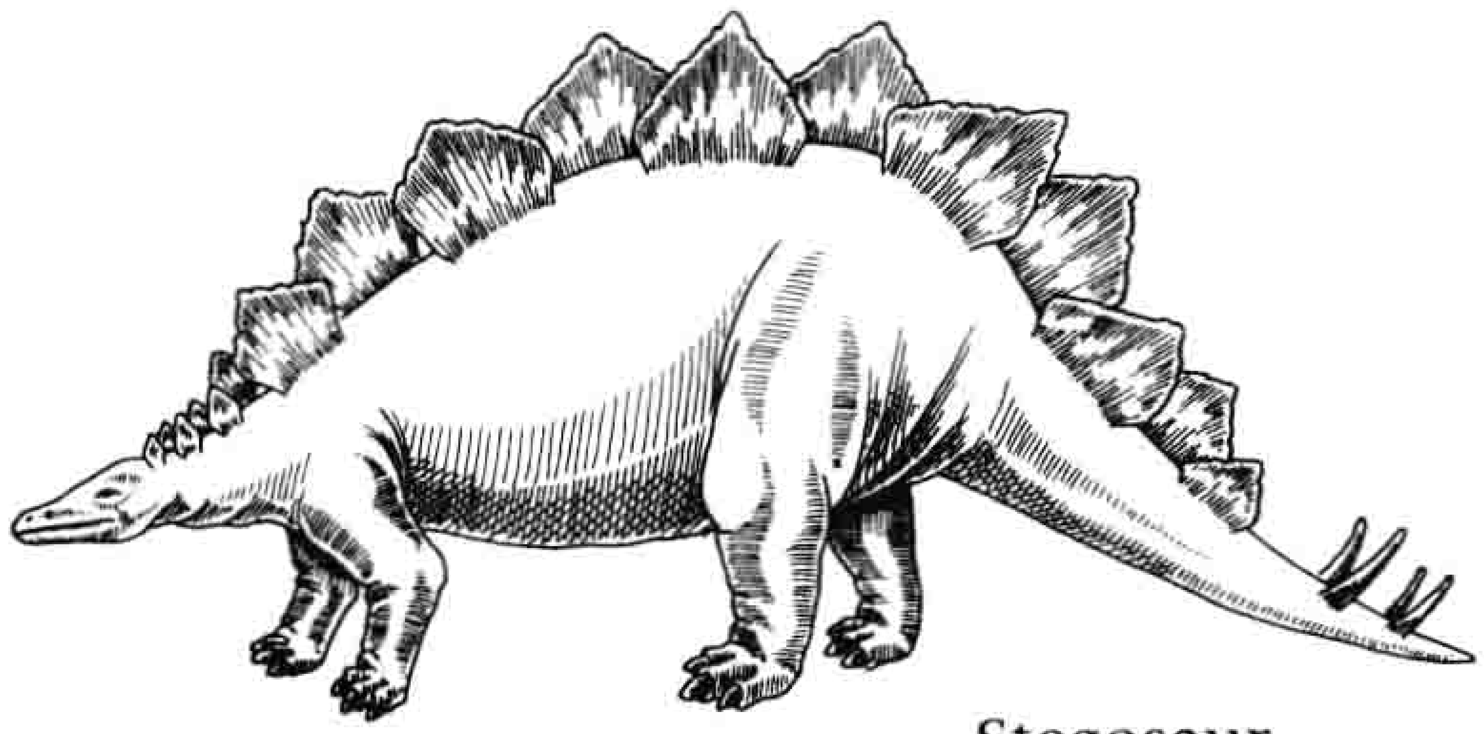
Not all dinosaurs were giants. Some, like *Ornithomimus,* were the size of ostriches, and others were considerably smaller. But most tended toward large size—the size of elephants or bigger.



