American Museum *of* Natural History

EDUCATOR'S GUIDE

Fossil Halls

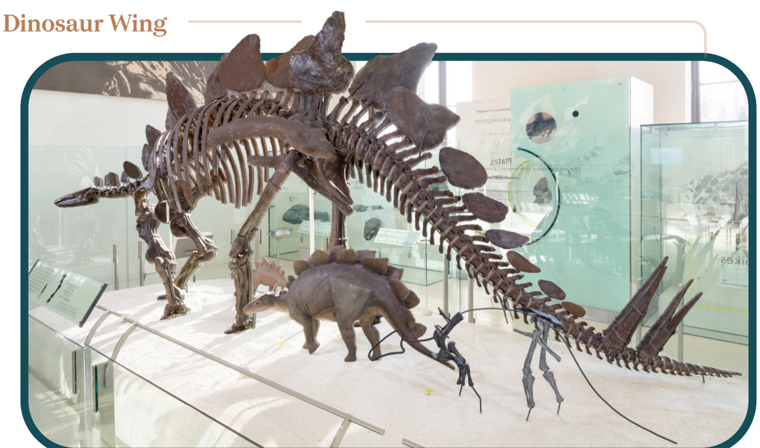
amnh.org/fossils-educators

Hall of **VERTEBRATE ORIGINS**

Miriam and Ira D. Wallach **ORIENTATION CENTER**

David H. Koch Dinosaur Wing

Hall of **SAURISCHIAN DINOSAURS**



Hall of **ORNITHISCHIAN DINOSAURS**

Lila Acheson Wallace Wing of Mammals and Their Extinct Relatives

Hall of **PRIMITIVE MAMMALS**

Paul and Irma Milstein Hall of **ADVANCED MAMMALS**

Essential Questions

What are fossils?

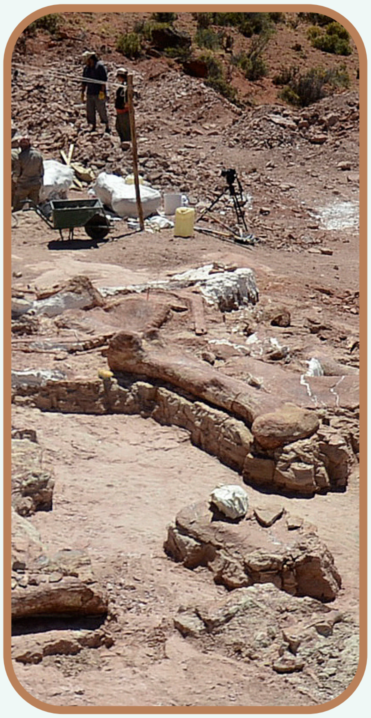
fossilized skeleton of a freshwater fish

Fossils are naturally preserved remains or traces of ancient life. When an organism dies, it generally decays or is eaten. Very occasionally, however, hard parts such as bones, teeth, and shells become buried in sediments and turn into rock, or **mineralized fossils**, over millions of years. Even more rarely, soft tissues like skin, feathers, and brains may become fossils. Similarly, traces of organisms such as leaf impressions, footprints, nests, and feces may become fossils. Most of the specimens in these halls are mineralized fossils of **vertebrates**, such as bones, teeth, and scales. Not all fossils are mineralized; some are preserved in other ways, such as freezing, **mummification**, or being embedded in **amber**. To be considered fossils, these must be more than 10,000 years old.

What do fossils tell us about the history of Earth and life on it?

Paleontologists study the **fossil record**, which consists of all the fossils on Earth, to solve mysteries about ancient organisms and environments. It is a record of hundreds of millions of years. Fossils form in sedimentary rock layers, with the oldest fossils found in the lowest layers. Dating rock layers can help paleontologists date the fossils within, above, and below them, while finding fossils in a layer can help geologists determine the relative dates of the rocks.

As helpful as individual fossils can be for revealing secrets about individual animals and species, the fossil record offers paleontologists a much deeper understanding of how species changed across time and space, and about relationships among species. Information preserved in the record can be extremely incomplete, however. Many aspects of organisms, including DNA and soft tissues such as skin, are rarely preserved, and long-extinct organisms can't be observed alive. Paleontologists must use their creativity, drawing on observations of living organisms along with research in disciplines such as biology, ecology, and biomechanics, to make inferences about what ancient organisms looked like and how they developed, moved, and behaved.



Paleontologists excavate fossils of a titanosaur in Patagonia. A cast of this 122-foot-long sauropod is on display in the Orientation Center.

What do fossils tell us about evolution?

