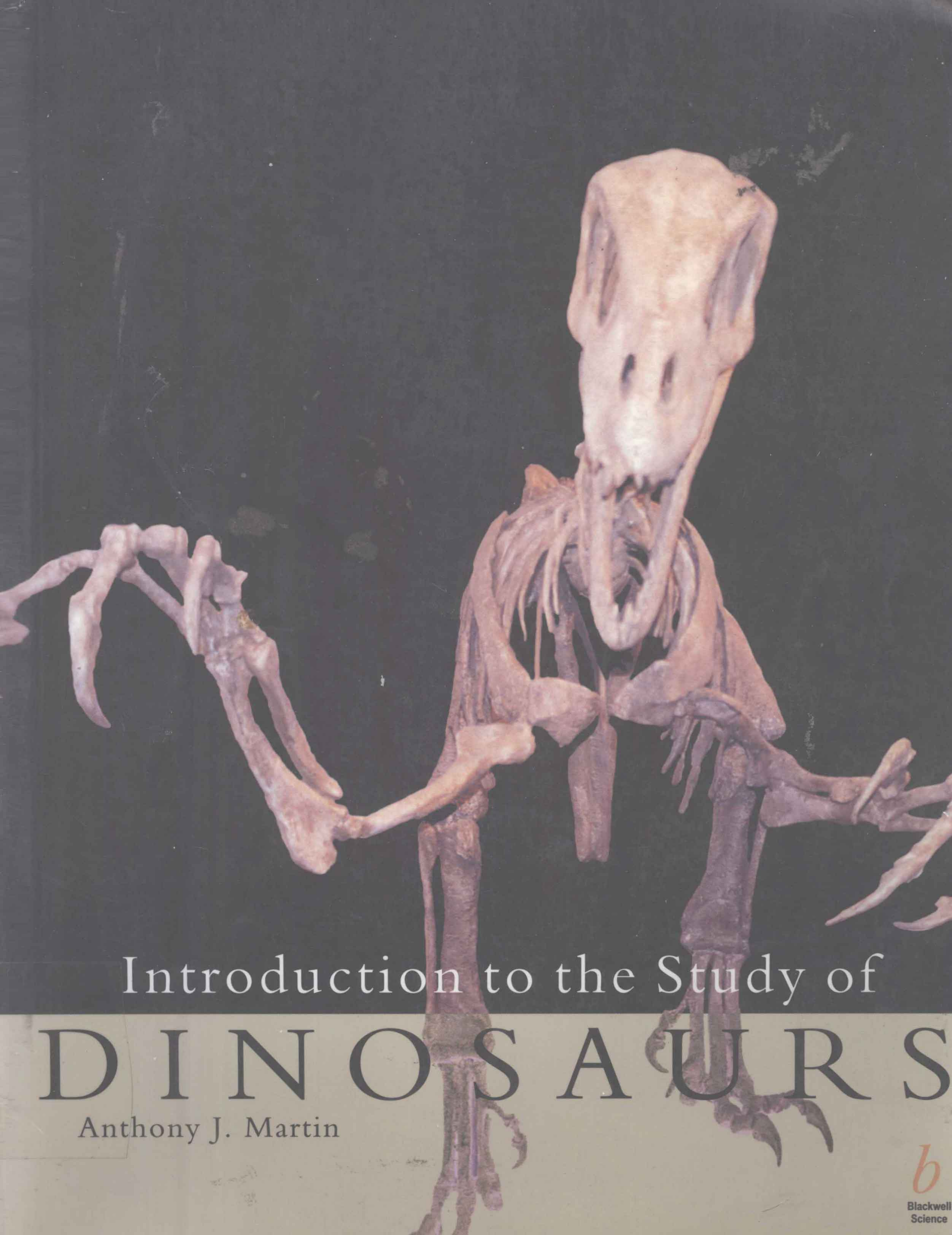

Introduction to the Study of DINOSAURS

Anthony J. Martin

Blackwell Science

INTRODUCTION TO THE STUDY OF DINOSAURS

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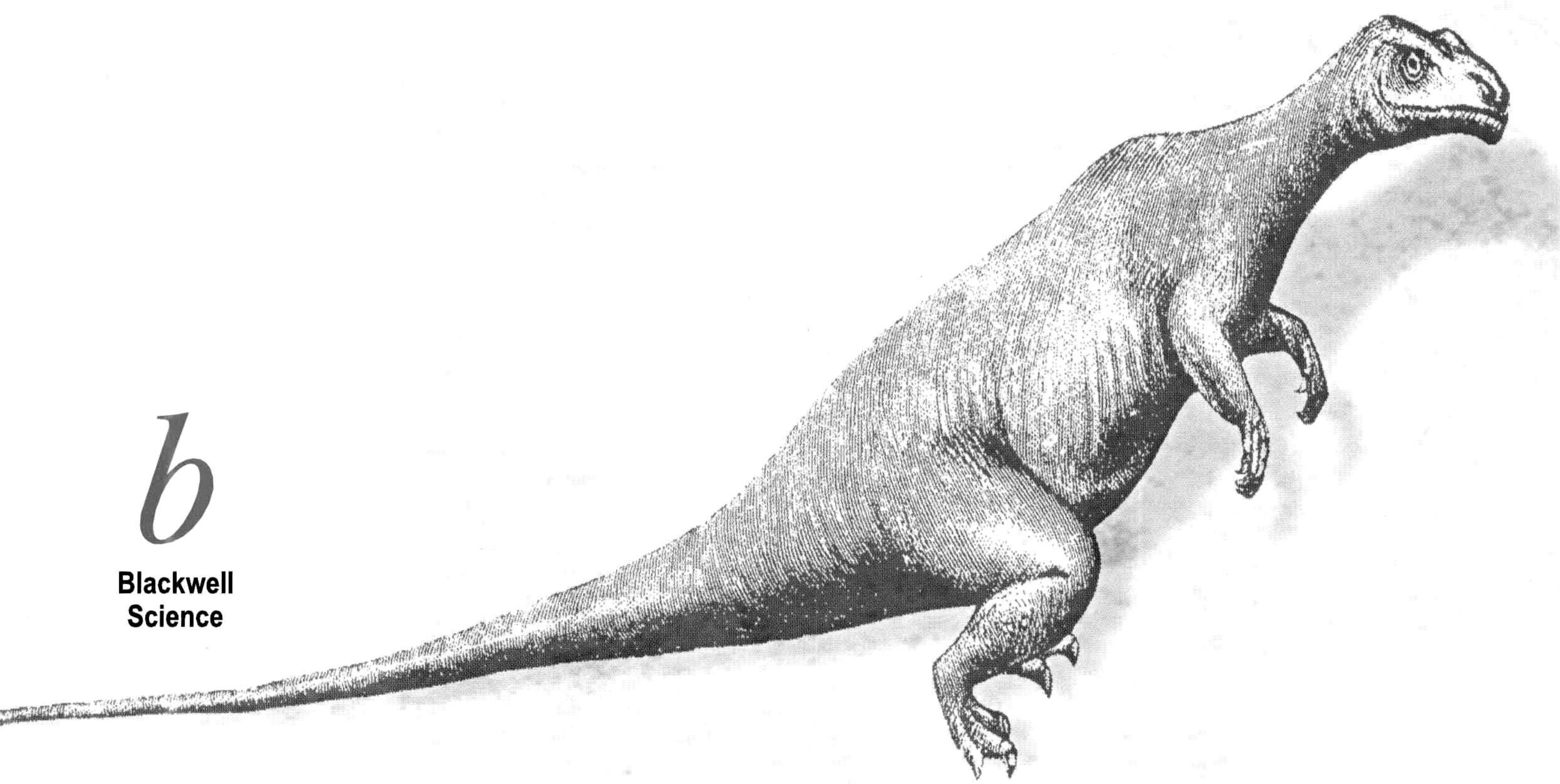

