
FOSSIL CANYON®
Dinosaurs of North America Card Game
SCIENCE
Learn more about the science behind the game!

FRONT COVER
Ambush at Hell Creek
by Franco Tempesta

Sixty-seven million years ago, a humid day in a subtropical forest of present-day South Dakota, off the western edge of the receding Western Interior Seaway. A group of Triceratops *stops for a drink at a watering hole, unaware of the danger stalking them. A sudden crash in the undergrowth sends them scattering in a panic as a massive* Tyrannosaurus rex *thunders from the trees, isolating a juvenile for its charge. Recovering from its initial surprise, the young* Triceratops *realizes the window for flight has passed, but it is not defenseless ...*

FOSSIL CANYON

Dinosaurs of North America Game Science Companion

Text by Kevin Lynch and Akiko Shinya | Design by Nathan Martel

This booklet provides an introduction to the science behind the game Fossil Canyon.

Whether you are headed toward a career in paleontology or another field of science, math, or engineering, or you are just curious about the fascinating creatures in the game, we hope Fossil Canyon will be a fun part of your discovery of the natural world!

We are deeply grateful for the generosity and vision of our Kickstarter backers to bring Fossil Canyon to life. We especially thank our patron-level supporters:

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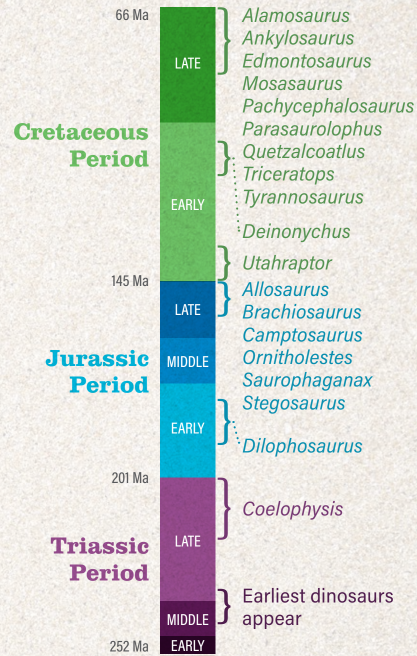
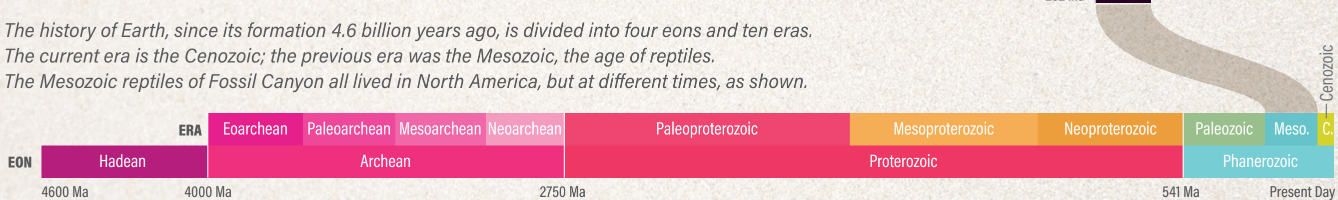
THE SCIENCE OF FOSSIL CANYON

Geological periods

The history of Earth is divided into a sequence of geological "eras," and all reptiles in this game lived during the Mesozoic Era, or the "age of reptiles." The Mesozoic is divided into three "periods": the Triassic, 252–201 Ma ("Mega annum," or millions of years ago); the Jurassic, 201–145 Ma; and the Cretaceous, 145–66 Ma. Mass extinctions mark the boundaries of these geological periods. For example, the Triassic began with the largest mass extinction, when more than 80% of marine species and 70% of land species were lost. The primary cause is believed to be an increase in volcanic activity, leading to acid rain and rising temperatures on land and in the sea, as well as acidification of the ocean. The mass extinction at the end of the Cretaceous began with increased volcanic activity and falling sea levels, and it culminated dramatically when an asteroid smashed into Earth, causing global climate change that led to the collapse of food chains and the demise of 75% of species. (See page 8.)



The history of Earth, since its formation 4.6 billion years ago, is divided into four eons and ten eras. The current era is the Cenozoic; the previous era was the Mesozoic, the age of reptiles. The Mesozoic reptiles of Fossil Canyon all lived in North America, but at different times, as shown.



