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Excerpt
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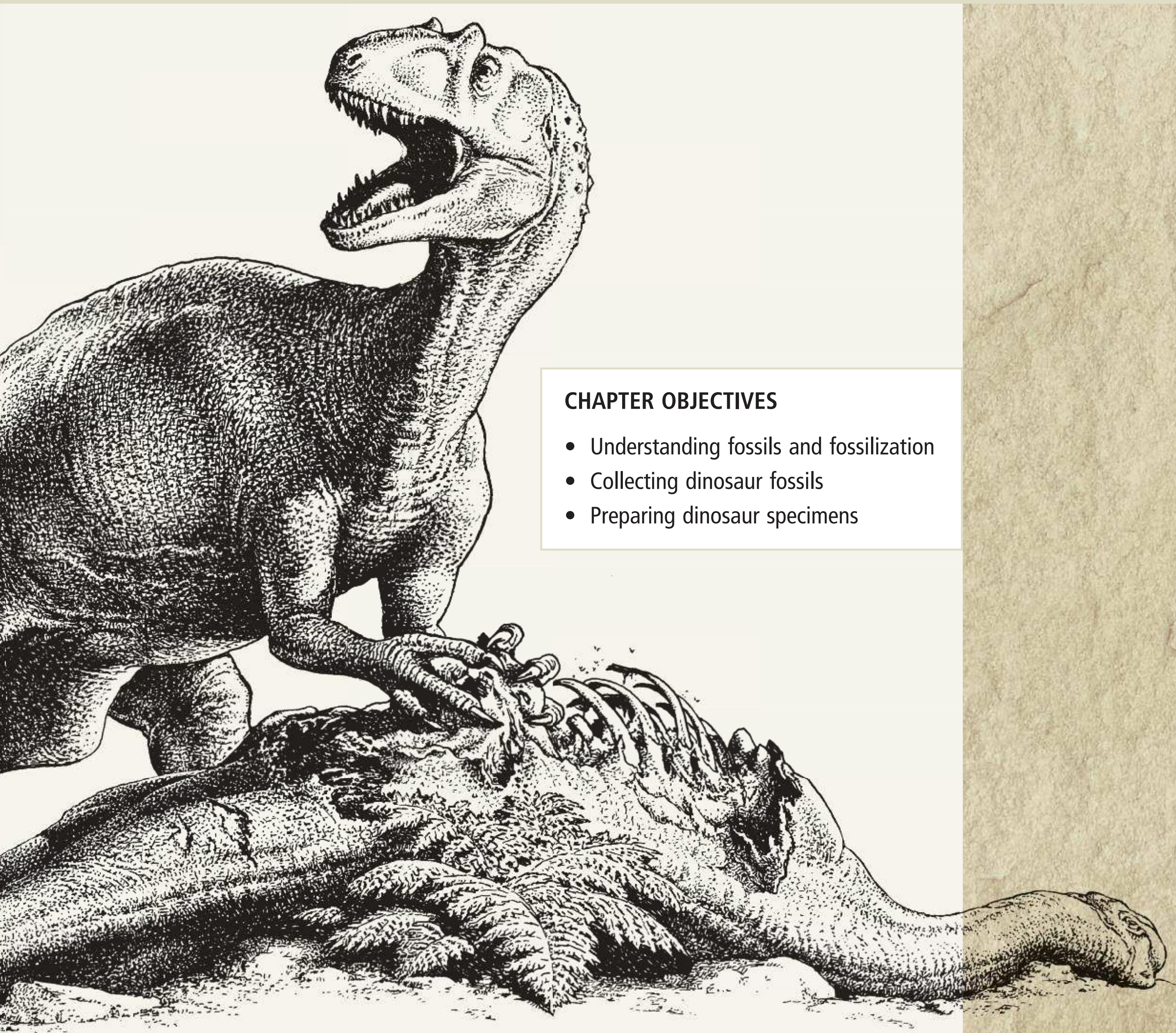
# 1 To catch a dinosaur



## CHAPTER OBJECTIVES

- Understanding fossils and fossilization
- Collecting dinosaur fossils
- Preparing dinosaur specimens

## Preservation and fossils

That we even know there ever were such creatures as dinosaurs is near-miraculous: throughout their time on Earth, a few individuals of the innumerable dinosaurs that must have once lived, happened to be preserved as fossils, the buried remains of organic life. There are many types of fossils: most familiar are body fossils, which commonly involve some part of the animal (e.g., bones). Trace fossils, impressions such as footprints, are also familiar. Finally, there are a variety of other kinds of fossils, including things as disparate as molecules and skin impressions.