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This book is dedicated to my parents,
who made me possible,
and to Robert W. Frey,
my mentor and an example of a scientist and a gentleman,
both of which I aspire to be some day.

Preface

Yes, I know, another book on dinosaurs. Don't we have enough already?

I tried to make this more than a book about dinosaurs, though. We are living in a time when science literacy (basic knowledge about facts in science) and scientific literacy (the ability to apply scientific methods in everyday life) are perceived as difficult-to-reach goals in education for those who are not professional scientists, despite the increasingly important role of science in everyday life. Dinosaurs represent a partial solution to this problem by providing a hook for people who may not have been properly introduced to science, or in extreme cases have not had the opportunity to learn about science. In our culture, "opinions" may be considered as synonymous with "facts" and science is viewed as a dull enterprise that primarily facilitates the invention of new forms of technology, which in turn fuel commerce. But a journey into the geologic past, with dinosaurs as a central theme, inspires many exciting opportunities to reevaluate such assumptions.

Although dinosaurs have been studied more intensively than any other facet of paleontology during the past 170 years or so, (for better or worse), they continue to be a focus of public fascination. Part of this fixation may be related to the fact that paleontology has had important discoveries made in it by people who are not professional scientists. Paleontology also does not necessarily require multimillion-dollar research laboratories or high-tech equipment; in other words, it is a populist science available to any able-bodied person with patience, curiosity, and a love of the outdoors. People can thus identify with paleontology on many levels, especially when they realize that their chances of finding fossils (maybe even scientifically important ones) are much better than those for winning a lottery. Dinosaurs, for whatever reasons, are the most popular of fossils, so scientifically examining them can help to introduce science in a form that already motivates students to learn. Quite simply, dinosaurs can reach from the past to help with the teaching of science today.

As a result, this is a book showing my view of how an introduction to the study of dinosaurs can be used for general-science education. It is written primarily at the college undergraduate level for non-science majors, but also for anyone interested in learning more about the natural world around them by using dinosaurs as a uniting theme. Many wonderful educational opportunities are offered by using dinosaur studies as a vehicle for learning about how science works (or in some cases doesn't work). Realistically, very few of the people who use this book will become paleontologists, geologists, or any other type of professional scientist. However, I do want them to learn how to learn, appreciate the integrative nature of science, note the humanity that shines throughout its endeavors, and marvel at the beauty of the interwoven web of life and how it changes through time. These are the long-term goals that I hope will cause intangible personal and societal rewards reaching far beyond any aspirations of being a professional scientist.

I am an educator and a scientist, and in that order. Thus, the title of this book is very much deliberate. It is an introduction to the study of dinosaurs, and thus represents a starting point for their study. As a paleontologist I have tried to provide an adequate introduction to the science behind the study of dinosaurs. However, because I am human, errors of both format and content are no doubt present in places throughout the text. As the only author, (without a co-author to blame), I take full responsibility for such errors, which I actually expect are few. Nevertheless, I will face reality if confronted. Your detection of such errors will be welcomed and encouraged, although the happiness of my learning of these perhaps will be preceded by chagrin. Such attention to detail will serve as a fine example of how peer review is supposed to work in science. (I already optimistically look forward to working on a second edition with such future input in mind.)

Of course, dinosaurs in particular are controversial as a scientific topic anyway, regardless of who is talking about them. This circumstance is at least partially related to their popularity with professional and amateur paleontologists alike, but is more likely attributable to their longevity, complexity, and diversity as a distinctive group of animals. As a result, not everyone will agree with some of what is presented in this book. As a scientist, I say "Great!" to this inevitability. Scientific methods work best when ideas and hypotheses are questioned and tested, rather than blindly accepted. Critical reviews are expected from anyone (especially students) reading about evidence, hypotheses, and conclusions about dinosaurs presented in this text. The only criticisms that should be seriously considered, however, are those based on scientific principles (Chapter 2). Oddly enough, I will be disappointed if I only hear praise and complete acceptance of the scientific content in this textbook. To my students I emphasize skepticism of whatever they read in their textbooks and hear me say in class. Because you are reading this textbook, you are also my student. So please be skeptical.