EARLY TRIASSIC • 251 Ma

MIDDLE JURASSIC • 165 Ma

LATE CRETACEOUS • 86 Ma

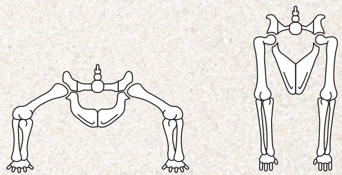
The changing map of Earth during the Mesozoic. In the Late Cretaceous, a shallow sea with abundant marine life, called the Western Interior Seaway, split western North America (Laramidia) from eastern North America (Appalachia).

Drifting continents

Because of plate tectonics (large-scale processes causing motion of Earth's crust), a map of Earth today looks very different from how it would have looked at any time during the Mesozoic. In the Triassic, the supercontinent Pangaea incorporated nearly all dry land on Earth. Pangaea began to break up during the Jurassic, and continued drifting led to the seven continents of the present day. This is why animals that lived near each other in Pangaea are found as fossils on different continents today.

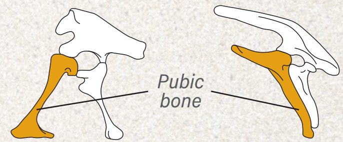
Dinosaurs and their reptile cousins

Dinosaurs began to appear around 240 Ma, during the Triassic Period. Dinosaurs are a subgroup of archosaurs (a group of reptiles including dinosaurs, crocodilians, and flying pterosaurs) that evolved thigh bones (femora) with heads turning inward and inserted into open sockets in the hips. This allowed the hind legs to be vertical under the body, unlike the sprawling stance of a crocodile, for example. This erect arrangement may have given dinosaurs advantages such as faster or more efficient locomotion,



SPRAWLING STANCE (CROCODILES)

ERECT STANCE (DINOSAURS)



SAURISCHIAN HIP BONES

ORNITHISCHIAN HIP BONES

For saurischian dinosaurs, the pubic bone of the hip points forward. For ornithischians, the pubic bone extends backward. Here, dinosaurs face left.

the ability to support greater weight and therefore grow bigger, and the ability to breathe more easily while walking or running.

Dinosaurs are still alive today! We now know that all birds, including more than 10,000 living species, evolved from dinosaurs of the Mesozoic, and therefore they are dinosaurs too. Birds and *Triceratops* share a common evolutionary ancestor, and dinosaurs are defined as the descendants of that ancestor, including all birds ("avian" dinosaurs), living and extinct, and all "non-avian" dinosaurs, which are all extinct.

The first dinosaurs were small and bipedal (walked on two legs), and they diversified into a huge variety of species, including quadrupeds (animals that walk on four legs) and bipeds, herbivores (plant eaters) and carnivores (meat eaters), tiny hummingbirds and the largest land animals of all time. Non-avian dinosaurs lived on every continent and were the dominant land animals during the Jurassic and Cretaceous periods, more than 130 million years.

