

Chapter 24

The Mesozoic and Cenozoic Eras

What You'll Learn

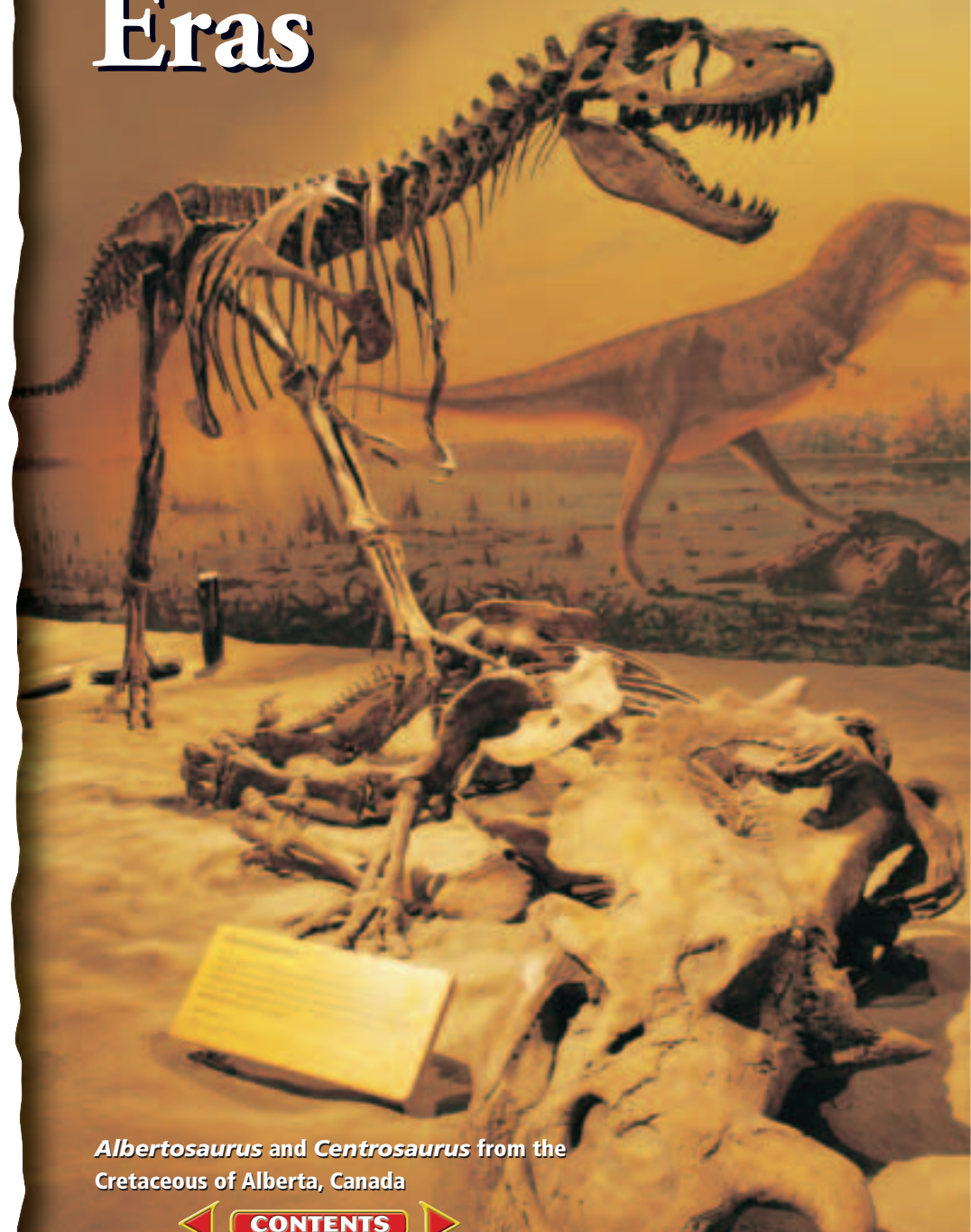
- How plate tectonics shaped the landscape of western North America.
- What the characteristics of a dinosaur are.
- How dinosaurs and many other organisms became extinct at the end of the Mesozoic Era.

Why It's Important

As the physical geology of Earth changed, so did the biosphere. Reptiles ruled the land during the Mesozoic, but their reign ended abruptly with the dawn of the Cenozoic.



To find out more about the Mesozoic and Cenozoic Eras, visit the Earth Science Web Site at earthgeu.com



Albertosaurus and *Centrosaurus* from the Cretaceous of Alberta, Canada

Discovery Lab

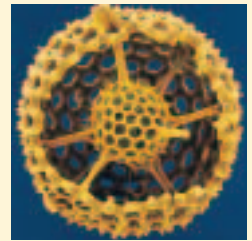
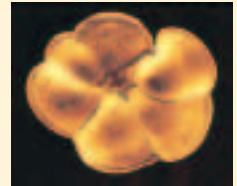
Determining the Effect of Shape on Buoyancy

How can the shape of a microfossil help paleontologists determine whether it floated or whether it lived on the seafloor? In this lab, you will learn how the shape of a fossil shell affected the animal's buoyancy, and how this information helps paleontologists determine how the animal lived.

1. Fill a 1000-mL beaker with water.
2. Using plasticene, make two solid spheres that are each 1.5 cm diameter.
3. Deform one of the spheres by pinching the plasticene into 5 "spines" that extend around the sphere.