Pedagogy

To achieve such the lofty goals of educating non-scientists and scientists alike, as well as encouraging spirited debate, I had to risk unconventionality in some ways. The first apparent oddity is an imaginary (but still fathomable) scenario stated at the beginning of each chapter titled "Dino Thoughts." In each scenario, some facet of dinosaurs is placed in the context of an everyday experience of the student, then questions are formulated from this experience. Examples of questions include simple but serious ones, such as "What was or was not a dinosaur?" (Chapter 1), "How do people know how old rocks are?" (Chapter 3), and "How were crocodiles, birds, and dinosaurs related to one another?" (Chapters 5, 10, 16). Many of you may ask more mundane questions, such as "How do I know that movie depicted dinosaurs inaccurately?" (Chapter 7) or "How many dinosaur eggs would have been needed to make an omelette?" (Chapter 8). This is an attempt to engage students by showing how questions arise on a daily basis, whether they are about dinosaurs or any other phenomenon. To answer the questions, the student must read and study the chapter that follows. They are not answered in any "answer key," although the summary statement at the end of each chapter, "Dino Afterthoughts," may give some clues. In fact, students may find that some of the questions remain unanswered, which may lead to asking more questions. Science does not always provide answers, but the process of science always involves questions and operates on the principle that answers can be found to questions if we look in the right places. Also, the journey is sometimes more fun than the destination.

Another way in which this textbook is a little bit different than many introductory college textbooks in geology is that it unabashedly displays chemical, physical (as in physics), and mathematical relationships. For those of you who break into a cold sweat as soon as you see an equation, all I can say is don't panic. Instead, think of the symbols used in chemistry, physics, and math as a form of language, which means that their main purpose is communication. Through this philosophical approach, the bipolar end members of "quantitative" and "verbal" information can merge, showing that they are interdependent with one another when relating scientific concepts. In terms of the usefulness of numbers and other symbols in science, a well-defined equation is a form of shorthand that can communicate more information in one line than in pages of verbal explanation. In every equation presented in this textbook, I define the terms presented in it and try to go through their solutions step-by-step and with examples, so that students can see, for example, that what they initially thought was a *Velociraptor* (Chapter 11) is actually a parakeet (Chapter 16). The Web page associated with this textbook also provides links to other Web sites that cover basic principles of chemistry, physics, and math in greater detail. (Just look for the theropod-computer icon in the margins and the World Wide Web Resources listings at the ends of some chapters for more information!) Although anecdotes do not necessarily constitute evidence (Chapter 2), I can tell you that I, too, feared math (and not coincidentally performed poorly in math classes) until I told myself that maybe, just maybe, I could do it. The same can be said for other fields of study that use numbers and seemingly arcane symbols. Give them a try and if you believe that you can't understand them, think of how fun it might be to prove yourself wrong later.

As mentioned earlier, I do not expect the vast majority of the readers of this book to become dinosaur paleontologists, or even scientists, for that matter. Thus I am not trying to be a "dino-evangelist" and convert people to such a career so that they can be just like me (heaven forbid). Instead, I emphasize what dinosaur-related phenomena they might actually experience in ordinary, non-professional life, such as those included in the "Dino Thoughts." Some readers will have already seen dinosaurs in museums, but fewer will have seen dinosaur fossils (bones, tracks, or eggs) in the field, and even fewer will have actual laboratory research experience with dinosaurs. This textbook is a balancing act where I try to show "real" dinosaur fossils (or at least casts of the originals) that students might encounter either in a museum or the field, while also relating the results of the laboratory science done by professional paleontologists and geologists. However, I have definitely leaned toward the easily accessible experiences of geology, paleontology, and dinosaurs, rather than the laboratory experiences. This bias is simply because a reader of this textbook is much more likely to travel through a national park containing spectacular geology and fossils than he or she is to look through a petrographic microscope or use a mass spectrometer (Chapter 3). Additionally, because this textbook is only an introduction to the study of dinosaurs, I have not delved into much of the more advanced and fascinating literature on, say, computer matrices associated with cladistic classifications (Chapter 5), dinosaur bone histology (Chapters 11, 16), or three-dimensional scanning and imaging of skeletal interiors. The people who will be most disappointed with my lack of coverage of these and other topics, I predict, are the very same people who do such research. My apologies in advance; you were neglected but not forgotten.

As far as the chapters are concerned, they are not arranged randomly. The first nine chapters (more than half of the book) is are devoted to providing the tools and background knowledge needed to assess and analyze paleontological evidence related to specific dinosaur clades that are then covered in Chapters 10–16. For example, the stage is set with Chapter 1 by asking why should people study dinosaurs, giving an introduction to how dinosaurs are classified, and exploring how they relate to human culture. This primer is followed by Chapters 2 and 3, which establish basic scientific methods and geological principles, (respectively) that will aid in answering questions posed in the first and subsequent chapters. Chapter 4 attempts a historical perspective on how scientific methods have been applied to dinosaurs throughout the time that humans have been aware of them and hopefully illustrates how science has been (and is) a self-correcting process. Chapter 5, through its coverage of dinosaur anatomy, provides important tools for understanding dinosaur paleobiology and behavior, but also better connects how anatomy is used to classify dinosaurs (as introduced in Chapter 1). Chapter 6 departs from many dinosaur books by devoting its subject material to everything that happened to a dinosaur after it died. It is linked to Chapter 5 in that certain body parts of dinosaurs became preserved preferentially and explains why some dinosaurs were more commonly preserved than others. It also relates to subsequent chapters by bringing up the question, "How did other dinosaur fossils get preserved?," whether they were tracks (Chapter 7), eggs and nests (Chapter 8), gastroliths, coprolites, teeth, or toothmarks (Chapter 9). Collectively, these dinosaur fossils are far more abundant than dinosaur bones, and (more so than bones) they can support important hypotheses about how dinosaurs behaved. Studying these fossils provides for a more holistic and balanced approach to studying dinosaurs than might have been previously experienced by studying mounted dinosaur skeletons in museums that are perhaps only accompanied by a token dinosaur track or egg.

Chapter 10 then represents a turning point in the book by showing the evidence for the evolutionary roots of dinosaur clades that are covered in the remaining chapters. Such a review requires a basic understanding of evolutionary theory, thus the best-supported and oldest theory in all of the sciences is given the detailed treatment it deserves. Evolutionary theory then is used as a predictive framework for dinosaurs where the evidence for their evolution is supported by paleoenvironmental information, including body and trace fossil evidence. Cladism, the classification system used for dinosaurs and other fossil and modern organisms (Chapters 1, 5), is also designed to work in accordance with evolutionary theory through its identification of inheritable traits. Cladism is then the starting point of every subsequent chapter in the textbook (Chapters 11–16). However, it is not the primary focus of each chapter and is instead presented as only one of the many tools used to understand the relations between and within the clades of theropods (Chapters 11, 16), sauropodomorphs (Chapter 12), ornithopods (Chapter 13), thyreophorans (Chapter 14), and marginocephalians (Chapter 15). The majority of material in each chapter is instead devoted to evidence of where these dinosaurs lived, how long their clades lived, and how they lived. As interesting as cladism is to many dinosaur researchers and as intrinsic as it is to understanding dinosaur classification, I somewhat doubt that the majority of readers of this book could have borne a detailed accounting of the synapomorphies of each and every dinosaur clade defined by humankind. Therefore I tried to present just enough of it, rather than too much.