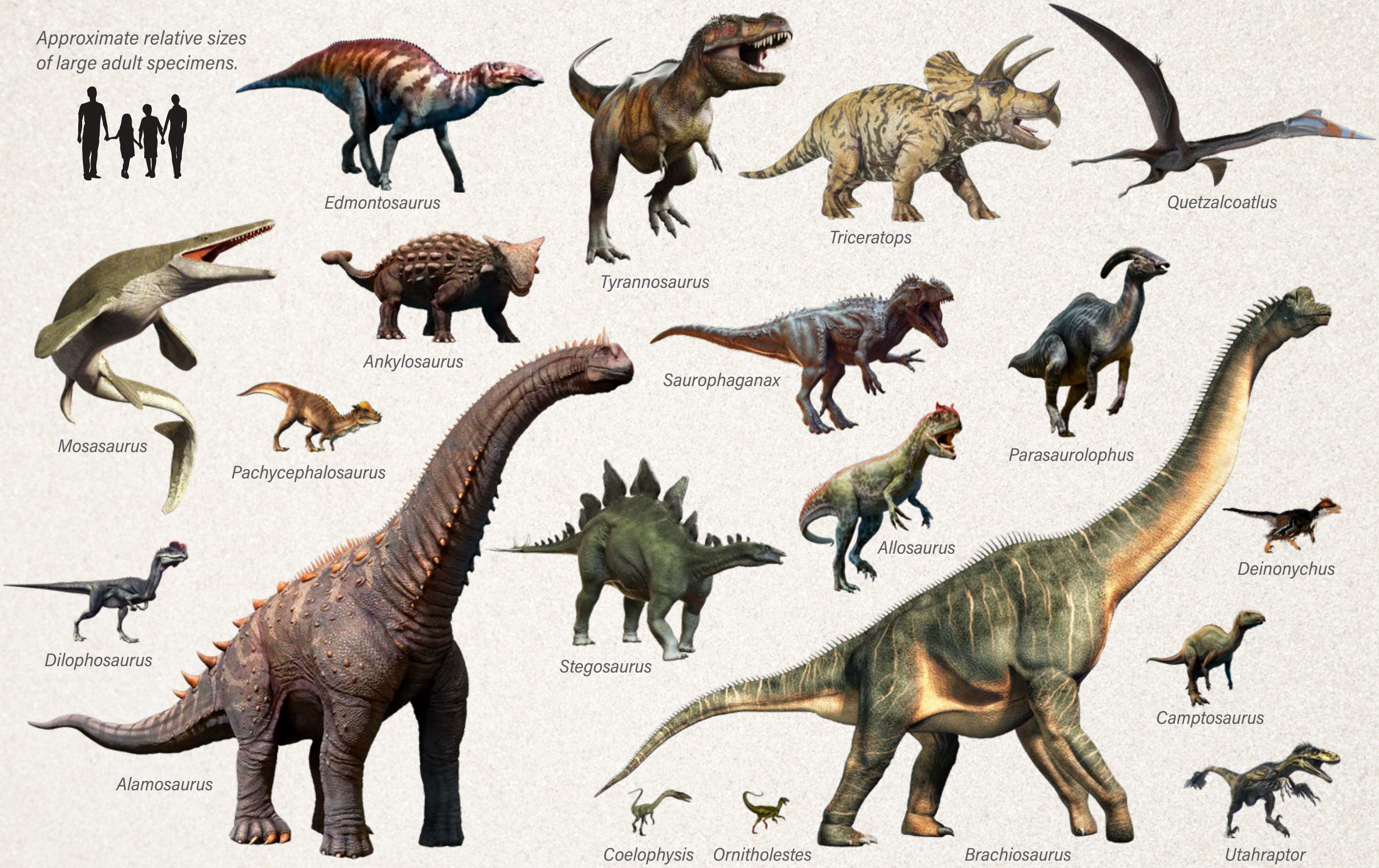
Dinosaur groups

More than a thousand species of extinct dinosaurs have been identified, and more are being discovered every year. Our understanding of dinosaurs is constantly evolving, but dinosaurs are traditionally classified into one of two categories, depending on the shape of their hips: the saurischians ("lizard-hipped" dinosaurs), with a pubic bone pointing forward, and the ornithischians ("bird-hipped" dinosaurs), with a pubic bone extending backward.