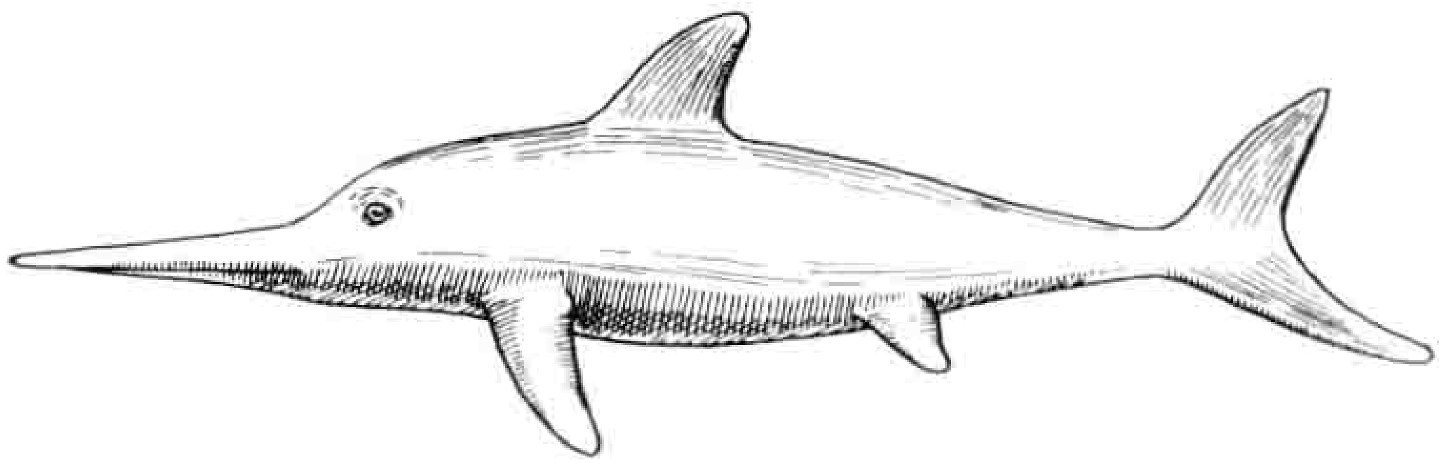
Pachycephalosaur



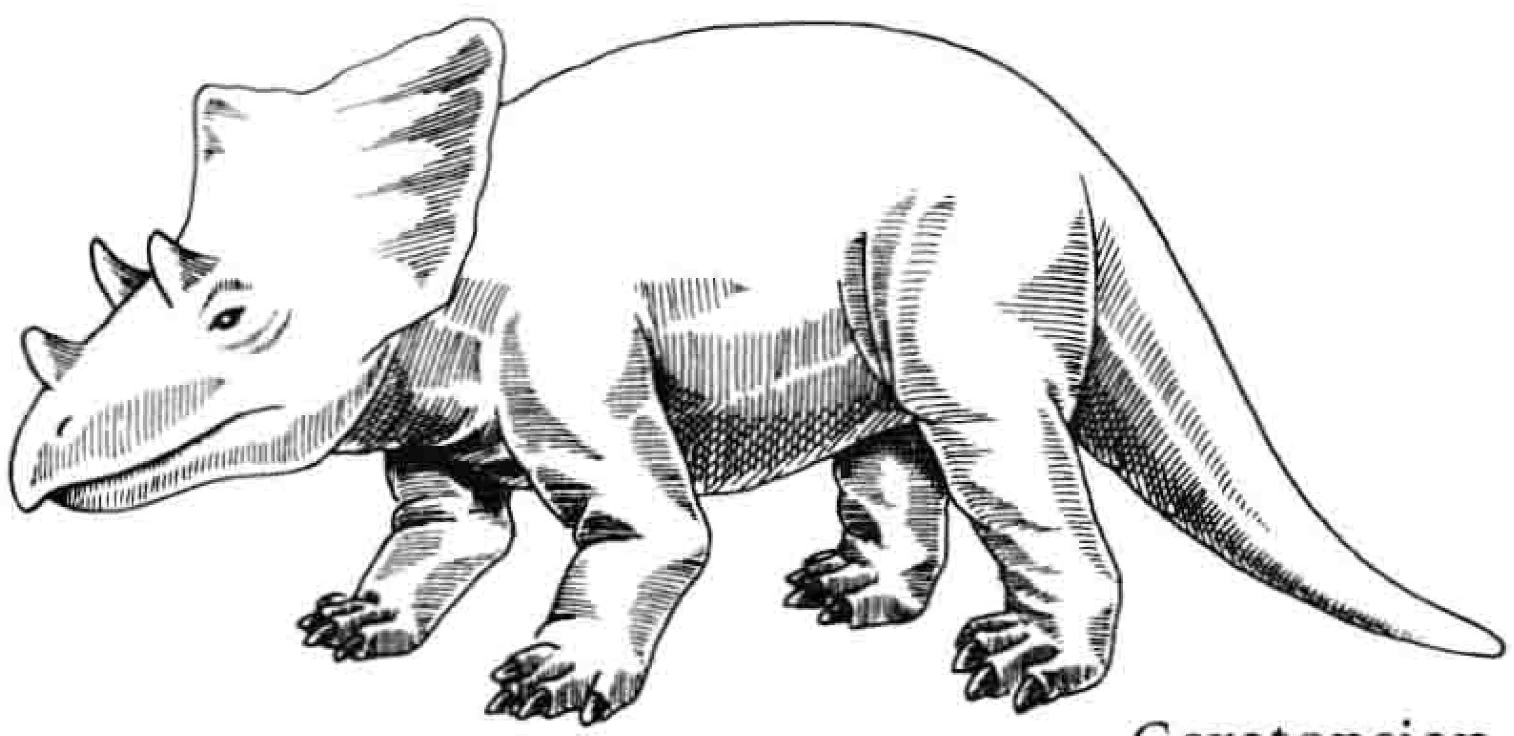
Pterosaur



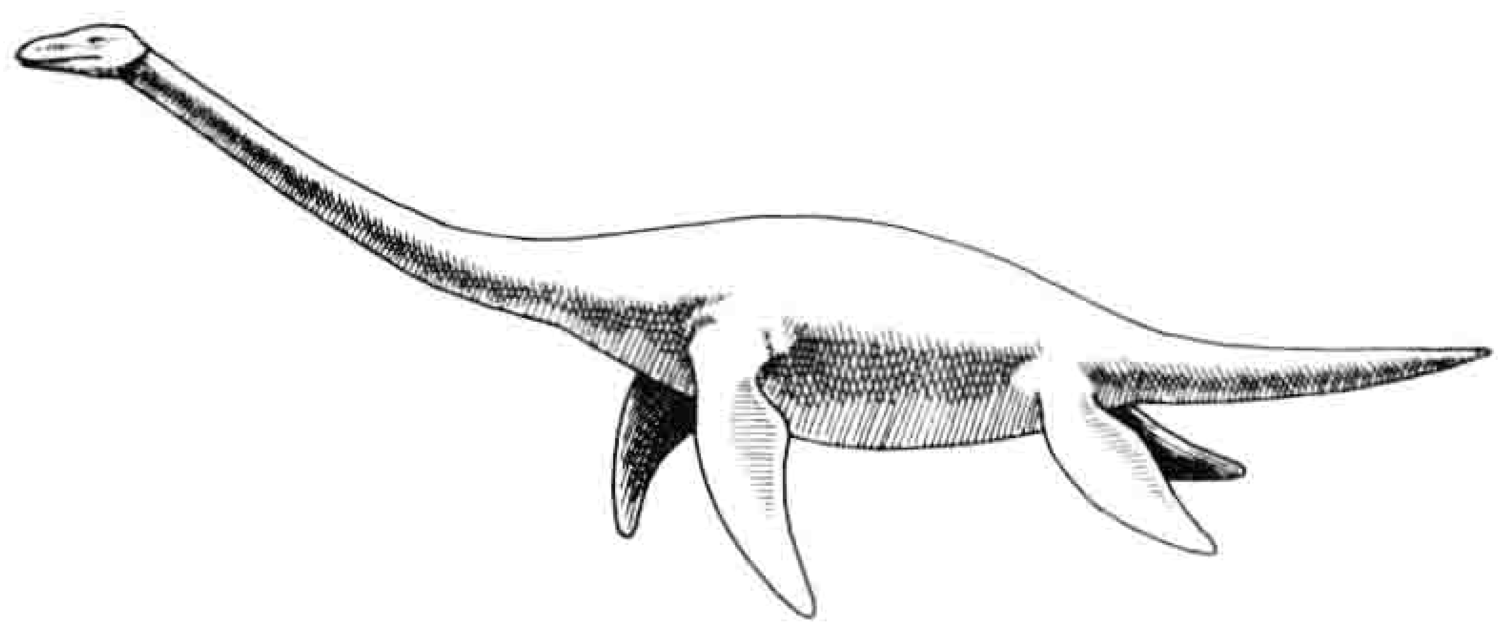
Stegosaur



Ichthyosaur



Ceratopsian



Plesiosaur

And the sauropods, the largest of them all, were the heaviest animals ever to walk the land.

A century and a nalf has passed since Richard Owen coined the name *dinosaur* ("terrible lizard") for these incredible animals. During that time there has been an explosive growth in knowledge, not only about dinosaurs and other animals but in all branches of the sciences. So let us turn the pages and see how the Mesozoic world is viewed from the perspective of the late twentieth century.

ONE

Material Things

BONES and teeth are a paleontologist's stock in trade because these are the parts of an animal that are most resistant to decay and are therefore the most likely to be preserved. Fossil bones were once part of the skeleton of a living, moving creature; they were the architectural framework upon which the whole animal was constructed, and we can learn a great deal about an animal and its way of life by studying its skeleton. But there is more to a skeleton than just an assortment of bones. There are the ligaments that help hold the individual bones together, the tendons that connect muscles to bones, and the cartilage that forms the surfaces of joints. We may not see all of these components in a given fossil—ligaments and tendons are seldom preserved, nor is cartilage—but we need to know about them if we are to understand how a living skeleton functions. Similarly, we may learn about an animal's habits and its diet by studying its teeth.