Dinosaurs last romped on Earth ~66 million years ago, and until the very latest part of the twentieth century, paleontologists mostly assumed that dinosaur soft tissues – muscles, blood vessels, organs, skin, fatty layers, etc. – were long gone, with the only observable vestiges being the hard parts: generally, bones and teeth. Hard parts were presumably not as easily degraded over time as the soft tissues that constitute most of the body. Yet as it turns out, new techniques and determined study are revealing all kinds of preservation in unexpected places, including tissues, cells, and molecules (for example, the discovery of actual red blood cells and connective tissues from *Tyrannosaurus*; see Box 6.3). Fair warning: it's no longer just about old bones, and we'll visit some of these newer discoveries throughout this book.

### Making body fossils

#### Before burial

Consider what might happen to a dinosaur – or any land-dwelling vertebrate – after it dies (Figure 1.1).

Carcasses are commonly disarticulated (dismembered), first by predators and then by scavengers ranging from mammals and birds to beetles and bacteria. Some bones might be stripped clean of meat and left to bleach in the sun. Others might get carried off and gnawed. Sometimes the disarticulated remains are trampled by herds of animals, breaking and separating them further. Plants produce acids that dissolve bone. But ultimately, the nose knows that most of the heavy lifting in the world of decomposition is done by bacteria that feast on rotting flesh. The sum total of all the earthly remains of the animal will end up lying there: a few disarticulated bleached bones in the vegetation (Figure 1.1).

**Figure 1.1.** Bones. A wildebeest carcass, partly submerged in mud and water and on its way to becoming permanently buried and fossilized. If the bones are not protected from scavengers, air, and sunlight, they decompose rapidly and are gone in 10–15 years. Bones destined to become high-quality fossils must be buried soon after the death of the animal.