4. Drop both spheres into the beaker at the same time and observe what happens.

Observe In your science journal, record your observations. What effect does the shape of the spheres have on their buoyancy? The photos on this page show marine microfossils. Based on your observations in this lab, which one do you think floated in the water? Which one lived on the seafloor? Explain your reasoning.



SECTION

24.1

Mesozoic Paleogeography

OBJECTIVES

- **Explain** the breakup of Pangaea.
- **Distinguish** between the different tectonic characteristics of the Mesozoic Orogenies.

VOCABULARY

Cordillera

The Mesozoic Era consisted of the Triassic, Jurassic, and Cretaceous periods, as shown in *Figure 24-1* on page 626. Movies such as *Jurassic Park* and *The Lost World* have popularized the Mesozoic as the age of the dinosaurs. What was the world like in which dinosaurs such as those pictured on page 624 lived? Why did this chapter in Earth's history end? These and other questions make the Mesozoic one of the most fascinating times of study in Earth's history.

THE BREAKUP OF PANGAEA

An important event that occurred during the Mesozoic Era was the breakup of Pangaea. Because heat causes solid objects to expand, the heat coming from within Earth beneath Pangaea caused the continent to expand. By the Late Triassic, the brittle lithosphere of Pangaea had cracked and broken apart. As some of the large cracks, or rifts, widened and as the landmasses spread apart, the ocean flooded the rift valleys. This resulted in the formation of new oceans that divided the newly separated continents.

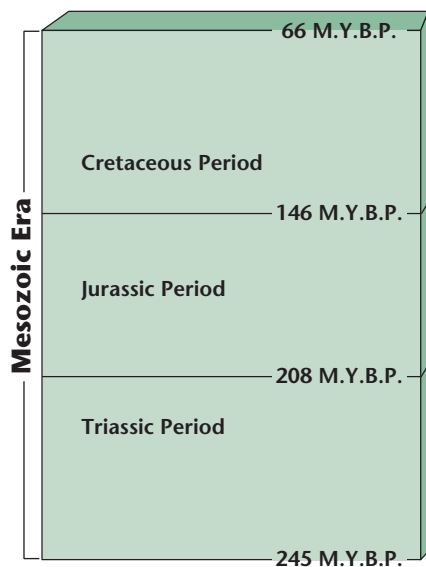


Figure 24-1 Each Mesozoic period is distinct. Pangaea broke apart and new seaways formed during the Triassic. Dinosaurs dominated the land during the Mesozoic. Flowering plants evolved during the Cretaceous. You'll learn more about these events as you study this chapter.

The breakup of Pangaea resulted in the formation of the Atlantic Ocean. As North America rifted away from Europe and Africa, some of the spreading areas joined together to form a long, continuous rift system called the Mid-Atlantic Ridge. The Mid-Atlantic Ridge is still active today.

ACTIVE TECTONISM IN WESTERN NORTH AMERICA

In contrast to the passive margin that existed along eastern North America during the Mesozoic, active subduction along the western coast continued through the Middle Triassic. Geologists refer to the mountain ranges that formed in western North America during this time as the **Cordillera**, which means “mountain range” in Spanish.

Deformation along the western margin of North America increased substantially when Pangaea broke apart. Three major episodes of orogenies—mountain building—occurred along the western margin of North America during the Mesozoic. Different types of deformation occurred during each of these orogenies.

The oldest orogeny was characterized by a tremendous number of igneous intrusions. Large bodies of granite called batholiths exist throughout the cordillera. The spectacular exposure of Half-Dome at Yosemite National Park was intruded during this orogeny.

The next orogeny was characterized by low-angle thrust faulting and folding. This was caused by collisional tectonism along the western margin of North America. This type of deformation began in the Late Jurassic and continued through the Late Cretaceous. The thrust faults run north-south and place older rocks on top of younger rocks in Utah, Idaho, Wyoming, western Canada, and Montana, shown in *Figure 24-2*.

Figure 24-2 These Paleozoic limestones in the Sawtooth Mountains, MT were faulted and thrust eastward during the second Mesozoic orogeny.



The third Mesozoic orogenic event was characterized by vertical uplifts. This orogeny mainly affected the area east of the folds and faults caused by the second orogeny. Deformation caused by the third orogeny began during the Late Cretaceous and continued into the Cenozoic.

SEAWAYS AND SAND DUNES

Throughout the Early and Middle Triassic, the supercontinent Pangaea and a single global ocean defined Earth's paleogeography. As Pangaea began to split apart, numerous rift basins formed in eastern North America, and large blocks of crust collapsed to form deep valleys. The Triassic ended with a rapid drop in sea level that caused sedimentation in the western United States to change dramatically during the Late Triassic and Early Jurassic. Western North America became much more arid, and it was covered by a thick blanket of sand. Strong winds shaped the sand into dunes. Evidence of this ancient desert is preserved in large-scale, cross-bedded sandstone deposits some of which are shown in *Figure 24-3*.

Sea level rose again in the Jurassic, and a shallow sea covered central North America. The Appalachian Mountains still rose high in the east, and the newly formed mountains of the Cordillera rose high in the west. As the mountains continued to uplift in the west, large river systems transported sediments from the mountains into the sea. The deposits of the Late Jurassic river systems are preserved today as multicolored sandstones, siltstones, and mudstones. They are well known for large numbers of dinosaur fossils.

The ocean continued to rise onto North America during the Cretaceous Period, and the Gulf of Mexico flooded the entire southeastern margin of North America. As a result, a sea covered the interior of North America from Texas to Alaska.