Modern birds are a kind of dinosaur because they share a common ancestor with non-avian dinosaurs.

The halls showcase ancient animals dramatically different from those alive today, showing that species evolve, or change over time. Charles Darwin's **theory** of **evolution** explained these changes as descent with modification. As new traits arose and Earth's environments changed, natural selection reshaped species. Some survived and evolved gradually into new species; some could not compete and became extinct. Paleontologists use the fossil record to piece together the complicated history of how life evolved and diversified over hundreds of millions of years. They identify **adaptations**—**traits** that helped organisms survive and reproduce in particular environments—such as eggs with membranes that keep embryos from drying out, upright gait, large body size, and crushing bite force. Paleontologists apply methods of data science to traits that different specimens have in common, building **evolutionary trees** to understand how extinct organisms are related to one another and to modern animals.

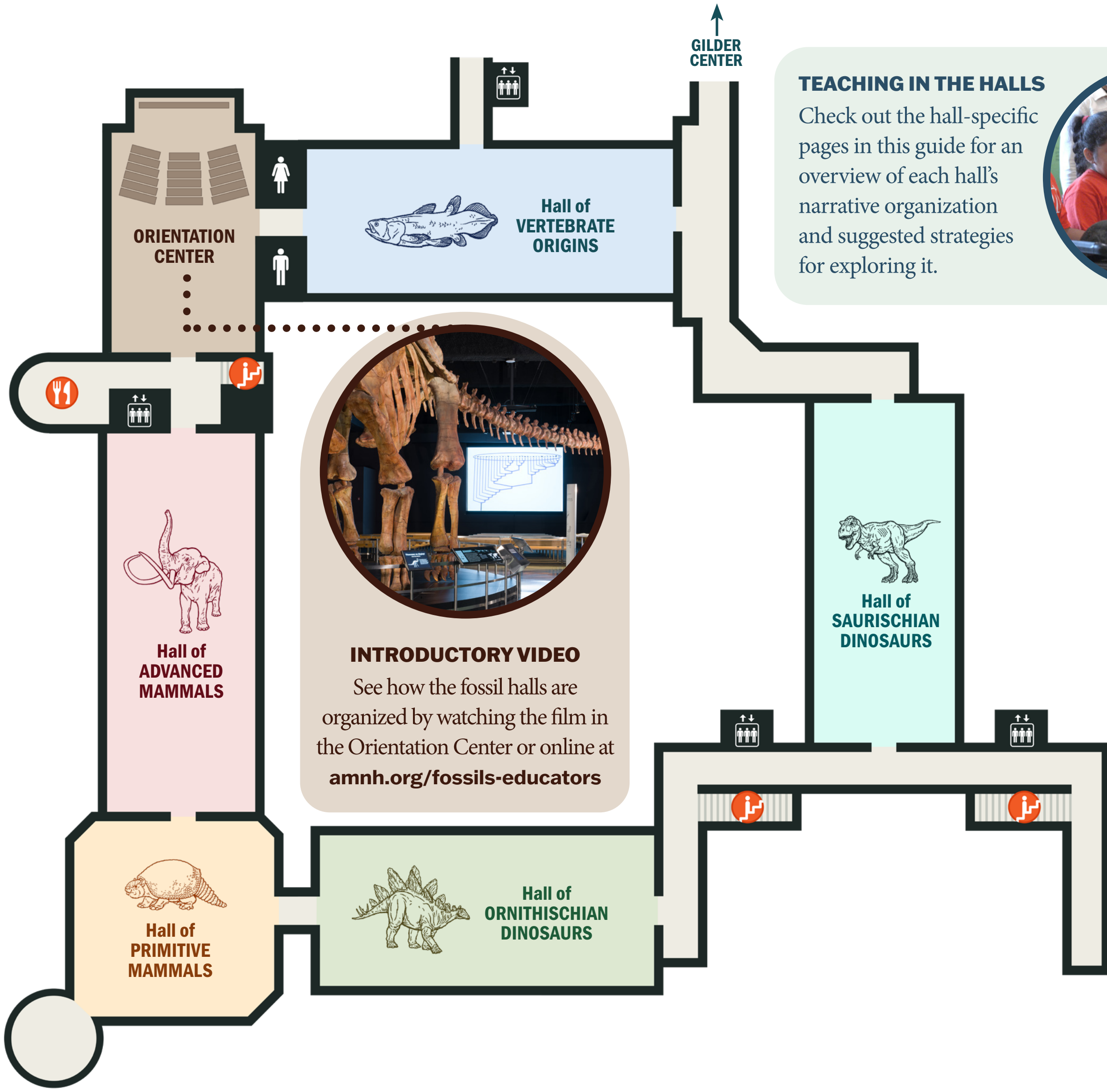
What do fossils tell us about extinction?