Lastly, Chapter 16 might seem on the surface like a hodge-podge of seemingly unrelated topics, but there is a method to its apparent madness. If dinosaur paleontologists and the general public were to sit down together and vote on the three most controversial topics in the study of dinosaurs, those topics would be, in no particular order: (1) the evolution of certain dinosaur lineages into birds; (2) dinosaur physiology, epitomized by the "cold-blooded" versus "warm-blooded" debate; and (3) dinosaur extinctions, especially their linkage to the end-Cretaceous mass extinction. I decided, with the best of intentions, to attempt a coverage of all three topics in one chapter but as interrelated ones that in a unified way would help to answer the question, "What happened to the dinosaurs?". Of course, we are rather certain that dinosaurs are with us today in the form of birds, but everyone who has ever heard about dinosaurs is still very curious why all of the other dinosaurs are not with us today. The topic of extinctions in general closes the book with some thought-provoking questions regarding modern extinctions, which I hope will impart lessons regarding how the lives and deaths of dinosaurs relate to our world today and into the future.

Although the chapters are connected to one another in sequence, an instructor or student could certainly skip to specific chapters in the book, out of sequence, and not be completely lost. Small signposts along the way that will help to guide readers to important concepts in preceding chapters are the cross-references to chapters (like those in this preface). However, I also want to encourage curiosity and exploration of the textbook by referring to future chapters, too. Do not feel compelled to wait for the future when you can learn today!

Oh yes—I must have some acknowledgments. Nancy Whilton of Blackwell Science deserves credit for urging me to write a prospectus for this textbook, which much to my shock was accepted and lauded by the editorial staff at Blackwell. As a result of her encouragement, I now know much more about dinosaur paleontology than I ever thought that I would learn in a lifetime. Ms. Whilton was frequently involved in the midst of the book's production, encouraged me to meet deadlines, and provided appropriately timed praise when it was needed. (The potentially deadly combination of commercial enterprise and academic idealism came to a compromise and we both survived the endeavor, I am happy to say.) My energetic, cheerful, and enthusiastic assistants in editorial development and production at Blackwell included Jill Connor, Shawn Girsberger, and Irene Herlihy. They deserve not only raves, but raises. This book would be much less educationally valuable without the illustrative talents of Caryln Iverson, who provided the majority of illustrations in the book. I am extremely happy that she chose my book to showcase her abilities and now cannot imagine anyone else who could have accomplished what she did. I was continually amazed when I saw proofs of her illustrations that perfectly matched my sketches and descriptions of the educational concepts I envisaged for such figures. She even participated in my more whimsical takes on some dinosaur-related subjects (how many dinosaur books show an insurance salesman juxtaposed with *Deinonychus*?: Chapter 5).

Various reviewers, formal and informal, added considerable insights and corrections through their feedback on the first drafts of chapters. Their guidance helped to tighten the text, better define the educational objectives, and teach me about what methods and subjects would work best for their students. In a few cases I respectfully disagreed with their suggestions, but quite often their intentions were good, so I listened carefully to what they had to say and tried to respond to their concerns as well as possible. Some stayed anonymous, while others did not. Of the latter people are David Schwimmer (Columbus State University, Columbus, Georgia) and Raymond Freeman-Lynde (University of Georgia, Athens, Georgia), who were exceedingly thorough and supportive with their constructive criticisms. Other folks who were gracious enough to read and comment on a few chapters were James Albanese (SUNY at Oneonta), Sandra Carlson (University of California at Davis), Stephen W. Henderson (Oxford College of Emory University, Oxford, Georgia), Stephen Leslie (University of Arkansas at Little Rock), Scott Lilienfeld (Emory University, Atlanta, Georgia), Franco Medioli (Dalhousie University), Charles Messing (Nova Southeastern University Oceanographic Center), David Meyer (University of Cincinnati), Mark Messonnier (Centers for Disease Control and Prevention, Atlanta, Georgia), Ronald Parsley (Tulane University), Andrew K. Rindsberg (Alabama Geological Survey, Tuscaloosa, Alabama), Roy Scudder-Davis (Berea College), and William Zinsmeister (Purdue University). They gave assessments that were independent of ones selected by Blackwell (my own little experiment, in other words). A few others, through research done in the field or in conversations with me, helped by inspiring many thoughts and insights about dinosaurs and the Mesozoic world. One of them was Stephen T. Hasiotis (Indiana State University, Terre Haute, Indiana), who introduced me to the Late Triassic with the Petrified Forest of Arizona. David Varricchio (Museum of the Rockies, Bozeman, Montana) also gave me an all-too-brief tour of the Late Cretaceous Two Medicine Formation of western Montana and its dinosaur fossils (both bodies and traces) soon after the first draft of the book was completed. This visit helped to give me a perspective on how much I had learned about dinosaurs and how much I still needed to learn. Christine Bean and Nancy Huebner (Fernbank Museum of Natural History, Atlanta, Georgia), who both teach K–12 students and deal with the everyday public thirsting for more knowledge about dinosaurs, were extremely helpful in providing hints about what interested people about dinosaurs.

Three dinosaur paleontologists are to be thanked for not only being world-class scientists but also for taking time out to teach students in a dinosaur field course (led by Stephen Henderson and me) when we dropped in to visit them during the course. These paleontologists are James Kirkland (Utah Geological Survey), Martin Lockley (University of Colorado, Denver, Colorado), and Don Burge (College of Eastern Utah Prehistoric Museum, Price, Utah). The students were thrilled to interact with them and we were ecstatic to have our students learn from them. These opportunities gave the students personal perspectives on paleontology that they might not have been gained from, say, only reading a textbook. However, I tried to reproduce the spirit of this excitement as much as possible in this book.