Figure 24-3 The effects of the wind is preserved in these sand dunes in the Vermillion Cliffs Wilderness, AZ.

SECTION ASSESSMENT

1. Explain why Pangaea rifted apart.
2. Describe the difference between the three major episodes of mountain building that occurred during the Mesozoic.
3. **Thinking Critically** What might happen if a continent stops rifting apart?

SKILL REVIEW

4. **Recognizing Cause and Effect** Explain how heat that is generated in Earth's interior can cause continents to rift apart, as in the case of Pangaea. For more help, refer to the *Skill Handbook*.

OBJECTIVES

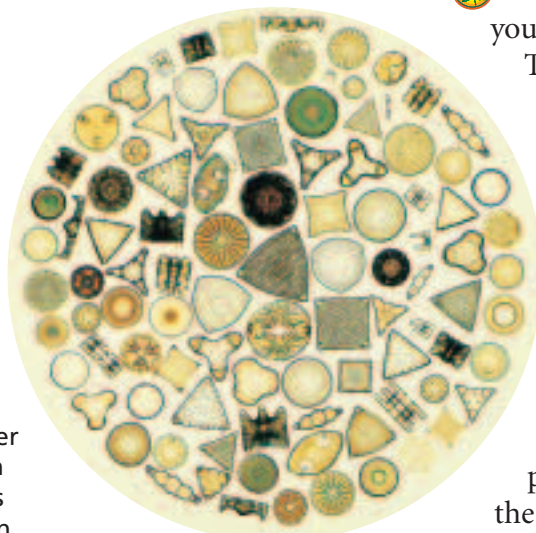
- **Discuss** why many paleontologists theorize that birds are descended from dinosaurs.
- **Describe** how paleontologists distinguish among reptile, dinosaur, and mammal fossils.
- **Explain** the evidence indicating that a meteorite impact caused the Cretaceous-Paleogene mass extinction event.

VOCABULARY

modern fauna
angiosperm
dinosaur
Ornithischia
Saurischia
ectotherm
endotherm
iridium

**ENVIRONMENTAL CONNECTION**

Figure 24-4 These phytoplankton are diatoms; tiny freshwater or marine plants. Upon death, their silica shells contribute to the ocean floor sediment.



Magnification 48x


The Mesozoic is commonly referred to as the Age of Reptiles. However, the Mesozoic also was a time of some other very important biological firsts, such as the first mammals, the first birds, and the first flowering plants. The mass extinction at the end of the Paleozoic Era had left Earth's biosphere quite barren, and therefore ripe for the appearance of new organisms.

As Pangaea began to split apart during the Triassic, much of the habitat on the continental shelves that was lost during the formation of Pangaea became available again. New marine organisms, which are collectively called the **modern fauna**, evolved which filled this habitat. The modern fauna includes crabs, lobsters, shrimps, sponges, sea urchins, modern corals, snails, and clams. The major marine vertebrate groups include bony fishes, sharks, aquatic reptiles, and aquatic mammals.

LIFE IN THE OCEANS

Much attention is given to the large animals of the Mesozoic. It is important, however, to remember that then, as now, the base of the food chain that supported all the large animals consisted of tiny, ocean-dwelling organisms called phytoplankton, shown in **Figure 24-4**. Phytoplankton float near the surface of oceans and lakes and make their own food through the process of photosynthesis. You examined the relationship between shape and floating ability in the *Discovery Lab* on page 625.



Reef Builders Arise Again As you learned in Chapter 23, the Permo-Triassic Extinction Event wiped out the reef-building corals of the Paleozoic. By the end of the Triassic, the modern corals had evolved to fill this same niche. In addition to corals, a new group of clams called rudists developed the ability to build reefs during the Cretaceous. Rudists are important because the reefs that they built were very porous and today contain some of the largest Cretaceous oil deposits in areas such as West Texas. 

Important Index Fossils Ammonites are related to modern nautilus, octopuses, and squids. Ammonites were abundant and diverse throughout the Late Paleozoic and Mesozoic, and their abundance indicates that they were very successful predators. Several ammonites are shown in *Figure 24-5*. Ammonite fossils are widespread and abundant. Because ammonite species were also short-lived, they are excellent index fossils.



Figure 24-5 These ammonites are from the Lower Jurassic of Europe. Their distinct shell shape and ornamentation adds to their usefulness as index fossils. The use of ammonites to determine the age of Mesozoic rocks is usually much more accurate than radiometric dating.

While the ammonites were successful Mesozoic marine predators, they were by no means the top predators of the Mesozoic. In fact, swimming reptiles ruled the Mesozoic oceans. Ichthyosaurs resembled modern dolphins while plesiosaurs were more like walrus and seals. Predatory mosasaurs lived only during the Cretaceous, but for that time in the history of life, the sea was theirs to rule. These Mesozoic reptiles are shown in *Figure 24-6*.

LIFE ON THE LAND

Life on land changed dramatically as the cool climate that characterized the end of the Paleozoic over many parts of Earth came to an end during the Mesozoic. The large, temperate coal swamps dried up, and the climate gradually warmed. Fossils of insects that dominated the Paleozoic coal swamps, such as flies, mosquitoes, wasps, and bees, were also present but were not as common in Mesozoic rocks.