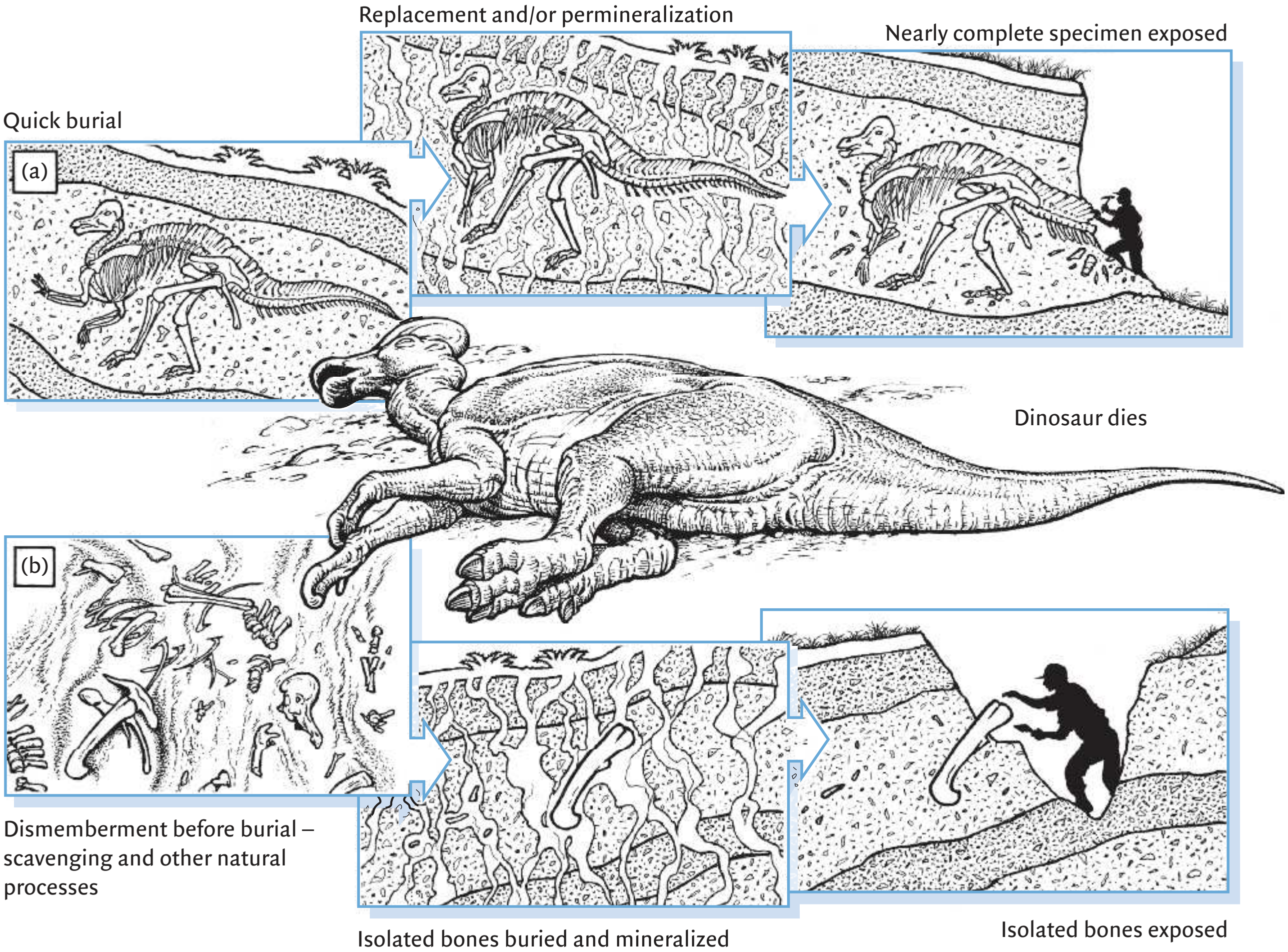



**Figure 1.2.** Two endpoint processes of fossilization. In both cases, the first step is the death of the animal. Some decomposition occurs at the surface. In the upper sequence (a), the animal dies, the carcass undergoes quick burial, followed by bacterial decomposition underground, and permineralization and/or replacement. Finally, perhaps millions of years later, there is exposure. Under these conditions, when the fossil is exhumed, it is largely complete and the bones articulated (connected). This kind of preservation yields bones in the best condition. In the lower sequence (b), the carcass is dismembered on the surface by scavengers and perhaps trampled and distributed over the region by these organisms. The remains may then be carried or washed into a river channel and buried, replaced, and/or permineralized, eventually to be finally exposed perhaps millions of years later. Under these conditions, when the fossil is exhumed, it is disarticulated, fragmented, and the fossil bones may show water wear and/or the gnaw marks of ancient scavengers. Different conditions of fossil preservation tell us something about what happened to the animals after death.

If the animal isn't disarticulated right away, it is not uncommon for a carcass to bloat, as feasting bacteria produce gases that inflate the dead body. After a bit, the carcass will likely deflate (sometimes explosively), and then dry out, leaving bones, tissues, ligaments, tendons, and skin crusty and inflexible.

## Burial

Sooner or later bones are either destroyed or buried. If they aren't gnawed and digested as somebody's lunch, their destruction can come from **weathering**, which means that the minerals in the bones break down and the bones wash away. But the game gets interesting for paleontologists when weathering is stopped by rapid burial. At this point, they (the bones, not the paleontologists) become fossils. Figure 1.2 shows two of the many paths bones might take toward fossilization.

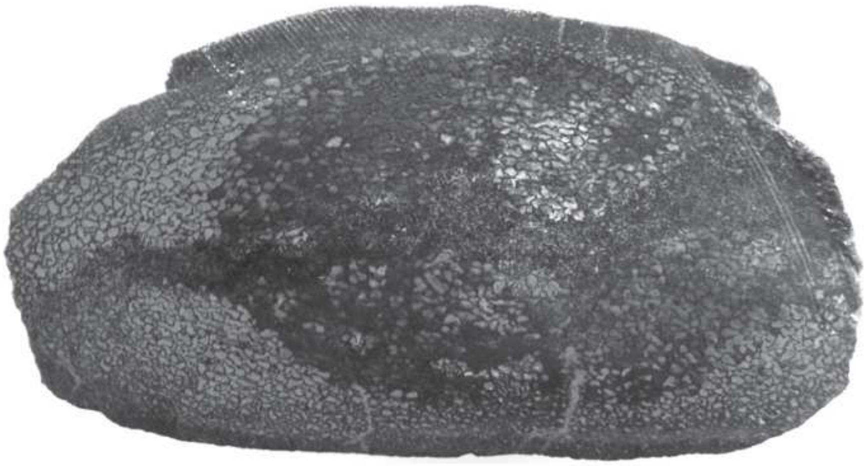


**Figure 1.3.** Permineralized bone from the Jurassic-aged Morrison Formation, Utah, USA. The fossilized bone is now a solid piece of rock.