Extinctions are a natural part of the evolution of organisms. They include extinctions of individual species and mass extinctions in which many species die out at the same time. Asteroid strikes, volcanic activity, and climate change—the main causes of mass extinctions—can leave traces in the geologic record, such as iridium from the asteroid that hit Earth 66 million years ago. That impact caused the Cretaceous-Paleogene (K-Pg) extinction in which all non-avian dinosaur species died in a blink of geologic time. Different fossils are found in rock layers above and below such traces; paleontologists study those differences to understand the extinction events. Not all individual species or groups of related species became extinct during mass extinctions; for example, one group of dinosaurs, the birds (or "avian dinosaurs"), survived the K-Pg extinction along with our mammal ancestors. Survivors then evolved to fill the ecological gaps left by the extinctions. Natural fluctuations in climate also leave traces that geologists can read. Climate change is an important driver of extinctions and evolution: Some species flourish under new climate conditions, while others have difficulty surviving. Many extinctions are happening right now, as people alter Earth's climate by burning fossil fuels, pollute the air and water, and destroy habitat to grow crops and build cities. These activities and the resulting extinctions are leaving their own traces in the geologic and fossil records of the future.

This block of rock shows a thin layer of clay that indicates the asteroid impact at the end of the Age of Dinosaurs.

About the Fossil Halls

In the fourth floor fossil halls, you and your students can explore the evolutionary story of vertebrates: animals, like us, that have braincases and backbones. There are more than 600 specimens here. An unusually high number of these are real fossils—85 percent! The rest are casts, or exact, scientifically accurate replicas. They include major vertebrate groups from fishes to mammals—including, of course, dinosaurs.



TEACHING IN THE HALLS

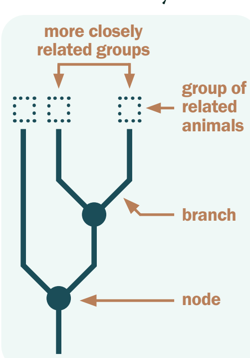
Check out the hall-specific pages in this guide for an overview of each hall's narrative organization and suggested strategies for exploring it.

INTRODUCTORY VIDEO

See how the fossil halls are organized by watching the film in the Orientation Center or online at **amnh.org/fossils-educators**

Understanding the Layout of the Halls

Each hall tells a story about a group of related species. The halls were renovated in 1996 to emphasize **evolutionary relationships**, not chronology or geography. Animals displayed next to each other are very closely related, but they may have lived millions of years apart or thousands of miles away! Scientists use evolutionary trees, or tree-shaped diagrams, to show how living things are related through time.



As you and your students walk through the halls, you'll be walking through a **cladogram**—a simplified tree diagram that shows evolutionary relationships, but not time or ancestry.

Along the central pathway of each hall, **silver lines** on the floor represent the **branches** of the cladogram.

Pillars represent **nodes** (branching points identified based on shared traits).

Displayed on either side of the node you'll find **glass cases** containing examples of fossils with these shared traits. You can walk around each group of cases to explore the story it tells about the evolution of these **related animals**.

Hall of Vertebrate Origins

In this hall, you and your students can explore the story of how vertebrates first evolved, beginning with **jawless fishes** ❶, such as ostracoderms. These earliest vertebrates lack not only **jaws** ❷, but also many other traits we're accustomed to seeing, such as fins, limbs, and teeth. The development of jaws helped vertebrates diversify into a rich variety of different species. Jaws not only enabled jawed vertebrates to bite, but also provided anchoring places for parts like grinding teeth, venomous fangs, and filtering structures.