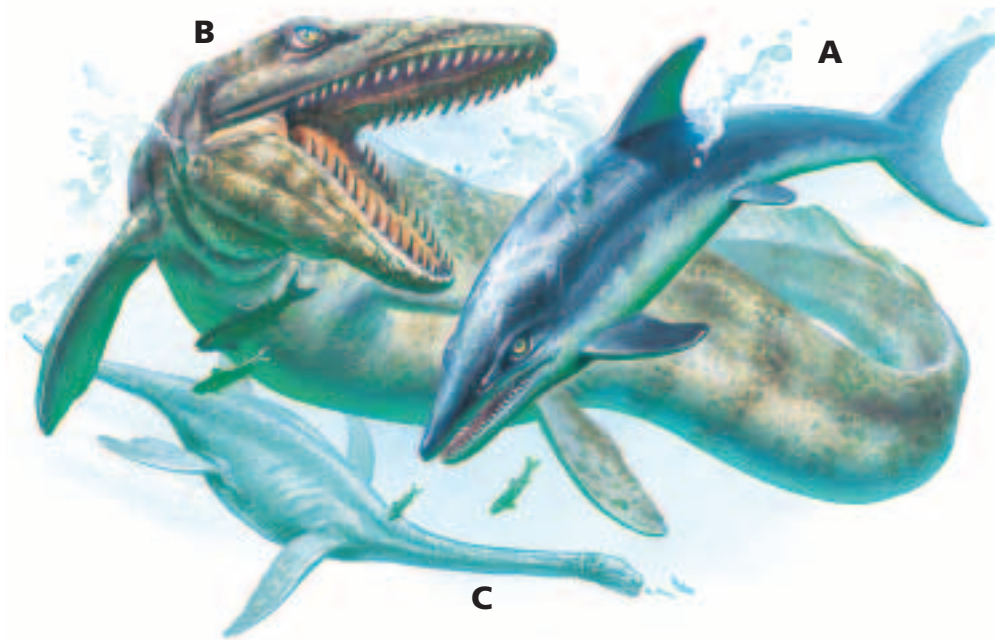


Figure 24-6 The presence in the oceans of aggressive marine predators, such as ichthyosaurs (A), mosasaurs (B), and plesiosaurs (C), no doubt kept their intended prey on alert.

Figure 24-7 Cycads have a limited distribution today. They grow only in the southern hemisphere, in Central America and in Florida. Only one species of ginkgo survives today, *Ginkgo biloba*, and it is quite common.



Figure 24-8 Fossils clearly show the progressive enlargement of one of the lower jawbones in mammal-like reptiles and its evolution into a single jawbone, which is characteristic of mammals. At the same time, the other jawbones decreased in size and became ear bones.

Primitive mammal-like reptile



Primitive therapsid



Advanced therapsid



Mammal



The land flora also changed substantially during the Mesozoic. Paleobotanists rightly call the Mesozoic the Age of Cycads. Cycads are seed plants that do not have true flowers. During the Jurassic, tall cycad trees along with ginkgoes and conifers dominated the landscape, as shown in *Figure 24-7*.

Angiosperms Evolve A new kind of plant evolved during the Cretaceous that would come to dominate the terrestrial landscape. This important group of plants was the **angiosperms**, which are seed-bearing plants that have flowers. Before the Cretaceous, there were no flowers. By the Middle Cretaceous, however, flowering plants were common. By the end of the Cretaceous, the land was covered with flowering trees, shrubs, and vines.

Early Mammals Small, primitive mammals evolved during the Late Triassic. Mammals are easily recognizable today because they are warm-blooded, have hair or fur, and mammary glands. How do scientists identify fossils of mammals? One method is to examine the structure of the lower jaw, middle ear, and teeth. A reptile has one ear bone and multiple lower jawbones, whereas a mammal has one lower jawbone and three ear bones. Early mammals arose from mammal-like reptiles. The evolution of the mammal jaw is illustrated in *Figure 24-8*. Mammals have two sets of teeth during their lives, and their teeth are differentiated as incisors, canines, and molars. In contrast, reptiles generally have only one kind of tooth, and their teeth continually grow and replace older teeth throughout their lives.



Flying Reptiles Pterosaurs, as shown in *Figure 24-9*, were flying reptiles that dominated the air during the Mesozoic. The earliest pterosaurs were small and had long tails and wingspans of less than 60 cm. Their descendants had no tails and were generally much larger. One species had a wingspan of more than 12 m. Pterosaurs had light, hollow bones, like modern birds. The modification that allowed them to fly was the growth of a membrane from a greatly lengthened fourth finger.

Two groups of reptiles that arose during the Mesozoic and still exist are the crocodiles and turtles. Why crocodiles and turtles survived the great extinction at the end of the Mesozoic, while the mosasaurs, plesiosaurs, ichthyosaurs, and dinosaurs did not, puzzles paleontologists to this day.