### After burial

The burial environment is not chemically static, and the *bad* news is that bone is made out of calcium–sodium hydroxyapatite, a mineral that is not terribly stable on the Earth's surface. As a result, the original bone minerals are easily **replaced** by other minerals, commonly retaining the details and form of the bone. This is especially likely if the bone comes into contact with fluids rich in dissolved minerals, such as commonly occurs after burial. The *good* news is that, by few choice cation substitutions while buried, calcium–sodium hydroxyapatite commonly alters to more stable forms of apatite, a familiar one being fluorapatite.

If no fluids are present throughout the history of burial (a time interval that could be measured in millions of years), the bone may be unreplaced, which is to say that 100% of the original bone mineralogy remains. On the other end of the spectrum, a completely replaced bone is a magnificent natural forgery: chemically and texturally not bone, but retaining the exact shape and delicate features of the original bone. Given burial stays measured in tens of millions of years, however, most dinosaur bones are altered (replaced) to a greater or lesser degree. Alteration/replacement tends to be progressively greater in the case of older and older fossils; degrees of alteration are generally the norm.

Since bones are porous, the spaces once occupied by blood vessels, connective tissue, and nerves easily fill up with minerals. This is called **permineralization** (Figure 1.3).

Most fossil bones undergo a combination of some degree of replacement and permineralization.

The preceding description explains how isolated fossil bones, or perhaps most of a single animal, might come to be preserved. But along with these isolated finds, on rare and lucky days, we can sometimes come upon **bonebeds**, rich finds with hundreds – even thousands – of bones preserved. Sometimes, these bonebeds are **monospecific**, that is, they contain fossils of mostly one species, and one can't help but wonder if these perhaps reflect some kind of **gregarious**, or herding behavior captured in the fossil record.

## Trace and other kinds of fossils

### Trace fossils

Still the single most important type of dinosaur fossil, other than the bones themselves, is trace fossils. Dinosaur trace fossils (sometimes also called **ichnofossils** [*ichnos* – track or trace]), come as **footprints** or as complete **trackways**. Figure 1.4 shows a **mold**, or impression, of a dinosaur footprint. We also find **casts**, which are made up of material filling up the mold. Thus a cast of a dinosaur footprint is a three-dimensional object that formed inside the impression (or mold).

**Figure 1.4.** Theropod dinosaur footprint from the Early Jurassic Moenave Formation, northeastern Arizona, USA. Human foot for scale.

In the past 20 years the importance of ichnofossils has been recognized. Ichnofossils have been used to show that dinosaurs walked erect, to reveal the position of the foot, and to reconstruct the speeds at which dinosaurs traveled. Trackways tell remarkable stories, such as that fateful day 150 or so million years ago when a large predatory theropod stalked a herd of smaller animals (Figure 1.5).

### Other fossils

For want of a more imaginative name, we'll lump the various other kinds of fossils under "Other." Sometimes the fossilized feces of dinosaurs and other vertebrates are found. Called coprolites, these occasionally impressive relics can give an intestine's-eye view of dinosaurian diets. Likewise, as we shall see later in this book, fossilized eggs and also skin impressions have been found. Nests are also known (Figure 1.6). Molecules; cells; stomach stones (gastroliths; see Figure 6.20); soft tissue; the list is really as long as there are parts of a dinosaur!

## Finding fossils

So, if the fossils are buried, how is it that we find them? The answer is really in the luck of geology: if fossil-bearing sedimentary rocks happen to be eroded, and a paleontologist happens to be looking for fossils at the moment that one is actively eroding from a rock, the fossil *may* be observed and *may* be collected. Who knows how many times, throughout their 160+ million-year existence on Earth, dinosaurs stepped on exposed, weathering fossils of earlier dinosaurs, now surely lost to eternity (Figure 1.7)?

It's a tenuous connection: the vagaries of fossil preservation, the chance of geological exposure, and their discovery by an ambitious paleontologist. And yet they're out there – the fossils and the paleontologists!