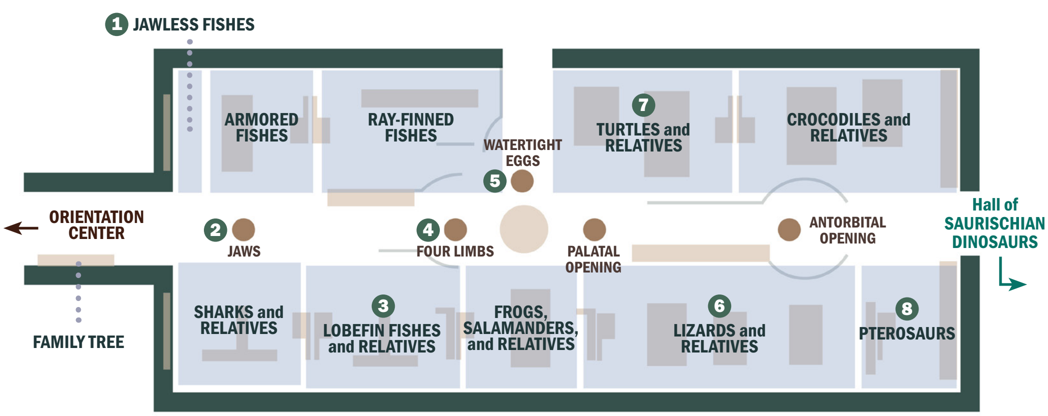
Megalodon jaw

Vertebrates continued to diversify with the development of lungs and new body plans. Air-filled swim bladders, which help fishes maintain their depth in water, evolved into lungs in the ancestors of coelacanths, lungfishes, and tetrapods. Coelacanths have four limb-like **lobefins** ❸ that they use to propel themselves through water with motions similar to those of walking limbs. A **four-limbed** ❹ body plan evolved in their close relatives the tetrapods. The earliest tetrapods include *Acanthostega*, from the Devonian period, discovered in Greenland.

Today's tetrapods use limbs to walk on land and get their oxygen from air (unlike fishes, which use gills to get their oxygen from water). And the evolution of **eggs** ❺ with semipermeable membranes provided a contained micro-environment for the embryos of amniotes, allowing them to develop on land without drying out.

Some **lizards** ❻ and their relatives such as ichthyosaurs, plesiosaurs, and mosasaurs, as well as sea **turtles** ❼, evolved flipperlike limbs that allowed them to return to living in water like their distant ancestors.

Tetrapods took to the air as **pterosaurs** ❽ evolved. These flying reptiles, which had wings as forelimbs, were the first vertebrates with powered flight.



PALEONTOLOGY MYSTERIES

How Did They Swim?

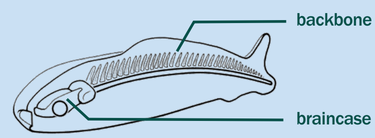
To deepen their understanding of the dynamic nature of science, students can examine the open questions posed in the **plesiosaur exhibit**. How these animals and their relatives swam is still disputed. Did they "fly" underwater like a sea turtle? Did they row or paddle? A combination? Students can observe other swimming animals throughout the hall to formulate possible explanations.

Teaching in the Hall

Comparative Anatomy

Students can identify features in the skeletal structures of animals throughout this hall to *Construct Explanations (SEP)* about what they observe, incorporating the following Disciplinary Core Ideas (DCI) and Crosscutting Concepts (CC).

VERTEBRAE: All vertebrate animals have a backbone (a series of vertebrae) and a braincase, a pattern that students can identify throughout the hall and use as evidence to explain common ancestry among these diverse animals. These traits also exist in the human body, connecting humans to animals that evolved more than 500 million years ago.
DCI-LS4.A: Evidence of Common Ancestry and Diversity • CC: Patterns



LIMBS AND HANDS: By observing differences in sizes and positions of fins and limbs, students can explain how the structure of these adaptations help animals function in different kinds of environments. (For example, coelacanths use four fins to paddle through water with a motion like walking; crocodilians tuck their short legs close to their bodies when they swim and spread them wide to support them when they run on land.) Students can also look for differences in the number and length of fingers and then infer how those arrangements might help animals. (For example, pterosaurs' elongated fingers, which make up their wings, enable them to fly; the flippers of plesiosaurs and turtles allow these animals to propel themselves through water.)
DCI-LS4.C: Adaptation
CC: Structure and Function

Buettneria, with its large, toothed skull and small limbs, may have been a lurking aquatic predator, similar to modern crocodiles.