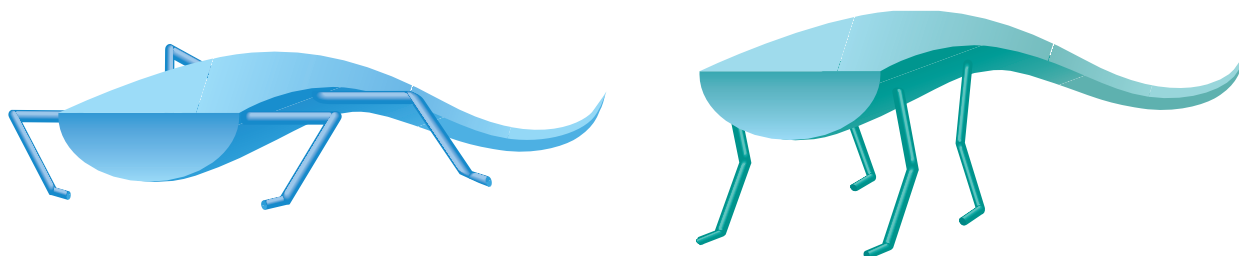
DINOSAURS RULE THE LAND

No other group of animals has captured the human imagination as much as the dinosaurs have. **Dinosaurs** were a group of reptiles that developed an upright posture about 228 million years ago. Even though our understanding of these rulers of the Mesozoic land has changed, our fascination with dinosaurs has remained. Dinosaurs came in all sizes, from the very small to the extraordinarily large, and all were terrestrial. You can learn how to estimate a dinosaur's weight in the *Science and Math* feature on page 644. Although the largest dinosaurs were most likely slow and plodding animals, many of them were quick and agile. All reptiles other than dinosaurs have a sprawling posture, that is, their legs are not set directly underneath their bodies. In contrast, as shown in *Figure 24-10*, dinosaurs' legs were set directly underneath their bodies because their hips and ankles were different from those of other reptiles.



Figure 24-9 This pterosaur fossil was found in Jurassic-aged rocks in Germany. The membrane that was attached to the fourth finger was actually a flap of tough skin that stretched from the finger to the sides of the pterosaur's body.

Figure 24-10 The characteristic sprawling posture of reptiles is shown here. Dinosaurs, with their straight shoulders, ankles, and hips, stood apart from the reptiles.



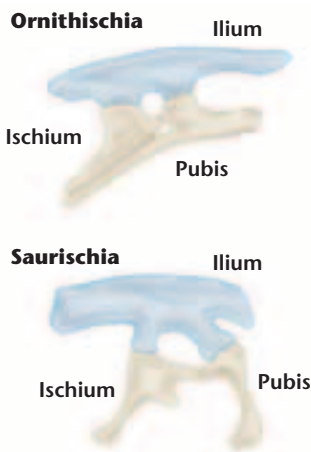


Figure 24-11 The arrangement of hip bones in dinosaurs serves as a basis for their classification.

Dinosaur Hips Two major groups of dinosaurs are recognized based on their hip structure: Ornithischia and Saurischia. Three bones comprised the hip, as shown in *Figure 24-11*. The ischium and pubis were parallel to one another in ornithischian dinosaurs. This is similar to the orientation of these bones in modern birds, which is why scientists named this group of dinosaurs **Ornithischia**, meaning “bird-hipped”. This name is unfortunate, however, because birds likely did not evolve from Ornithischia. The ischium and pubis were at an angle to one another in Saurischia, similar to the orientation observed in modern lizards. **Saurischia** means “lizard hip.” Scientists hypothesize that birds are actually descended from the Saurischia.

There were five different groups of ornithischian dinosaurs: stegosaurs, ankylosaurs, pachycephalosaurs, ceratopsians, and ornithomimids. All ornithischian dinosaurs were plant eaters, also called herbivores. There were two different groups of saurischian dinosaurs: sauropods and theropods. Although they shared a similar hip structure, these two groups of dinosaurs were quite different. The sauropods were all quadrupedal—walked on four legs—plant eaters, and some grew to enormous sizes. They were the largest land animals to have ever lived. In contrast to the sauropods, all theropods were bipedal—walked on two legs—carnivores. Your research results from the *GeoLab* on page 642 will help you interpret what dinosaurs ate. *Figure 24-12* shows some representative Mesozoic dinosaurs.

NATIONAL GEOGRAPHIC

To learn more about dinosaurs, go to the [National Geographic Expedition](#) on page 892.


Figure 24-12 Herbivores such as *Parasaurolophus* (right) and *Triceratops* (center) had to constantly be on the lookout for carnivores such as *Tyrannosaurus*.



Dinosaurs to Birds? The idea that birds are related to dinosaurs stems from the amazing similarities between theropods and the oldest known bird, *Archaeopteryx*. Fossils of feather impressions and a wishbone provide clear evidence that *Archaeopteryx* was definitely a bird, even though it did have teeth and a theropod-like skeleton.

Ectotherm or Endotherm? All living reptiles are **ectotherms**, meaning that their body temperatures vary in response to outside temperatures. All living mammals and birds are **endotherms**, meaning that they maintain relatively constant body temperatures, regardless of temperatures outside. Some paleontologists hypothesize that at least some groups of dinosaurs were endotherms. One reason is that bones of endotherms typically have more passageways for blood than bones of ectotherms do, and dinosaur bones have numerous passageways. Critics of the hypothesis that some dinosaurs were endotherms correctly point out that the bones of crocodiles and turtles also have numerous passageways, and yet they are ectotherms.

A recent discovery of a possible fossilized heart in a dinosaur supports the hypothesis that some dinosaurs were endothermic. The heart has four chambers and one aortal arch, which is a condition that exists only in endothermic animals. Whether dinosaurs were ectotherms or endotherms is still controversial, but for now, there seems to be evidence that perhaps some dinosaurs were endotherms.



Using Math

Using Numbers The end of the Permian is marked by an extinction event in which 80 percent of all marine genera became extinct, and the end of the Cretaceous is marked by an extinction event in which 50 percent of all marine genera became extinct. How many times greater was the Permian extinction event than the Cretaceous extinction event?