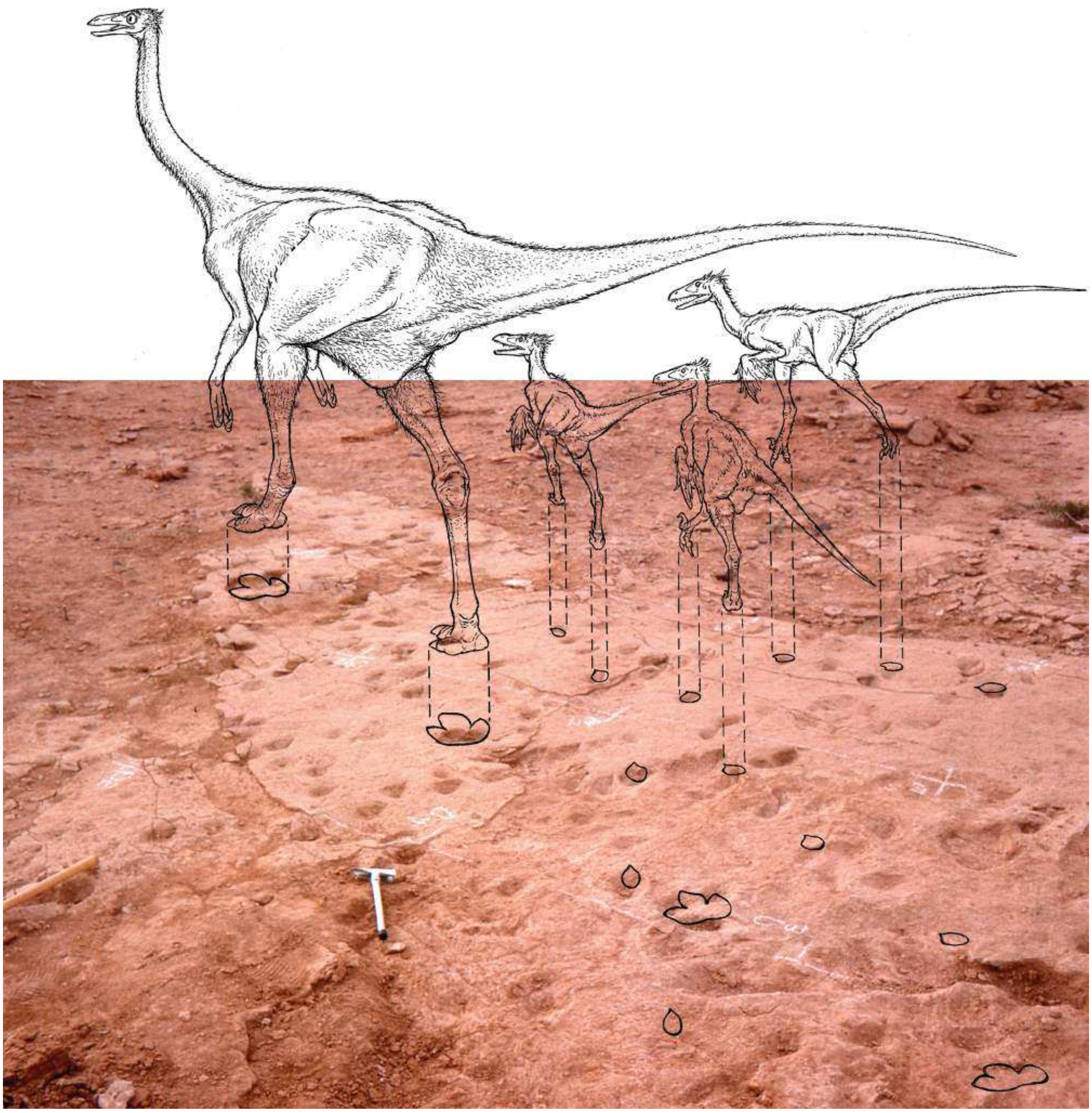


**Figure 1.5.** Photograph from Shar-tsav, Gobi Desert, Mongolia, showing the tracks of a medium-sized theropod dinosaur among those of a pack of smaller theropods. Our drawing suggests an interpretation consistent with the evidence: a *National Geographic* moment in the Late Cretaceous when a pack of *Velociraptor* attacked a single *Gallimimus*.

## Collecting

The romance of dinosaurs is bound up with collecting: exotic and remote locales, heroic field conditions, and the manly extraction of gargantuan beasts (see Chapter 15). But ultimately dinosaur collecting is a process that draws upon good planning, a strong geological background, and a bit of luck. The steps are:

(1) planning;
(2) prospecting; that is, hunting for fossils;
(3) collecting, which means getting the fossils out of whichever (usually remote) locale they are situated; and
(4) preparing and curating them; that is, getting them ready for viewing, and incorporating them into museum collections.