Last but not least, I must thank Michael Parrish (Northern Illinois University, DeKalb, Illinois), who provided a "foundation for the foundation" of this book through his teaching an National Science Foundation-sponsored Chautauqua course for college teachers on the paleobiology of dinosaurs in 1996. Soon after I took this course, I wrote a World-Wide Web page about dinosaur trace fossils that was my first attempt at public outreach in scientific literacy through the subject of dinosaurs. The Web page was a big success in terms of numbers of visitors during subsequent years and gave me the confidence to say "Why not?" after Ms. Whilton stepped into my office one serendipitous day and asked if I would be interested in writing a dinosaur textbook. The answer to that question is now before all of you. Why not read this book and learn as I did?

Contents

Definition of a Dinosaur

1

DINO THOUGHTS

Your 9-year-old nephew draws a picture of a plesiosaur (a large, extinct marine reptile, some of which had long necks and well-developed fins) swimming in an ocean. The picture also includes a few pterosaurs (flying reptiles) in the sky, one of which is carrying a cow in its claws. He patiently explains to you that the "dinosaur" in the water is just like the Loch Ness monster, and the "dinosaurs" flying overhead saw some cows in a field and because one of them was hungry and wanted to feed its babies, it captured the cow and was carrying it off to its nest.

How do you explain to him, without crushing his imagination or ego, some of the scientific inaccuracies of what he illustrated and told you?

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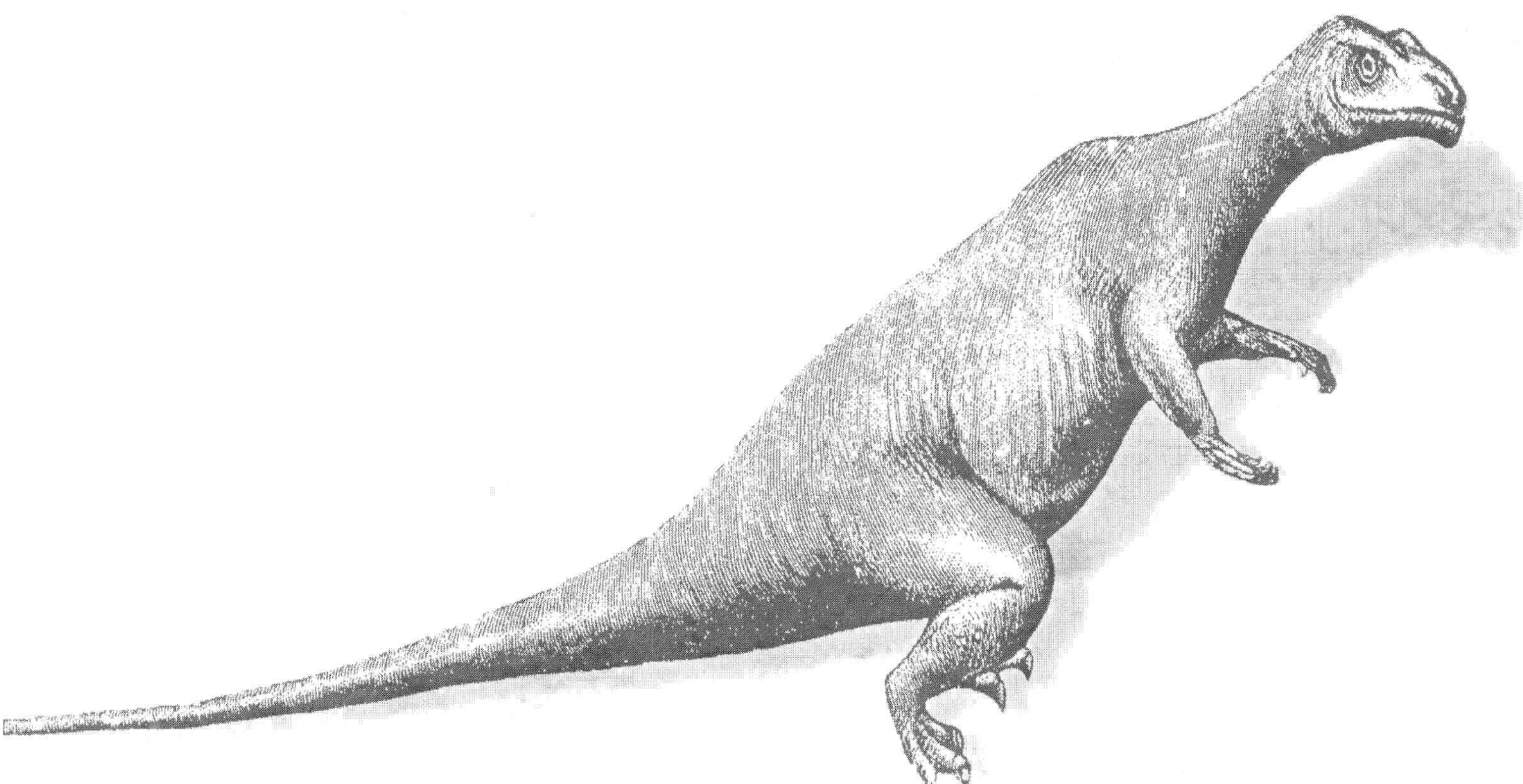


What Is a Dinosaur?