MASS EXTINCTIONS

A major mass extinction event ended the Mesozoic. Most major groups of organisms were devastated and all known species of dinosaurs, pterosaurs, ammonites, mosasaurs, and plesiosaurs



Figure 24-13 The circular shape and underlying layer of melted iridium-rich rock provides evidence of a meteorite impact. It was named the Chicxulub crater after a nearby village.



Topic: Meteor Impacts and Extinctions

To find out more about mass extinction, visit the Earth Science Web Site at earthgeu.com

Activity: Prepare a map of the world showing three large meteor impacts besides the Chicxulub impact. Indicate the approximate dates on your map. Do any of these dates correspond to other mass extinctions?

became extinct. Geologists theorize that a large meteorite, at least 10 km in diameter, slammed into the Yucatan Peninsula shown in **Figure 24-13** on page 633, at a speed of up to 240 000 kph. Such an impact would have blown 25 trillion metric tons of rock and sediment high into the atmosphere. Organisms lucky enough to have survived the impact would have faced a millennium of greenhouse warming and increased levels of UV radiation from the Sun.

The chemistry of a clay layer that separates Cretaceous from Paleogene rocks in Italy provides evidence of such a meteorite impact. An unusually high amount of **iridium**, a metal that is rare in rocks at Earth's surface but is relatively common in meteorites and asteroids, is found not only in Italy but in Cretaceous-Paleogene boundary sites worldwide. Soot and charcoal, which are evidence of widespread fires, are also common in the sediments.

A buried crater in the Gulf of Mexico contains iridium, which has a radiometrically dated age of approximately 65 million years. This age is close to the time of the Late Cretaceous mass extinctions. It is important to note, however, that elevated amounts of iridium are also present in Earth's interior, and thus, volcanic deposits can be enriched with iridium. During the Late Cretaceous, massive volcanic eruptions occurred in India.

Today, most scientists agree that both a large meteorite impact and massive volcanism occurred at the end of the Cretaceous. In the midst of a stressful time of climatic cooling, changing plant populations and a gradual decline in dinosaur diversity and abundance, a large meteorite struck Earth. The extraordinary stress that the impact added to an already stressed ecosystem likely caused the climax of the Cretaceous-Paleogene mass extinction.

SECTION ASSESSMENT

1. How do paleontologists distinguish between fossils of mammals and fossils of reptiles?
2. Discuss how *Archaeopteryx* supports the hypothesis that birds are descended from dinosaurs.
3. Explain why a cycad is not an angiosperm.
4. What is the main characteristic that separated dinosaurs from all other reptiles?
5. Describe the differences between Saurischia and Ornithischia.
6. **Thinking Critically** What conclusions can be stated, based on tooth characteristics, regarding the differences in diet between reptiles and mammals?

SKILL REVIEW

7. **Comparing and Contrasting** Compare and contrast the evidence for meteorite impact and volcanism at the end of the Cretaceous. For more help, refer to the *Skill Handbook*.



You are living during the Cenozoic, which means “recent life.” The Cenozoic Era encompasses approximately the last 66 million years of Earth’s history. The Cenozoic portion of the geologic time scale is shown in **Figure 24-14**. The final breakup of Pangaea occurred during the Cenozoic. Earth’s life-forms and surface features continued to change, evolving into their present form. The Cenozoic has been a time of major climate changes, which have been in part, caused by the positions of the continents.

The Ice Ages As Australia split apart from Antarctica during the Middle-to-Late Eocene, the warm climate began to deteriorate. A change in ocean circulation is thought to be the cause. When Antarctica and Australia were connected as shown in **Figure 23-15** on page 612, a current of warm water from the north moderated the temperature of Antarctica. When Antarctica split apart from Australia during the Oligocene, it was isolated over the south pole. A cold current began to flow around Antarctica, and glaciers began to form.

The climate began to warm again during the Early Miocene. The glaciers on Antarctica began to melt, and the sea rose onto the margin of North America. In the *Problem-Solving Lab* on page 637, you will consider glacial melting and the length of time involved. Glaciers returned to Antarctica during the Middle and Late Miocene. During the Pliocene, the water of the Arctic Ocean began to freeze to form an arctic ice cap, which set the stage for the ice ages of the Late Pliocene and the Pleistocene.

During the Late Pliocene through the Pleistocene, the northern hemisphere experienced extensive glaciation, or an ice age. Glaciers from the arctic advanced and retreated in at least four stages over North America. The paths of the Ohio River and the Missouri River roughly mark the southernmost point to which glaciers advanced in North America. During the peak of Pleistocene glaciation, glaciers up to 3 km-thick covered some areas north of these rivers. You will model the effect glaciers have on sediment deposition when you complete the *MiniLab* on page 636.

TECTONIC EVENTS

Western North America had been tectonically active throughout the Cenozoic. The orogenic events that occurred at the end of the Mesozoic uplifted massive

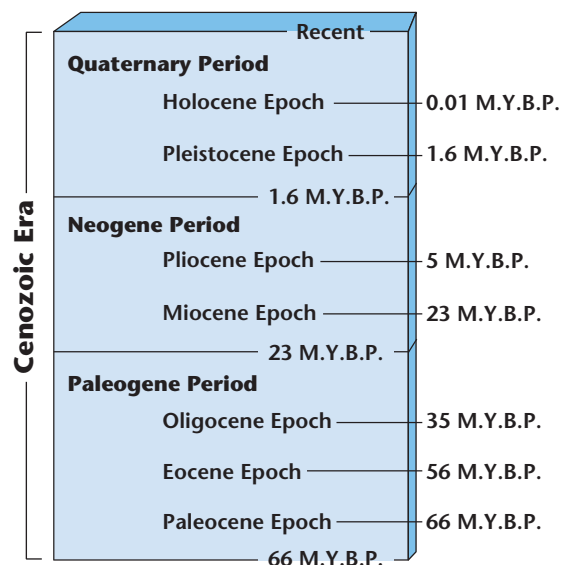
OBJECTIVES

- **Describe** the type of tectonism that characterized the Cenozoic orogeny.
- **Understand** the extent of glaciation that occurred in North America.