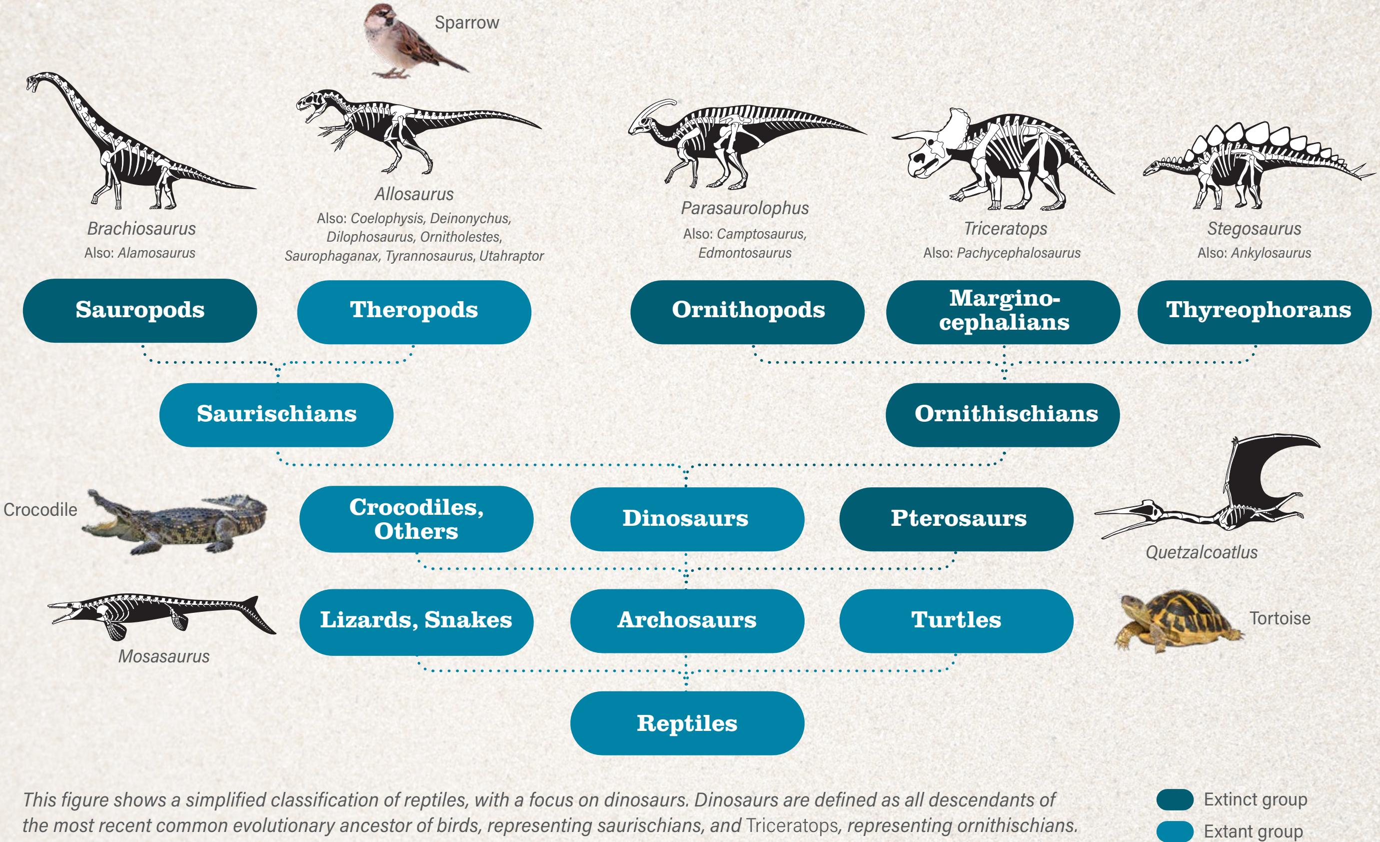
Major groups of saurischian dinosaurs include the theropods and the sauropods. Theropods are bipedal carnivores such as *Allosaurus*, *Coelophysis*, *Deinonychus*, *Dilophosaurus*, *Ornitholestes*, *Saurophaganax*, *Tyrannosaurus*, and *Utahraptor*. This family of dinosaurs evolved into modern birds. Sauropods are quadrupedal herbivores like *Alamosaurus* and *Brachiosaurus*. The largest land animals ever were sauropods.

Major groups of ornithischian dinosaurs include ornithopods, the bird-footed herbivores like *Camptosaurus* and duck-billed *Edmontosaurus* and *Parasaurolophus*; marginocephalians, the fringe-headed herbivores like thick-skulled *Pachycephalosaurus* and the beaked and horned *Triceratops*; and thyreophorans, armored herbivores like *Ankylosaurus* and *Stegosaurus*.

Quetzalcoatlus is a pterosaur (flying reptile), not a dinosaur. *Mosasaurus* is not an archosaur but a marine lizard classified as a squamate, an order of reptiles including all lizards and snakes. **Although "saur" and "saurus," taken from Greek, commonly translate as "lizard," dinosaurs and pterosaurs were not lizards!** To avoid this confusion, some people translate "saur" to mean "reptile" in the context of dinosaurs and pterosaurs.



Approximate relative sizes of large adult specimens.