Hall of Saurischian Dinosaurs

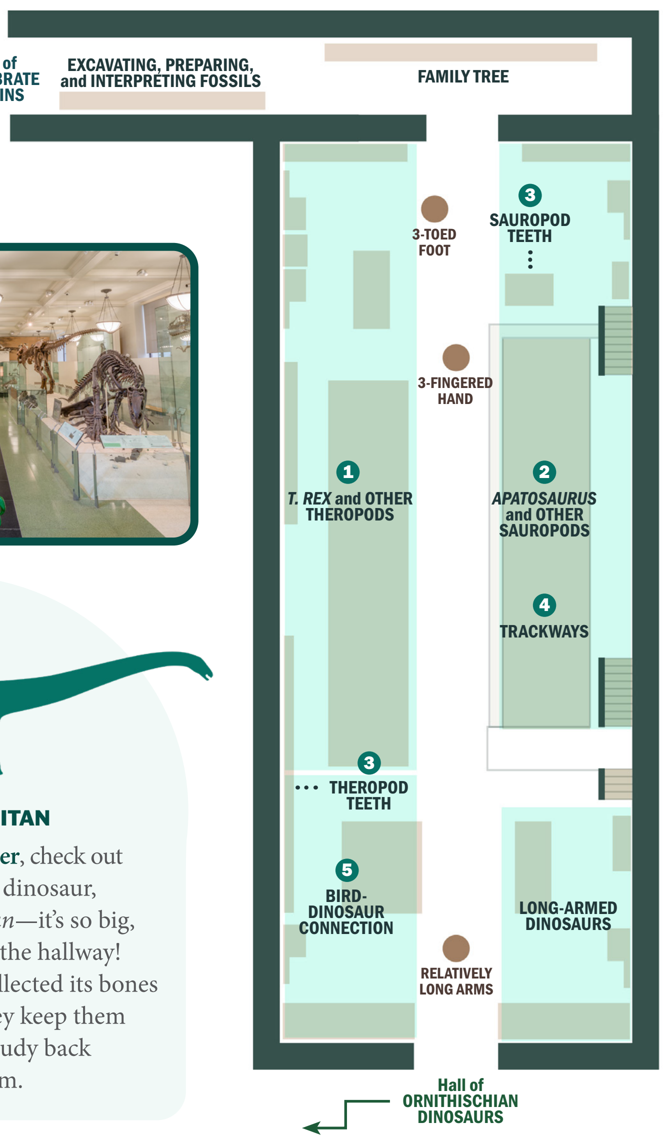
In this hall, you and your students will meet the three-toed bipedal dinosaurs called **theropods** ❶, along with five-toed quadrupeds called **sauropods** ❷. This branch of the tetrapod family tree includes familiar giants: sauropods like *Apatosaurus*, with small heads and long necks and tails, and theropods like *Tyrannosaurus rex*, with sharp teeth and claws.

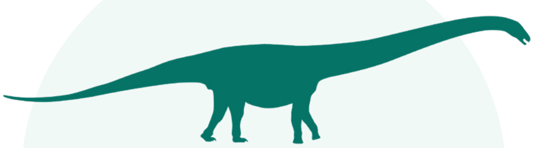
Archaeopteryx fossil shows imprint of its wings and feathers

Studying fossils like those in this hall, paleontologists make inferences about the lives of animals from the distant past.

The shapes of **teeth** ❸ provide evidence about diets; the arrangements of digits hint at dexterity; fossil **trackways** ❹ suggest modes of locomotion. *T. rex*, for example, ate meat, as you can see by observing its giant, deeply rooted teeth, good for crushing prey with its powerful bite. Sauropods ate plants, as you can infer from the leaf-shaped teeth of species like *Camarasaurus*, well adapted for cutting and shredding vegetation, or from the rakelike teeth of species like *Apatosaurus*, well adapted for stripping leaves from branches.

You can follow the evolution of theropods by examining fossils from non-avian (non-bird) species like *Deinonychus* to early examples of the only dinosaurs living today, the **birds** ❺, and observe traits these groups share, such as feathers and grasping hands.





A SAUROPOD TITAN

In the **Orientation Center**, check out the Museum's biggest dinosaur, the titanosaur *Patagotitan*—it's so big, its head sticks out into the hallway! Discover how scientists collected its bones in the field and how they keep them safe and ready for study back at the Museum.

Teaching in the Hall

Comparative Anatomy

Students can identify features in the skeletal structures of animals throughout this hall to ***Construct Explanations (SEP)*** about what they observe, incorporating the following Disciplinary Core Ideas (DCI) and Crosscutting Concepts (CC).

TEETH: Throughout the hall, students can examine the size, shape, and texture of different teeth to explain what the teeth enabled the dinosaur to eat. (For example, *T. rex* had sharp, serrated teeth for ripping meat; *Diplodocus* had pencil-shaped, rakelike teeth for stripping leaves from tree branches.) Students can also examine the structure of their own teeth and discuss how they function to help students eat their favorite foods.

DCI-LS1.A: Structure and Function
CC: Structure and Function

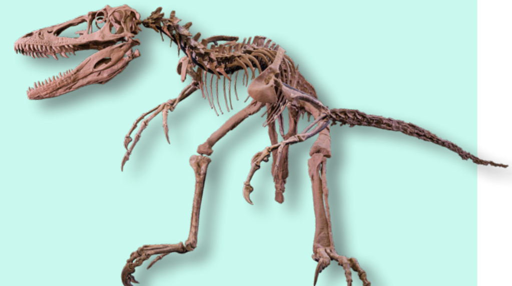
T. rex

Diplodocus

THREE TOES, GRASPING HANDS, ELONGATED ARM BONES:

Theropods—including modern-day birds—share these three traits, a pattern that students can identify throughout the hall and use as evidence to explain common ancestry among these diverse animals.