VOCABULARY

Basin and Range Province
Tethys Sea

Figure 24-14 Although the last Ice Age began about 2 million years ago during the Pleistocene, ice age conditions really began about 40 million years ago during the Oligocene Epoch.



Glaciers and Deposition

Model the deposition of sediment by melting glaciers.

Procedure

1. Pour water into a large, wide-mouthed jar until it is approximately 3/4 full.
2. Add a mixture of clay, silt, sand, and pebbles to the jar. Put the lid tightly on the jar.
3. Shake the jar for 30 seconds and allow the contents to settle.
4. Finely crush enough ice to fill approximately three-fourths of a second large, wide-mouthed jar. Stir a mixture of clay, silt, sand, and pebbles into the ice and pour the mixture into the jar.
5. Allow the ice to melt and the particles to settle overnight.

Analyze and Conclude

1. Describe the differences in the way the sediments settled in the two jars.
2. Compare and contrast the sorting of the grain sizes in the two jars.
3. How could geologists use this information to determine whether sediment had been deposited by a glacier or by running water?

blocks of crust to form the Rocky Mountains. Large basins that formed adjacent to the Rocky Mountains were filled with as much as 3000 m of sediment from the uplifted and eroded mountains. The sediment that filled these basins contains beautifully preserved fish, insect, frog, plant, and bird fossils. A fossil fish from the most famous of these deposits, the Green River Formation in Wyoming, is shown in **Figure 24-15**. The basins in Wyoming that filled with huge, swampy, river deposits provided an ideal environment for the accumulation of vast amounts of coal. These coal seams are close to Earth's surface, and some are more than 50 m thick. Wyoming is one of the largest coal mining regions in the world. The coal there is especially valuable because it has a very low sulfur content, and thus, it burns cleanly.

Subduction in the West Volcanism returned to the western coast of North America at the end of the Eocene. The Cascade Mountains in the Pacific Northwest are the result of the subduction of an oceanic plate beneath the western coast of North America. During the Miocene, the North American Plate was forced over the East Pacific Rise resulting in the creation of the San Andreas Fault. Because there is currently

Figure 24-15 Fossil fish, like this 50 million year old *Phareodus sp.* from the Eocene-aged, Green River formation in Wyoming, are preserved in spectacular detail.



no subduction beneath southern and central California, the volcanoes in most of California are geologically inactive.

The subduction of the East Pacific Rise beneath the North American plate coincides with pull-apart, or extensional, tectonism in the southwestern United States and north-central Mexico. A series of mountains that trend north-to-slightly-northeast are separated by long, linear valleys and extend from Nevada and western Utah to north-central Mexico. This area, shown in **Figure 24-16**, is called the **Basin and Range Province**. As extensional tectonism has pulled the crust apart, large blocks of the crust have dropped down along normal faults to form the basins, leaving other blocks at higher elevations to form the mountain ranges. This extension is still occurring today.

Hot Spots in the West In Chapter 18, you learned that hot spots are mantle plumes that rise to Earth's surface. Some of the hot spots that occur in the western United States are related to the continuing subduction along the western coast of North America. Yellowstone National Park is famous for its beautiful geysers and hot springs. The land that makes up Yellowstone National Park is situated on a hot spot that has been active since the Early Cenozoic. The rocks at Yellowstone

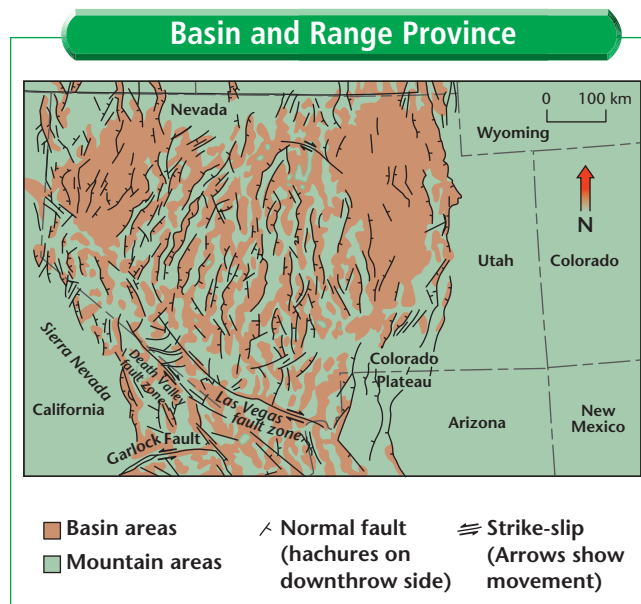


Figure 24-16 The extensive development of basins and mountain ranges in this area is a clear example of the results of extensional tectonism.

Problem-Solving Lab

Using Math

New Continental Shorelines? If all the ice on Earth were to melt, sea level would rise to approximately 50 m above its current level. Sea level is rising today at an average rate of 2 mm per year. Assuming that sea level will continue to rise at this rate, how long will it take for all the ice on Earth to melt and sea level to rise to its maximum? Use the relationship $\text{distance} = \text{rate} \times \text{time}$. Remember that 1000 mm = 1 m.