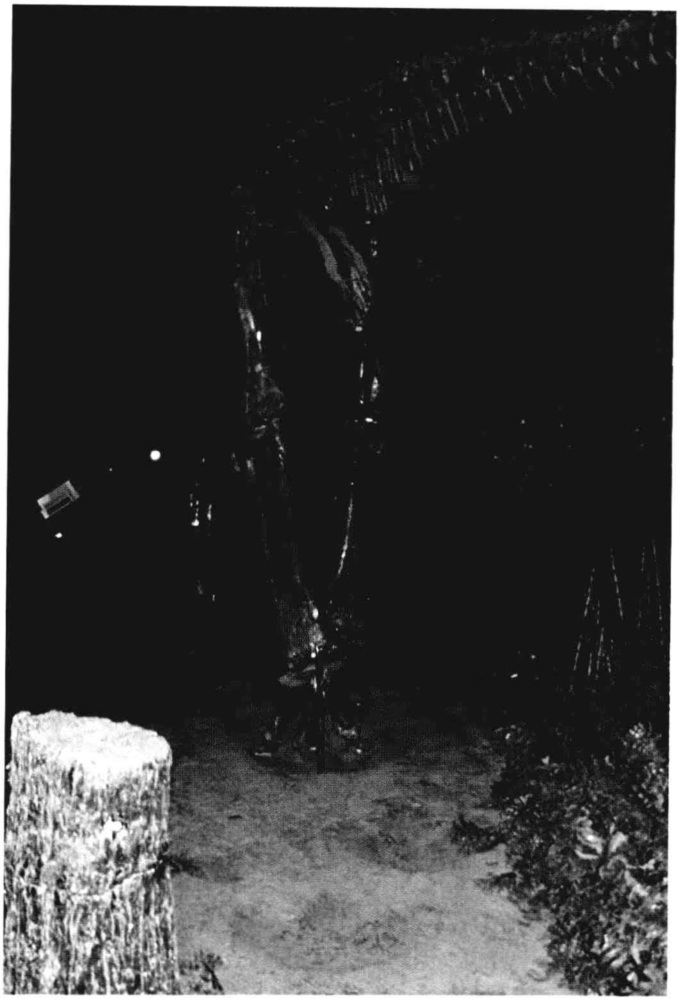
Because this book is about **dinosaurs**, probably the most appropriate way to start it is to discuss what constitutes a dinosaur. However, just defining what is and is not a dinosaur is a difficult task for children, adults in the general public, and dinosaur experts alike. Here is a preliminary attempt at a working definition:

> *A dinosaur was a reptile-like or bird-like animal with an upright posture that spent most (perhaps all) of its life on land.*

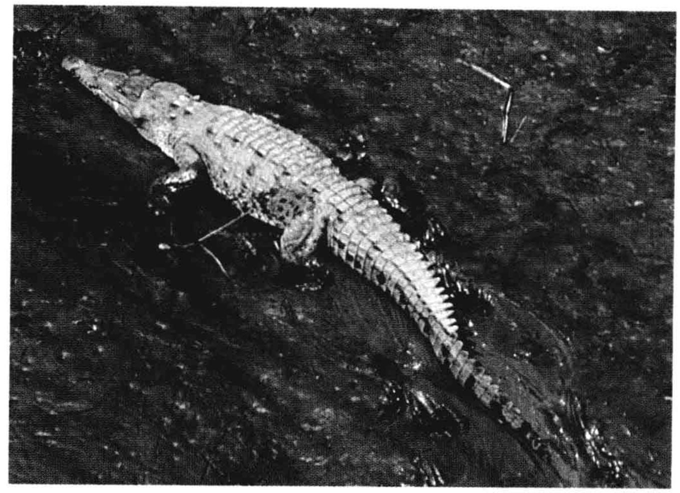
The term "reptile-like" is in recognition that although dinosaurs certainly were derived evolutionarily from reptilian ancestors, they were clearly different from the reptiles we see today, such as crocodiles, alligators, and lizards. Hence, these modern animals are not "living dinosaurs," nor were their ancient counterparts. Anatomical distinctions and differing lineages separate modern reptiles and dinosaurs, although both groups had common ancestors. Nevertheless, because dinosaurs were descended directly from reptile-like ancestors, they have many features similar to modern reptiles, which warranted their original classification as such (Chapters 4 and 5). Yet some dinosaurs also had some anatomical and attributed behavioral characteristics similar to modern birds and, according to a preponderance of evidence, birds were indeed derived from dinosaurian ancestors (Chapter 16). For now think of dinosaurs as transitional organisms between certain ancestral reptiles and modern birds; these relations will be expanded upon and clarified later.

Upright posture is very important to the definition of dinosaurs. "Upright" means that an animal stands and walks with its legs directly underneath its torso, which is also known as an **erect** posture. This posture is distinguished from **sprawling** or **semi-erect** postures, where the legs project considerably outside the plane of the torso (think about elbows and knees sticking out to the sides), seen in modern amphibians and reptiles with legs (Fig. 1.1). As far as we know, dinosaurs were among the first animals to habitually walk on two legs (**bipedal**), as suggested by both the anatomy and tracks of early dinosaurs or dinosaur-like animals (Chapter 10), and a bipedal stance that is not upright simply does not result in effective movement. Of course, not all dinosaurs were bipedal, but even the four-legged (**quadrupedal**) dinosaurs had an upright posture that is also reflected by their anatomy and tracks (Chapters 5 and 7). Dinosaurs interpreted originally as "big lizards" were given sprawling, reptile-like stances that are evident in older illustrations of them. However, now that we know differently, people who make museum mounts of dinosaurs and better-informed illustrators reconstruct dinosaurs with their legs under their torsos, although some controversy still exists over the exact posture of a few dinosaurs (Chapter 15). Why dinosaurs developed an upright posture is not yet understood completely, but current evidence points toward the adaptation of dinosaur ancestors to more efficient movement on land (Chapter 10).

The land-dwelling habit of dinosaurs is important to defining them, too. Based on all information we have now, dinosaurs did not fly as part of their normal lifestyle. Likewise, no conclusive evidence indicates that dinosaurs swam, although some of their remains in deposits from ancient aquatic environments may mean that they drowned while attempting to negotiate water bodies (Chapter 6). Dinosaurs had some reptile-like contemporaries, pterosaurs and plesiosaurs, that flew and swam, respectively (Chapter 10), but these were not dinosaurs, although all three groups had common ancestors at different times. For further clarification of how dinosaurs lived, no convincing evidence has shown that dinosaurs either lived in the ground or dwelled in trees, because no dinosaur has ever been found in a burrow or in direct association with a fossil tree. Thus, any speculation that they had such lifestyles is currently just that. Dinosaurs simply seemed very well



(A)



(B)

FIGURE 1.1. *Differences in postures of a dinosaur and a large modern reptile.* (A) *Skeleton of the Late Cretaceous ornithopod* Edmontosaurus annectus *from Alberta, Canada. Posterior view of rear limbs leaving a trackway, showing the typical dinosaurian trait of legs held underneath its body (erect posture). Specimen in the Royal Ontario Museum of Toronto, Ontario, Canada.* (B) *American crocodile,* Crocodylus acutus, *in Costa Rica, showing a sprawling posture and also leaving a trackway. This same typical reptilian posture can change to a semi-erect posture by the crocodile standing up and walking. Photo by Nada Pecnik, from Visuals Unlimited.*