DCI-LS4.A: Evidence of Common Ancestry and Diversity • CC: Patterns



With its sickle claws and sharp teeth, *Deinonychus* was likely a formidable predator

Hall of
Ornithischian Dinosaurs

Ornithischians, the dinosaurs on this branch of the **family tree** ❶, are characterized by a backward-pointing extension of the pubis bone inherited from a common ancestor. ("Ornithischia," meaning "bird-hipped," is a misnomer; early paleontologists interpreted the pubis as a birdlike feature, but we now know that birds are saurischians.) Ornithischians include some familiar species with baffling features, such as spikes, bumps, clubs, and headpieces. Did these features serve as protection against predators? As weapons for battling rivals? As social signals for courtship?

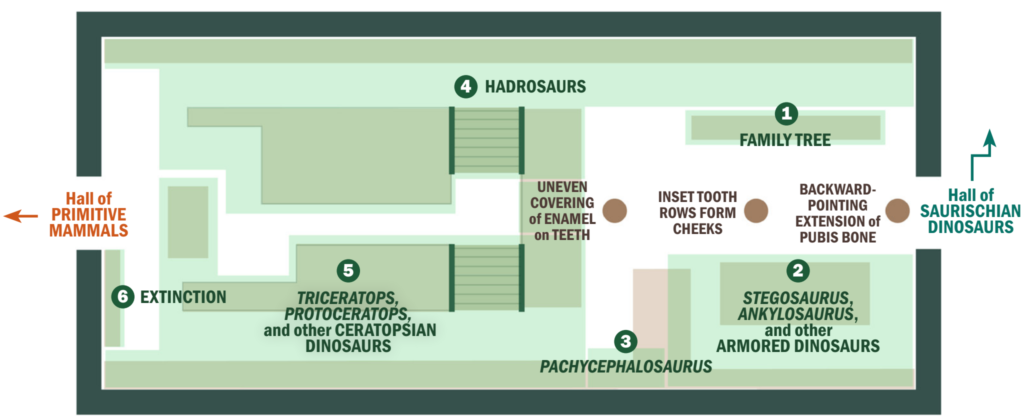
In this hall you and your students will find the famous ***Stegosaurus*** ❷, with its rows of triangular plates along its back. You'll also find lesser-known but equally striking animals, such as **ankylosaurs** ❷, with heavy tail clubs, and **pachycephalosaurs** ❸, with lumpy skull caps.

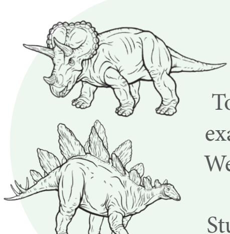
The hall includes **hadrosaurs** ❹ as well, with their mysterious soaring crests containing air passages. Paleontologists can confidently draw conclusions about some features, such as that the teeth of hadrosaurs were well suited for grinding vegetation, while the beaks and teeth of horned dinosaurs would have worked well for shearing vegetation. But other features are open to interpretation until further fossil evidence emerges.

Another familiar ornithischian in the hall is ***Triceratops*** ❺, an enormous animal with a hooked beak and a huge, armored headpiece with hornlike spikes.

Evidence of ornithischian reproduction and development are also on display, with a nest of eggs and a sequence of ***Protoceratops*** ❺ skulls from young to adult.

What killed all non-avian (non-bird) dinosaur species 66 million years ago? Students can view a large half globe showing sites of volcanic activity and an impact crater left after a huge meteor struck the Yucatan Peninsula. Students can inspect evidence for the causes of the **extinctions** ❻: a slice of layered rock with a layer of ash from the time the meteor hit, dividing the age of dinosaurs from the age of mammals.





PALEONTOLOGY MYSTERIES

Walk, Don't Run

To deepen their understanding of the dynamic nature of science, students can examine the open questions posed in the ***Stegosaurus* and *Triceratops* exhibits**. Were the legs of these dinosaurs underneath them and upright, or sprawled out to the sides? Could they run like a rhinoceros, or only walk like a lizard? Students can use the examples of rhinos and lizards to propose hypotheses and weigh the cost and benefits of each type of movement.

Teaching in the Hall
Comparative Anatomy

Students can identify features in the skeletal structures of animals throughout this hall to ***Construct Explanations (SEP)*** about what they observe, incorporating the following Disciplinary Core Ideas (DCI) and Crosscutting Concepts (CC).