This figure shows a simplified classification of reptiles, with a focus on dinosaurs. Dinosaurs are defined as all descendants of the most recent common evolutionary ancestor of birds, representing saurischians, and Triceratops*, representing ornithischians. Birds (avian dinosaurs) actually evolved from the lizard-hipped saurischian theropods, not the bird-hipped ornithischians.*

Genus and species

Animals are referred to in this game by their genus, such as *Triceratops*. A genus may include multiple species, such as *Triceratops horridus* and *Triceratops prorsus*. (*T. horridus* had a small nose horn and a long beak, while *T. prorsus* had a larger nose horn and a smaller beak.) One of a genus' species is called the "type species," meaning that this species will remain associated with the genus even if later research indicates the various species do not belong to the same genus. For *Triceratops*, *T. horridus* is the type species. The "type specimen," or "holotype," is the unique skeleton or set of fossils used to define the species. Although SUE at the Field Museum in Chicago is a much larger and more complete *T. rex* skeleton, the holotype of the species *T. rex* is a partial skull and skeletal fragments at the Carnegie Museum of Natural History in Pittsburgh. These fossils were found by Barnum Brown in 1902 and were first to be named *Tyrannosaurus rex* by Henry Osborn in 1905.

The end of an era

Sixty-six million years ago, an asteroid ten kilometers wide, traveling 20 kilometers per second, slammed into Earth with the energy of billions of nuclear bombs, creating the Chicxulub (CHICK-shoo-loob) crater off the coast of Mexico. The enormous energy at impact vaporized nearby material; caused air pressure pulses and fires that scoured nearby land; and triggered massive

The Chicxulub impactor brought the Mesozoic Era, and the reign of non-avian dinosaurs, to a dramatic end.

earthquakes and tsunamis that traveled far inland. The impact also ejected scorching hot debris into the atmosphere, which rained back down on Earth for days, causing fires around the world. Oceans became more acidic and ash and dust blocked the sun worldwide, leading to a prolonged "impact winter" and the collapse of food chains. After the dust cleared, increased carbon dioxide in the atmosphere, due to vaporized rock and worldwide fires, caused greenhouse warming that may have lasted 100,000 years. This catastrophe wiped out the non-avian dinosaurs and brought the Mesozoic Era to an end, clearing the way for the rise of mammals, including humans.

Fossils and fossilization

A fossil is any evidence of ancient life preserved in rock. Fossils can be body fossils or trace fossils.

Trace fossils provide evidence of the behaviors of ancient life, and include fossilized footprints and trackways, tooth and claw marks, skin and feather impressions, nests, and coprolites (petrified poop).

Body fossils are typically formed from hard tissues such as bones, teeth, claws, and shells. (Soft tissues—skin, muscle, tendons that connect muscle to bone, ligaments that connect bone to bone, etc.—rarely fossilize because they usually decay before fossilization can occur.) Conditions must be just right for fossilization: the remains must be buried quickly before decay, decomposition, and scavenging, and mineral-bearing groundwater must seep into the tissue and replace the decaying tissue with minerals. Over time, the tissues become mineralized fossils. Fossilized tissue, such as a fossilized bone, weighs much more than the original tissue.

On rare occasions, a complete or nearly complete dinosaur skeleton is found with its bones in place relative to each other as they were in life. More often, however, most bones are missing or scattered. Museum skeletons are typically completed with casts (replicas made from other skeletons) or sculpted artificial bones.

Fossils are found in sedimentary rock, rock formed by "sediment" (minerals, organic material, and other matter) depositing and cementing under heavy pressure over many years, often at the bottom of a body of water such as a river, lake, floodplain, or ocean. The changing environment over millions of years leads to different mineral content of the sediment, creating different kinds of rock layers, often of different colors. These visibly different rock layers, evident in some eroded cliffs and canyons, are called "strata." Since younger sedimentary rocks lie on top of older rock, older fossils are usually found in deeper strata.

A dinosaur leaves behind a fossilized skeleton. From left to right: (1) The dinosaur dies near the edge of a river. (2) The body is covered by sediment and decomposes. Minerals replace the hard tissues (bone, teeth, and claws). (3) The layers of sediment are compressed and harden into rock, and the hard tissues become fossils. (4) Movement of the earth raises and tilts the layers of rock. (5) The rock erodes, exposing the fossils.

Only a small percentage of dinosaurs left behind fossil evidence, and most of these fossils are buried deep in the ground. Most dinosaur fossils in the exposed rock formations of western North America were discovered because mountain-building forces due to plate tectonics lifted and tilted the fossil-bearing sedimentary rock layers, and erosion has revealed the fossils over time.