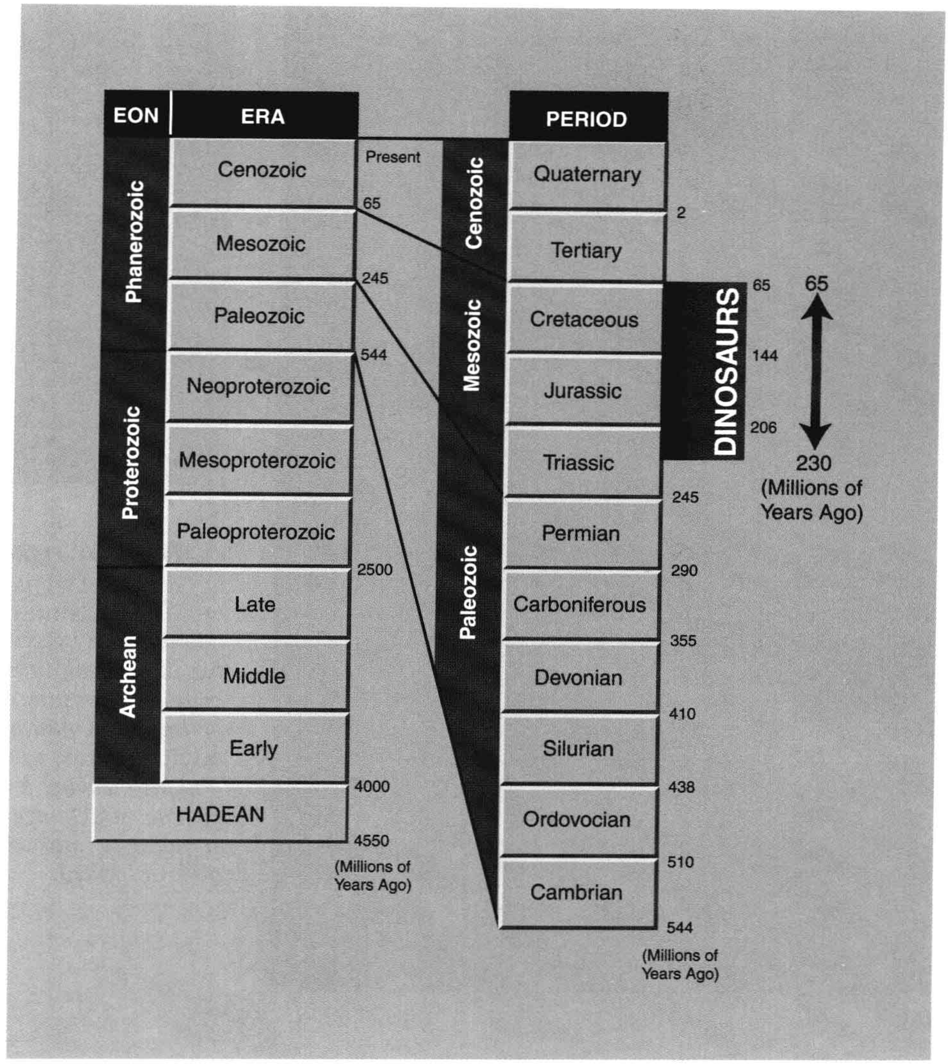
adapted to living in the many environments associated with land surfaces, which by all appearances worked very well for them during their 165-million-year existence.

Notice that the definition of a dinosaur says nothing about size. Dinosaurs are well known for the extraordinary size of some individual dinosaur species in comparison to living land-dwelling animals today, and indeed some dinosaurs did constitute the largest land animals that ever left footprints on the face of the earth (Chapter 12). However, many adult dinosaurs were smaller than the average human and some were about as big as the very recently deceased rotisserie chicken carcasses seen in some restaurants today. To say that large dinosaurs were the dominant species in their environments is a misconception at worst and an exaggeration at best, analogous to saying that a savanna in modern Africa is dominated by an elephant herd when more than half of the mammal species in that environment are smaller than domestic dogs.

Dinosaurs also lived only during the **Mesozoic Era** and their fossils are in rocks representing the last part of the **Triassic** and all of the **Jurassic** and **Cretaceous Periods** (230 to 65 million years ago) of the **geologic time scale** (Fig. 1.2).

As of the writing of this book, no indisputable scientific evidence has established the existence of dinosaurs from any times earlier than 230 million years ago and certainly none have been discovered in recent times, contrary to some tabloid headlines and the assertions of other nonscientific literature.

FIGURE 1.2. *Geologic time scale used as a standard by geologists and paleontologists worldwide. Largest units of geologic time are eons, followed (in order of most inclusive to least inclusive) by subdivisions eras, periods, and epochs. Figure is not scaled according to amounts of time.*



Because the geologic record for human-like animals only extends to about 4 million years ago, we are also very sure that no human has ever seen a living dinosaur, let alone been threatened by one. The only recorded death of a human by the actions of a dinosaur happened in 1969 when a coal miner fatally hit his head against an overlying dinosaur track on the roof of a coal mine. Nevertheless, the formation of the track and the unfortunate miner's death were separated by about 75 million years.

A stricter definition of what constitutes a dinosaur, based on detailed aspects of its skeletal characteristics, is covered later (Chapter 5), but for our purposes the preliminary definition given here will work for now. For those people who insist, on the basis of much scientific evidence, that living birds are dinosaurs and thus do not perfectly fit this initial definition (Chapter 16), this objection is acknowledged and thus the qualification is added that this book is mostly about non-avian ("non-bird") dinosaurs. For the sake of simplicity, the term "dinosaur" from now on will refer to those same animals limited to the Mesozoic Era, although some of them had bird contemporaries during the latter part of the Jurassic Period and all of the Cretaceous Period.

Once this definition and all of its amendments are in mind as a conceptual framework, think about what extinct or living animals are *not* dinosaurs and test the definition whenever possible. For the purposes of this book, a familiarity with the names given for different dinosaur groups and their general characteristics will help to reinforce the identification of certain names with dinosaurs, as introduced in the following section.