Like any other architectural structure, the skeleton is largely built of a series of beams and columns. And just as certain building materials are used for particular functions—concrete for supporting columns, aluminium for window frames—so do certain tissues have particular functions in the skeleton. We therefore need to know something of the physical properties of the various skeletal materials to see how they are suited to their particular roles. A knowledge of their microscopic structure and chemical composition is also useful, especially in understanding the changes that take place in them during fossilization. The purpose of this chapter is to look at skeletal structures and the materials from which they are built from an engineering perspective. Attention will naturally be focused on bone because most of the fossils dealt with in the chapters that follow are bony.

The subject of materials science, no longer the prerogative of the engineer, is as useful to biologists for answering questions such as why tendons are able to store so much energy during locomotion, as it is to the aircraft designer for understanding why turbine blades break. The limitations of space do not permit an in-depth treatment of the subject, but I hope to cover enough of the basics to provide important insights into the properties of skeletal structures. I will also touch upon some elementary engineering principles, including simple beam theory, and a little basic physics too, but do not despair—the subject is easy to follow. Many of the terms used, like *elasticity* and *stiffness*, are in everyday usage, but they have precise meanings in engineering science and will therefore have to be redefined.

Some thoughts on beams and columns

Let us imagine that we have two bricks and a stout plank of wood—one about six feet (2 m) long and two inches thick (5 cm) would do very nicely. We can set the plank up as a beam simply by supporting it at either end with a brick. If we now stand in the middle of the beam, we notice that it sags under the force of our body mass.[1] The lower surface is bowed out, and we can visualize how the wood fibers there are being stretched. The upper surface curves the other way, and the wood fibers there are being pushed together rather than pulled apart. When things are pushed together they are said to be in *compression*, and when they are pulled apart they are said to be in *tension*. The top surface of the beam is therefore being loaded in compression, the lower surface in tension.

Engineers are usually more interested in measuring force per unit area than total forces, and this is given the term *stress*. If my wife stepped on my toe with the heel of her running shoe I would feel it but it would not hurt. If she trod on me with a stiletto heel, however, the pain would be intense. The forces are the same in both cases (mass × acceleration due to gravity), but the stress is higher the second time simply because the area of a stiletto heel is only a fraction of that of a running shoe.

Suppose we could insert a probe into the wooden plank and measure the stresses in the wood at different levels.[2] The compressive stress would be highest at the top surface and would diminish as the probe went deeper into the wood. Similarly, the tensile stress would be highest at the bottom surface and lower toward the center. A point would be reached in the middle of the plank where there was no stress at all; this is called the neutral axis of the beam.

Not only do the magnitudes of the stresses change at different depths, they also change along the length of the plank for a given depth. The stresses are highest in the middle of the plank, where the bending is greatest, and decrease toward either end. The maximum, or peak, stresses would therefore be recorded in the middle of the plank. The peak compressive stress occurs at the midpoint of the upper surface, the peak tensile stress at the midpoint of the lower surface. When structures are loaded so that they bend, they always experience higher peak stresses than when there is no bending. They are therefore more likely to be broken under these conditions, as anyone who has broken a bone will attest—breaks usually occur when arms and legs are bent or twisted.

Although our plank makes a perfectly good beam the way we have it set up, it does sag rather a lot. And if we wanted to support the weight of several people, it would probably sag all the way to the floor. A simple solution is to turn the plank on its edge, and although it would require a bit of balancing now because we would have to stand on a two-inch width, the beam would probably not sag noticeably at all. If we could measure the stresses at the top and bottom of the plank in this new position we should find that they were much less than before. But they would still change from compression to tension in passing from the top to the bottom surface, with a neutral axis in the middle. Since the middle of the beam is not under stress, we could drill holes in it and barely diminish its bending strength. Indeed, this is the principle of the steel I-beams used in construction: the steel is concentrated in the areas of maximum stress, the top and the bottom, with relatively little material in the middle.

Instead of using the plank as a beam we could use it as a vertical column. It could, for example, be used as a prop to shore up the sagging roof of a mine shaft. In this situation the plank would be loaded in simple compression. If we were to measure the stresses within the wood we should find that they were compressive from top to bottom, with little, if any, variation from one region to another. We should also find that, for the same load, the stress at