HEADGEAR AND ARMOR: Students can observe the diverse array of interesting features on animals throughout the hall and explain how the structures of these features helped the animals defend themselves and attract mates.
DCI-LS1.A: Structure and Function
CC: Structure and Function

Triceratops

Pachycephalosaurus

Parasaurolophus

***PROTOCERATOPS* SKULL SIZES:** Students can explain what makes a dinosaur life cycle unique by observing the pattern of growth of skull size of *Protoceratops* from hatchling to juveniles to adult.
DCI-LS1.B: Growth and Development of Organisms • CC: Patterns

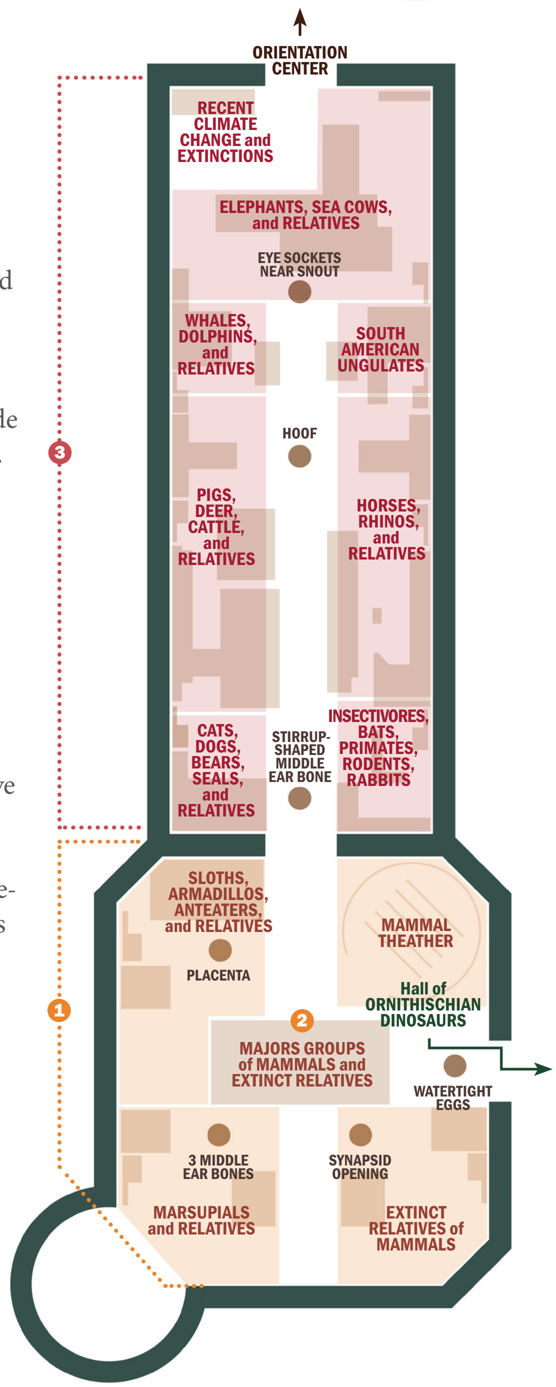
DUCKBILL PARENTAL CARE: Students can observe a hatchling, a juvenile, and the skull of an adult, and consider whether the discovery of their fossils together with broken eggshells and nests is conclusive evidence of parental care.
DCI-LS1.B: Growth and Development of Organisms • CC: Cause and Effect

Halls of Primitive and Advanced Mammals

In these halls you and your students can explore our own group, the mammals, along with their extinct relatives. The fossils here include not only easily recognizable animals, such as horses and bears, but also many with extreme traits (such as the huge domed shells of giant, armadillo-like glyptodonts) or familiar features expressed in unfamiliar ways (such as the four tusks of gomphotheres, ancient elephant relatives). Unlike dinosaurs, which are all extinct except for one group (birds), a wide variety of mammal groups are alive today. With so many living species to observe and compare with ancient mammals, paleontologists can piece together the story of mammals in rich detail.

It begins, in the **Hall of Primitive Mammals** ❶, with the closest relatives of mammals, extinct mammal-like reptiles. These extinct animals share a trait with mammals: the synapsid opening, a distinctive hole in the skulls that makes complex chewing motions possible. Mammals are distinguished by further adaptations: a single-boned lower jaw, and a group of three bones that moved from the jaw to the middle ear, improving hearing. Tiny marsupials, giant ground sloths (*Megatherium*), bats, humans, whales—all share this trio of earbones. The central **mammal diversity display** ❷ in this hall presents sample specimens from both the primitive and advanced mammal halls.