Fossil-rich formations

Some of the richest dinosaur fossil sites in the world are in western North America. For example, several hundred skeletons of *Coelophysis* are estimated to be fossilized in the Petrified Forest Formation at Ghost Ranch in New Mexico, USA. *Coelophysis* lived during the Triassic, and it is one of the earliest known dinosaurs in North America.

Two sedimentary rock formations in western North America are particularly well known for their dinosaur fossils: the Morrison Formation and the Hell Creek Formation.

The "Wall of Bones" at Dinosaur National Monument in Utah, USA. Over a time period of around 100 years about 149 million years ago, the bodies of many dinosaurs were swept to the bottom of an ancient river, where they were covered in sediment. Their bones fossilized, and the layer of sedimentary rock in which they were entombed was lifted up and tilted to approximately 67 degrees from horizontal by mountain-building forces. After erosion, the first dinosaur bone was discovered in 1909 by Earl Douglass. The result of excavation is a wall of fossilized bones still embedded in the Morrison Formation rock.

The Morrison Formation, named for the town of Morrison, Colorado, USA, is centered in Colorado and Wyoming, USA, but it extends into Canada and through many western US states, including Montana, Idaho, Utah, Arizona, and New Mexico. The sedimentary rock layers were deposited by rivers and floodplains of the Late Jurassic, and they range from about 156 Ma at the bottom of the formation to 146 Ma at the top. The western portion of the Morrison Formation was uplifted during the formation of the Rocky Mountains 70–40 million years ago and subsequently eroded, exposing fossils of *Allosaurus*, *Brachiosaurus*, *Camptosaurus*, *Ornitholestes*, *Saurophaganax*, and *Stegosaurus*. Much of the Morrison Formation remains buried under prairie to the east.

A view of the Green River at Dinosaur National Monument in Utah, USA. Different sedimentary rock layers ("strata") are clearly visible. These rock layers resulted from deposition and cementing of sediment over many millions of years. The rock was later uplifted by mountain-building forces and then eroded. At some places in Dinosaur National Monument, the erosion of the Morrison Formation, sedimentary rocks deposited 156–146 Ma, has exposed fossils of many Late Jurassic dinosaurs.

The sedimentary rock layers of the Hell Creek Formation were deposited approximately 68 to 66 Ma, during the Late Cretaceous. The Hell Creek Formation, named for Hell Creek in Montana, USA, extends through Montana, North Dakota, South Dakota, and Wyoming, USA, along the changing western shore of the Western Interior Seaway of the Late Cretaceous. The coastal plain environment, consisting of river deltas, swampy lowlands, and forested floodplains, provided an excellent environment for the fossilization of Late Cretaceous dinosaurs such as *Ankylosaurus*, *Edmontosaurus*, *Pachycephalosaurus*, *Triceratops*, and *Tyrannosaurus*.

Locations of fossils found of the animals in the game Fossil Canyon. Most of the fossils found outside of western North America are of Mosasaurus*. Data are taken from the Paleobiology Database and plotted using the online paleogeographic map generator at fossilworks.org.*

Paleontology

Paleontology is the study of ancient life. Much of the evidence of that life comes from fossil rocks, so paleontology is at the intersection of biology and geology.

To find fossils, paleontologists use geological maps to identify exposed sedimentary rock formations (sandstone, mudstone, limestone, or shale) of the right age and the right environment at the time the rock was formed. (For example, rock that was formed at the bottom of an ancient sea would not be a good place to look for dinosaur fossils.) They then scan the ground, cliffs, or canyon walls for fossils that are visibly eroding out of the rock. Fragments of fossilized bone at the surface may indicate that larger bones are nearby, waiting to be excavated.

Paleontologists search for fossils (prospecting); dig them out using shovels, rock hammers, chisels, brushes, and other tools, and encase them in plaster field jackets for safe transportation (excavation); bring them back to the lab or museum for cleaning (preparation); record their identification, site, and geological information (accession); use advanced instruments to study the fossils and apply scientific techniques to gain further insight into ancient life; and publish their findings for others. Fossils may be stored in a museum collection or displayed to the public.