These steps involve different skills and sometimes different specialists.

Figure 1.6. Fossil burrow of the dinosaur *Oryctodromeus*. Careful study of the sedimentary context of this dinosaur revealed the burrow.

## Planning

Collecting dinosaur fossils is not to be undertaken lightly. Dinosaur bones are – even in the richest sites – quite rare, and the moment they are disturbed the loss of important information becomes a concern. For this reason, most professional paleontologists have advanced degrees – often a PhD in the geological or biological sciences – but before actually leading an expedition themselves, *all* have acquired many years of experience both in the logistical as well as the scientific ends of fieldwork.

### Running an expedition

The logistical end of an expedition involves keeping one's team fed, watered, healthy, and happy in remote places where, in many cases, these commodities don't come easily. Relentless sun, extreme heat, dust, lack of amenities, subsistence on a limited diet, and isolation from the "real world," all conspire to wear down even the most robust of people. It's all happening in the Great Outdoors, true, but it's nothing like a camping catalog! Add to these, language problems when you are working in other countries and limited access to medical facilities in the event of an accident involving either you or one of your crew, and the potential for disaster increases dramatically.

Many expeditions have to carry everything with them – fuel, water, food, all gear for the maintenance of daily life – as well as all the maps and equipment necessary to successfully carry out the science and safely retrieve heavy, yet delicate, dinosaur bones. This takes some serious planning and experience; you and your crew's lives may depend upon it (Figure 1.8). You have to know what you are doing.

Fossils generally, and dinosaurs in particular, are not renewable resources, which means that collecting a dinosaur is a one-shot deal: it must be done right, because we will never be afforded another chance to do it again. Any information that is lost – any piece of it that is damaged – may be lost or damaged forever. For this reason, there are many regulations associated with collecting vertebrate fossils.

The most basic are the collection permits required for work on public lands. Obtaining the permits requires advanced planning because the agencies in charge of issuing the permits reasonably require detailed accounts of your plans before the process can go forward.

One important part of the permit-obtaining process, especially in the case of dinosaur fossils (which tend to be large and heavy), is the eventual location of the fossils. Who gets them? Does

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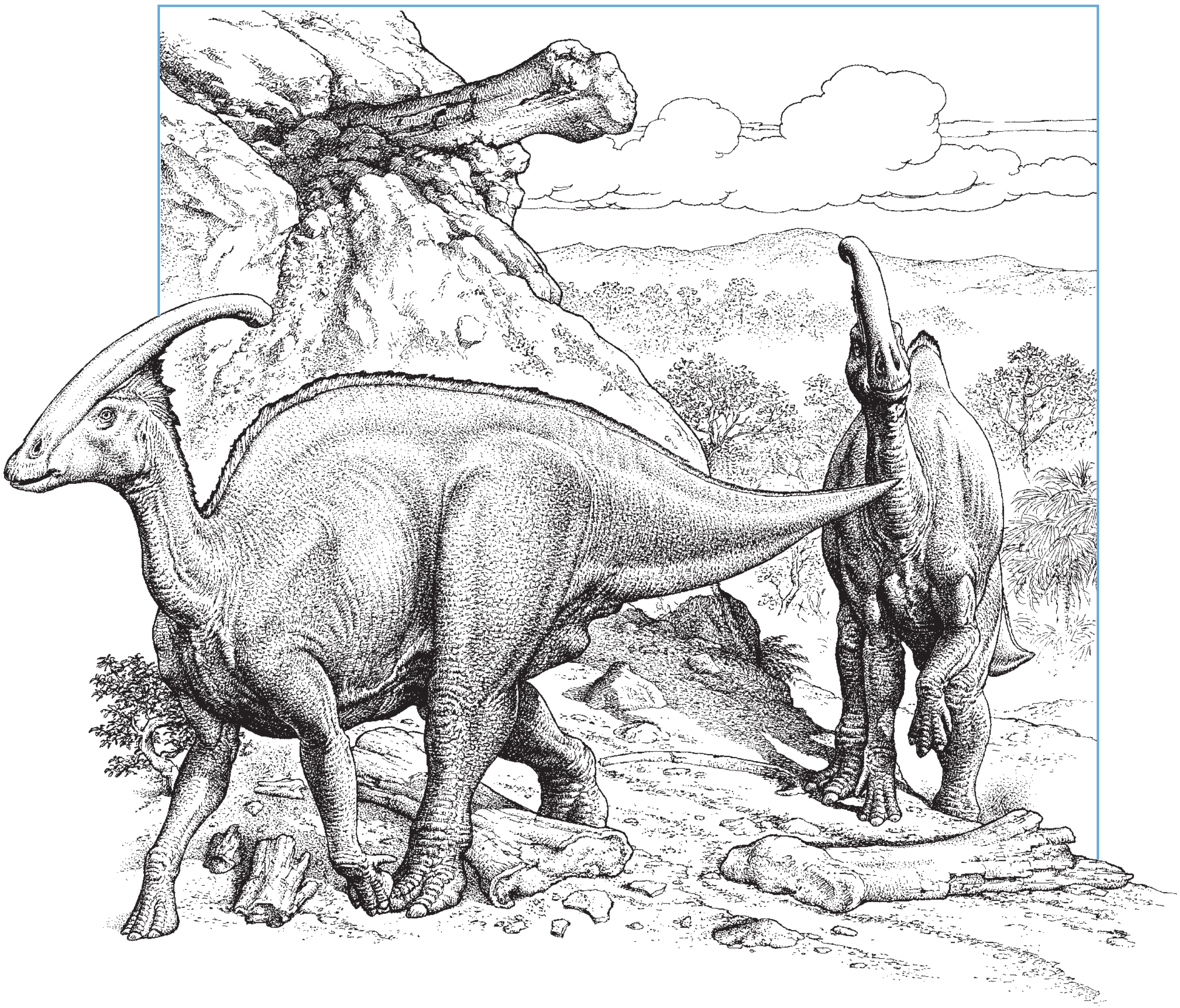