The **Hall of Advanced Mammals** ❸ features placental mammals, including many important to human history—animals with which we evolved, such as mammoths, horses, deer, dogs, and cats. It also includes stories of convergent evolution, when unrelated animals evolved very similar adaptations that serve similar functions. Saber teeth, for example, evolved in many predators, from *Thylacosmilus atrox*, a marsupial, to *Machairodus palanderi*, a cat. And mammals from diverse environments are on display here—such as bats, which use powered flight to hunt airborne prey, and whales, with true aquatic life.



mammal diversity display

Teaching in the Hall

Comparative Anatomy

Students can identify features in the skeletal structures of animals throughout this hall to ***Construct Explanations (SEP)*** about what they observe, incorporating the following Disciplinary Core Ideas (DCI) and Crosscutting Concepts (CC).

TEETH: Throughout the hall, students can examine the size, shape, and textures of different teeth to determine what the teeth enabled the mammal to eat. (For example, cats like *Smilodon* have carnassial teeth for slicing; horses have molars for grinding; pandas have a combination of both.) Students can also examine the structure of their own teeth and discuss what functions they play in eating their favorite foods.
DCI-LS1.A: Structure and Function
CC: Structure and Function

Smilodon skull

horse skull

FEET AND HANDS: By observing different kinds of feet and hands—from hooves to footpads to claws to opposable thumbs—students can explain how the structures of these adaptations help animals function in different kinds of environments. (For example, large claws help giant sloths climb trees and grip gourds; hard, thick, flat hooves help horses run long distances.) Students can also think about their own feet and hands and discuss what these enable them to do.
DCI-LS4.C: Adaptation
CC: Structure and Function

giant sloth paw

horse hoof

Come Prepared Checklist

- **Plan your visit.** For information and videos about reservations, transportation, lunchrooms, and everything else you need to prepare for your day at the museum, visit amnh.org/field-trips.
- **Read the Essential Questions** in this guide to see how themes in the fossil halls connect to your curriculum. Identify the key points that you'd like students to learn.
- **Review the maps and the Teaching in the Hall sections** for an advance look at what your class will encounter.
- **Decide how your class will explore the fourth floor:**
  - You and your chaperones can facilitate the visit using one or more Teaching in the Hall sections.
  - Students can use the maps to explore the halls on their own or in small groups.

Correlations to Standards

A FRAMEWORK FOR K-12 SCIENCE EDUCATION

Disciplinary Core Ideas • ESS1.C: The history of planet Earth ESS3.D: Global climate change • LS1.A: Structure and function • LS1.B: Growth and development of organisms • LS4.A: Evidence of common ancestry and diversity • LS4.B: Natural selection • LS4.C: Adaptation

Crosscutting Concepts • 1. Patterns • 2. Cause and effect: mechanism and explanation • 6. Structure and function

Scientific & Engineering Practices • 1. Asking questions 6. Constructing explanations (for science) • 7. Engaging in argument from evidence • 8. Obtaining, evaluating, and communicating information

Glossary

adaptation: a physical or behavioral characteristic that helps an organism survive in a particular habitat; adaptations are evolutionary responses to changing environments

amber: a hard, fossilized tree resin, usually semi-transparent and yellow or brownish in color

extinction: the death of all members of a group of organisms

evolution: the process of descent with modification of phenotypes (the observable properties of organisms), caused by the accumulation of genetic mutations

evolutionary tree: a diagram showing the evolution of, and the relationships within, a group of organisms through time; a **cladogram** is a simple type of evolutionary tree, a branching diagram in which branching points represent where advanced features appear and species diverge from common ancestors

fossils: traces or remains of ancient life—including bones, teeth, shells, leaf impressions, nests, footprints, and chemical signatures—that are typically preserved in rocks

mineralized fossils: remains of ancient life in which inorganic minerals have replaced organic material

mummification: a process, either natural (e.g., by drying or by immersion in a peat bog) or deliberate (e.g., by embalming), through which a dead animal's soft tissues or organs are preserved from decay

fossil record: all fossils on Earth including those that have not been discovered, along with their chronological and geographic placement in Earth's rock layers

theory: a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through multiple types of evidence; if new evidence is discovered that the theory does not accommodate, the theory is generally modified or rejected in light of this new evidence

trait: a distinguishing quality or characteristic of an organism

vertebrate: a member of the subphylum Vertebrata; vertebrates have a backbone that surrounds a spinal column

CREDITS

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American Museum *of* Natural History

IMAGE CREDITS

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