Science advisor Akiko Shinya at work in the field and in the lab.
Top: Akiko discovering the theropod Gualicho shinyae *in Argentina in 2007.*
Bottom: Akiko carefully removing a fossilized bone from surrounding rock in the lab. The whitish outer surface of the rock is the plaster field jacket.

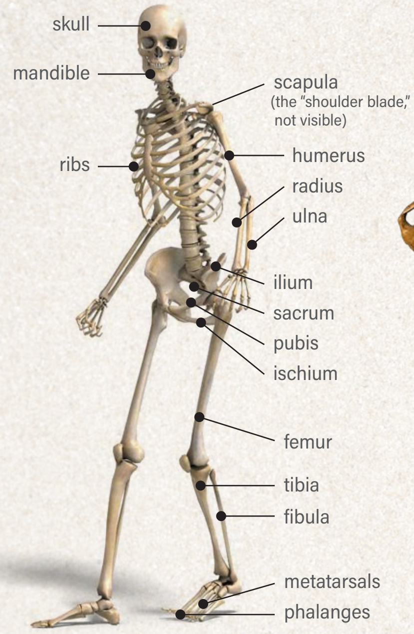
SUE and you

Walking along the base of a cliff of the Hell Creek Formation in South Dakota, USA, in 1990, Sue Hendrickson noticed bone fragments on the ground. Looking up, she saw larger bones protruding from the eroding cliff. It took a crew of six 17 days to excavate the fossilized bones of the *Tyrannosaurus rex* that would come to be known as SUE. SUE was acquired by the Field Museum in 1997 and first displayed to the public in 2000. SUE is perhaps the largest and most complete *T. rex* skeleton in the world (approximately 90 percent complete by bulk).

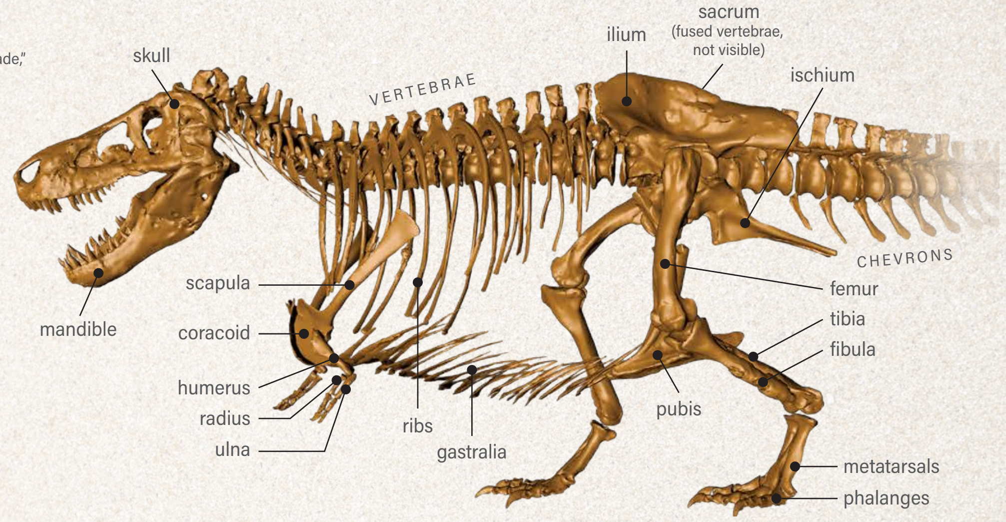
SUE lived to about 30 years of age, which was quite old for a *T. rex*. SUE's soft tissues did not fossilize, so we don't know whether SUE was male or female.

Although SUE lived 67 million years ago and weighed in excess of 8,000 kg more than you, your skeleton has similarities to SUE's. For example, *T. rex* and human legs both have a single bone attached at the hip (the femur) and two bones attached at the knee (the tibia and fibula), and *T. rex* and human arms both have a single bone attached at the shoulder (the humerus) and two bones attached at the elbow (the radius and ulna). Scientists believe this commonality comes from an evolutionary ancestor we share with *T. rex*: a 400 million-year-old "lobe-finned" fish, with muscle and bones in its fins, unlike the more common "ray-finned" fish, whose fins consist only of bony rays in a membrane of skin. Lobe-finned fish developed one bone-two bone pectoral and pelvic fins, with the "elbows swing forward" and "knees swing backward" arrangement of all later four-limbed land animals. Fish with these and other adaptations first began to adapt to life on land nearly 400 million years ago, later diversifying to become amphibians, reptiles, and mammals.