**Figure 1.7.** A pair of *Parasaurolophus* walking over some exposed fossilized bones of an earlier dinosaur that are weathering out of the cliff. Fragments of the fossilized bone have fallen at the dinosaurs' feet.

that person or place have the proper resources – or even the space – to store, preserve, and make them accessible to scientists and the general public? How is all this to be accomplished? Most of the truly great collections and many of the most important dinosaur fossils are housed in major museums, such as the American Museum of Natural History (New York), the Field Museum (Chicago), the Yale Peabody Museum (New Haven, CT), Tyrrell Museum (Alberta), the Smithsonian (Washington, DC), the Natural History Museum (London), the Musée National d'Histoire Naturelle (Paris) and many others around the world. These institutions have the resources required for the care of important specimens and the data associated with them.

Work overseas – and paleontology generally involves a lot of foreign travel, no matter where you live – involves a whole new level of administrative preparation. All of the problems described above are compounded by language barriers, by the necessity to obtain visas along with permits, by the logistics of preparing a field expedition in a foreign country, and by the necessity of arranging for the eventual disposition of the fossils. What country, after all, would gladly see its fossil resources dug up and exported elsewhere? It's a delicate balance, sometimes requiring the skills of a diplomat.

 

## Box 1.1 A dino named "Sue"

"Sue" is a spectacular fossil of a very large *T. rex* – and a notorious object lesson in the kinds of misunderstandings and problems that can arise when collecting dinosaurs. Paleontologist Peter Larson, co-founder and President of the Black Hills Institute of Geological Research (BHIGR; a company that collects, prepares, and sells fossils and casts), believed that he had obtained permission from South Dakota rancher Maurice Williams, for the rights to collect (and then, presumably, prepare and sell) fossils he and his crews might find on Mr. Williams' land. They agreed that BHIGR would pay Mr. Williams for any fossils that he found. In July, 1990, Sue Hendrickson, a volunteer crew member, discovered the dinosaur (hence the name). It was *very* rare – a *T. rex*: somewhat jumbled, but clearly large, semi-articulated, well-preserved, and obviously extremely valuable. Larson and his crews devoted considerable resources (ultimately, ~$209 000) and time to collecting the many parts of the specimen (the skull alone was almost 2 m long!), starting with shaving almost 10 m off of the top of the hill in which it had been found so that they could reach the bones. By the end of the field season, they had brought a very large chunk of the specimen back to their laboratory in South Dakota, where preparation began. In accordance with Mr. Larson's understanding of the original agreement, a check for $5000 was issued to Mr. Williams for rights to the specimen. Talks were presented at national scientific meetings; publications were planned; preparation continued apace; so far, it seemed as if it was exciting specimen, but not a socio-political phenomenon.