Classification of Dinosaurs

The method for how organisms or their byproducts are named, which provides a framework for communicating about a classification system, is called **taxonomy**, and a name given to a group of organisms in a classification system is a **taxon** (the plural is **taxa**). Dinosaurs can be classified in two ways, with one of those methods rapidly becoming the preferred one used by paleontologists worldwide. The older, traditional method is the **Linnaean classification**, named after the Swedish botanist **Carl von Linné** (1707–1778); Linné is better known by his pen name **Carolus Linneaus**. (Consequently, he also could be called "The Scientist Formerly Known as Linné.") In his botanical studies, Linné realized that a standard organized method was needed to name organisms, so he unveiled one in 1758. The Linnaean method is also known as **gradistics** because it is based on hierarchical **grades** of classification, which means that organisms are fitted into increasingly more exclusive categories based on a standard set of anatomical characteristics of members in that category. The grades become more stringent about which organisms belong to them on the basis of an arbitrary number of characteristics that an organism might have (or not have) that are identical to the well-studied, already placed members of the group. Such a classification system is typically stratified from groups containing many members to groups with progressively fewer members, such as (in order of largest to smallest group) **kingdom**, **phylum**, **class**, **order**, **family**, **genus**, and **species**. In botany, the equivalent grade to a phylum is a **division**, but otherwise the categories are the same. Under this classification scheme, dinosaurs are broadly categorized like so, with the more inclusive grades descending to the right:

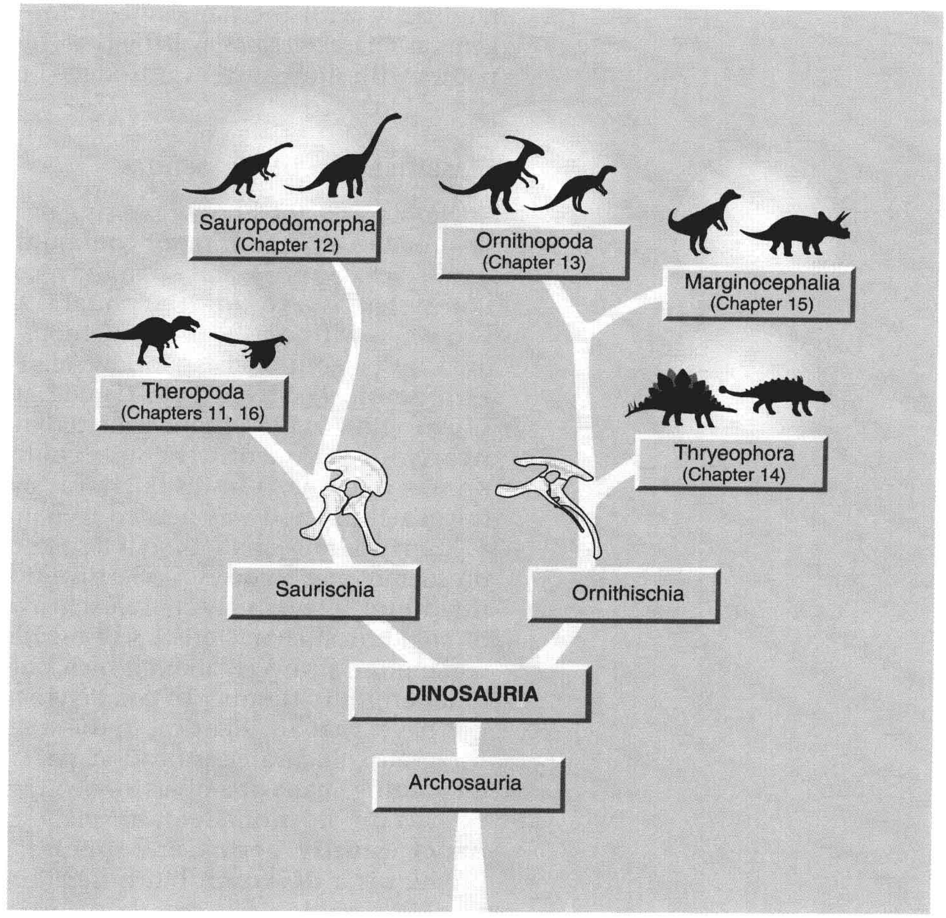
- Phylum Chordata
  - Subphylum Vertebrata
    - Class Reptilia
      - Subclass Diapsida
        - Infraclass Archosauria
          - Superorder Dinosauria
            - Order Saurischia
            - Order Ornithischia

As of 1984, the newer and more popular classification method applied to dinosaurs has been the **phylogenetic classification**, also known as **cladistics** because it is based on placing organisms into units called **clades**. Clades are defined on the basis of **synapomorphies**, which are shared, evolutionarily derived ("new" or "novel") anatomical characteristics (also known as **characters**) of organisms. Characters must be observable, not inferred, meaning that synapomorphies are factually based. Fundamentally, cladistic classifications are explanations of evolutionary relationships between organisms and are best summarized through a diagram called a **cladogram** (Fig. 1.3).

Rather than being stratified in relation to one another, clades can be nested within one another, conceptually producing a bush with many branches rather than a ladder with many rungs.

Here is a cladistic classification for dinosaurs, based on characters, in which one clade branches to another to show descent to the lower right:

FIGURE 1.3. *Cladogram of the major dinosaur clades covered in this text.*



Chordata
  Tetrapoda
    Amniota
      Reptilia
        Diapsida
          Archosauriformes
            Archosauria
              Ornithodira
                Dinosauria
                  Saurischia
                  Ornithischia

This "line of descent" is somewhat misleading because it does not reflect the many branches that can emanate from each clade, nor does it show the timing for the evolution of a new clade. In other words, a clade does not have to go extinct for the next clade to evolve. Because simply listing cladistic relations is potentially confusing, cladograms are the most common method for explaining phylogenetic classifications.

Although the Linnaean and phylogenetic classification methods for dinosaurs differ from one another, a comparison of categories used in each dinosaur classification shows that they use many of the same names. Unless antecedents such as "clade" or "order" are used, confusion may result from not knowing which scheme a paleontologist is using. However, many dinosaur paleontologists will merely abbreviate references to certain groups of dinosaurs through generalities, such as "theropods" (Chapter 11), "sauropods" (Chapter 12), or "ornithopods" (Chapter 13), although nowadays more often than not these designations implicitly refer to clades. In this book, the cladistic system is used because it is based more on a scientific methodology related to evolutionary relatedness and