Paleontologists are unsure why *T. rex* arms evolved to be so small, but *T. rex* is not the only dinosaur species to evolve small arms. For example, *Gualicho shinyae*, which was discovered by Akiko Shinya in Argentina in 2007, is also a bipedal meat-eating dinosaur (a theropod, like *T. rex*) with small arms and two-fingered hands, like *T. rex*. But *G. shinyae* lived approximately 93 million years ago and is only distantly related to *T. rex*. This has led paleontologists to conjecture that the evolution of small arms on theropods may be an example of **convergent evolution**, where common environmental pressures lead to similar characteristics evolving in different species at different places and times. Other examples of convergent evolution include the streamlined bodies and dorsal fins of sharks and dolphins. These features help to make sharks and dolphins well-suited to life as marine predators, but all ancestors of sharks were aquatic, while the ancestors of dolphins were land mammals 50 million years ago. Convergent evolution is in contrast to **divergent evolution**, where animals with a common ancestor (like the lobe-finned fish for all four-limbed land animals) develop different characteristics and specializations over many generations, resulting in new species.

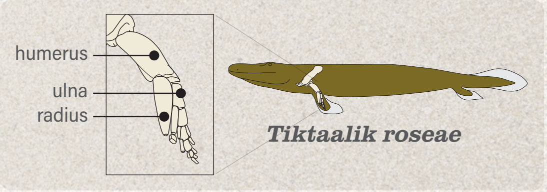


Homo sapiens



Tyrannosaurus rex

Human and T. rex *skeletons, like SUE above, share common features, such as a one-bone plus two-bone arrangement in the arms (humerus plus radius and ulna) and legs (femur plus tibia and fibula). Early lobe-finned fishes had already begun to evolve these features around 400 million years ago. As one example,* Tiktaalik roseae*, which lived 375 million years ago and may have spent time on land, had pectoral fins with one bone attached at its "shoulder" and two bones attached at its "elbow." (Images not to scale.)*



Tiktaalik roseae

REFERENCES AND FURTHER READING

Recommended books

National Geographic Kids Ultimate Dinopedia, second edition, Don Lessem (author) and Franco Tempesta (illustrator), National Geographic Children's Books, 2017.

Encyclopedia Prehistorica Dinosaurs: The Definitive Pop-Up, Robert Sabuda and Matthew Reinhart, Candlewick, 2005.

Dinosaurs: A Visual Encyclopedia, second edition, DK Publishing, a Division of Penguin Random House, 2018.

Dinosaurs: The Grand Tour, second edition, Keiron Pim, The Experiment Publishing, 2019.

The Rise and Fall of the Dinosaurs, Steve Brusatte, William Morrow and Company, 2018.

The Princeton Field Guide to Dinosaurs, second edition, Gregory S. Paul, Princeton University Press, 2016.

Your Inner Fish: A Journey into the 3.5-Billion-Year History of the Human Body, revised edition, Neil Shubin, Vintage Books, 2009.

Online resources

Wikipedia • www.wikipedia.com • Wikipedia is always a great place to begin your further reading (but not end it!).

Field Museum of Chicago • www.fieldmuseum.org/educators/learning-resources • Games, worksheets, and other resources for educators.

DK Publishing • www.dkfindout.com/uk/dinosaurs-and-prehistoric-life • An online version of some of the beautiful illustrations and facts about dinosaurs taken from DK's books.

Natural History Museum of London • www.nhm.ac.uk/discover/dino-directory.html • A searchable directory of dinosaurs.

American Museum of Natural History • www.amnh.org/explore/ology/paleontology • Games and other information on paleontology.

US National Park Service • www.nps.gov/dino/learn/nature/paleontology.htm • Learn about the dinosaurs of Dinosaur National Monument.

Fossil Fandom • fossil.fandom.com • A wiki devoted to fossils.

Paleobiology Database • paleobiodb.org • A database of paleontological data.

Scott Hartman's Skeletal Drawings • skeletaldrawing.com • Skeletal drawings of many of your favorite dinosaurs.

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POLYMATH PLAY

FIELD MUSEUM