Then the patient went septic. Mr. Williams claimed that he had not given BHIGR rights to the specimen; only that that they were allowed to remove the fossil and prepare it. Complicating the issue, because Mr. Williams is a member of the Sioux Tribe, the Sioux Nation claimed that the fossil belonged to it. And as if that weren't difficult enough to sort out, the US Federal Government claimed that Mr. William's land was held in trust by the United States, and therefore the fossil belonged to the United States as represented by the Department of the Interior!

In 1992, without warning, the feds moved in: guns, FBI agents, police.[a] Somewhat unceremoniously (by all accounts), the FBI searched the place, and the US National Guard forcibly removed Sue's remains from the BHIGR, storing them at the University of South Dakota School of Mines and Technology, a well-known facility able to handle a specimen of this magnitude – and equally importantly, presumably, neutral ground.

Then the courts took over. The dinosaur languished. After a rather lengthy trial, the court returned the specimen to Mr. Williams, who sought to auction it through the famous auction house of Sotheby's. In the mean time, Mr. Larson served jail time for permit infractions, unrelated to Sue; however, there are those who claim that the charges and subsequent sentencing were in effect political.

The value of the specimen was undoubted, and the concern was that it would leave the United States and end up in a private collection somewhere where it could not be appreciated. So, an unholy alliance formed between the Field Museum in Chicago, the California State University System, Disney Parks, McDonalds, the Ronald McDonald House, and private donors, who all pitched in to see the fossil displayed at the Field Museum, which won the bid for a total output of about $8.3 million.

Preparation was carried out both at the Field Museum and at Disneyworld in Orlando, Florida, where thousands of visitors to both venues saw the bones being freed of matrix, cast, and readied for mounting. Sue is now the star attraction of the Field Museum. All's well that ends well, right?

The "Sue" story is perhaps the most egregious example of the kinds of things that can go awry in paleontological collecting. By most accounts it ended well: the dinosaur is safe, intact – estimates are that it is an almost unbelievable 80% complete – and on display where it is properly maintained and optimally appreciated. On the other hand, maybe things didn't end so well: Sue changed the landscape of dinosaur paleontology, because now everybody recognizes that dinosaur fossils, formerly thought to be valueless, can potentially be sold for millions of dollars. Collecting dinosaurs has become an expensive business, and many scientists no longer have the resources to stay in the game.

[a] Larson quotes an FBI agent as saying, "This can be real easy, or real hard, depending on whether or not you are willing to cooperate." We favor Robert De Niro for the role.

**Figure 1.8.** Supplies for one of the American Museum of Natural History's 1920s expeditions to the Gobi Desert. In the intervening 90 years, nobody has found a way to get around hauling the basic necessities into the field.

### Science

All of that care expended upon all those logistics is meaningless unless our planning extends to the science as well. Paleontologists don't just go to weird places and grab bones. If they did, they'd lose, forever, essential information bearing upon four major problems.

(1) What kind of environment was it in which the dinosaur was preserved (because it might have lived somewhere else)?
(2) Where did it live (geographically)?
(3) When it did it live?
(4) How did it die?

*Oryctodromeus*, a small burrowing, herbivorous dinosaur (Figure 1.6), is a perfect example of the importance of geological context. Here was an animal found fossilized in its own burrow. Had the important geological context not been properly interpreted, the burrow would not have been recognized and this animal's unusual behavior (for a dinosaur, at least) would have gone unappreciated.

So before even collecting the fossil, the **locality** – the area in which the fossil or fossils occur – must be mapped geologically, in a way that records the most information possible about the setting in which the fossil was found. This kind of information requires specialized geological study of the **paleoenvironments**, that is the ancient environments represented by the rocks in which the fossils are found, as well as the geological context above and below the fossil. Usually this is accomplished by geological mapping and by detailed study of the sedimentary geology of the locality. Interpreting the ancient environment in which the bones came to rest commonly involves teaming up with **sedimentologists** – geoscientists with specialized knowledge of sedimentary rocks and the ancient environments that they preserve. This kind of teamwork allows paleontologists to develop the most complete picture of the fossils and the conditions in which they lived and died.[1]

[1] The study of all that happens to an organism after its death is called "taphonomy," and is a specialized field combining sedimentology and paleontology. Understanding the taphonomy of a fossil is the best way to know whether the animal actually lived in the environment in which its fossils were found, or whether its carcass was just deposited there after death.