Analysis

1. What assumption is this calculation based on?
2. How realistic are the average rates?
3. What are some possible shortcomings of this calculation?
4. What major cities would this rise in sea level endanger?

Thinking Critically

5. Where, if at all, would new coral reefs grow? Why?

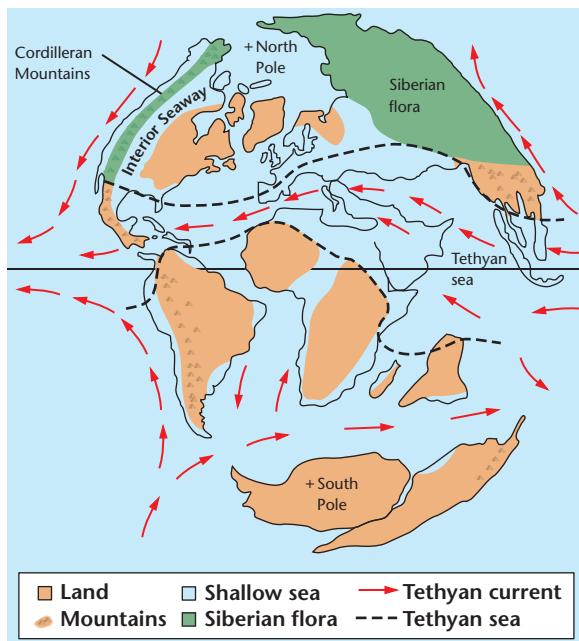


Figure 24-17 The Tethys Sea had a strong, westward-flowing current that transported organisms across large distances. Cretaceous-aged fossils that resemble fossils from the Tethys Sea area are found as far west as the Hawaiian Islands.

indicate that, in the past, this hot spot generated tremendous volcanic activity. Volcanic rocks that are Pleistocene in age record episodes of explosive volcanism. In fact, the yellow color of the extrusive volcanic rock rhyolite is responsible for the name of the river and the national park.

Continental Collisions While the final breakup of Pangaea occurred during the Cenozoic, plate tectonics also brought continents together during this time. The spectacular result of one such collision is the Himalayan Mountains. India traveled north and collided with the southern margin of Asia. The force of this tremendous continent-to-continent collision resulted in the formation of the Himalayan Mountains, which contain the point of highest elevation on Earth, Mt. Everest. The rocks at the top of Mt. Everest are

Ordovician marine limestones. Tectonic forces have pushed what was the seafloor during the Ordovician to the top of the world!

Africa also drifted north after the breakup of Pangaea and collided with the connected landmass of Europe and Asia, or Eurasia. This continent-to-continent collision formed the Alps. Before Africa collided with Eurasia, a narrow sea called the **Tethys Sea** separated the two continents, as shown in **Figure 24-17**. The collision between Africa and Eurasia continues today, and it is almost certain that in the geologic future, the last remnant of the Tethys Sea will dry up.

SECTION ASSESSMENT

1. What kind of tectonic deformation characterized the Cenozoic?
2. What was the southern boundary of Pleistocene glaciation in the Central United States?
3. What is the relationship between the East Pacific Rise, the North American Plate and the San Andreas Fault?
4. **Thinking Critically** The positioning of Antarctica over the south pole helped trigger the Cenozoic ice ages. There would be a major rise of sea level if all the ice on Antarctica melted. If Antarctica were

to move north of the south pole, as India did, it is likely that all the ice on the continent would melt. Explain why the movement of Antarctica should or should not be considered in predicting how a sea level change would affect the climate today.

SKILL REVIEW

5. **Recognizing Cause and Effect** Discuss the tectonic activity on the western coast of North America and the effect it had on the Basin and Range Province. For more help, refer to the *Skill Handbook*.

The modern marine fauna, including clams, snails, sea urchins, crustaceans, bony fishes, and sharks, survived the Cretaceous mass extinction to populate the modern oceans. Whales and dolphins evolved during the Cenozoic as completely aquatic mammals. Walruses and sea lions returned to the oceans. These mammals are still partly terrestrial today, but, like plesiosaurs were, they are much more at home in the water than on land.

LIFE ON LAND

Most of the currently living groups of mammals had evolved by the Eocene. Forests dominated North America during the Paleocene and Eocene. As the climate cooled during the Late Eocene, however, the forests gave way to open land. Grasses, which were important to many large mammals, appeared during the Eocene. Grasses spread out over the plains, and by the Late Oligocene, grassy savannas, like those in East Africa today, were common from Texas to South Dakota. The grasslands supported a large diversity of mammals, most of which are members of groups living today. These included dogs, cats, rodents, rabbits, camels, horses, pronghorn antelope, and mastodons. The rocks in Badlands National Park in South Dakota, shown in **Figure 24-18**, contain a treasure trove of fossils from the Oligocene. The rocks are made of clay, silt, and sand that were deposited in marshes and lakes and by slowly moving streams.

Pleistocene Mammals As the Pliocene ice age began, the great savannas were replaced by more arid land. The change in climate caused many of the savanna mammals to become extinct. A new group of animals evolved to populate the land as the Late Pliocene-Pleistocene ice age sent a chill across North America. Several of these animals are shown in **Figure 24-19** on page 640.



OBJECTIVES

- **Describe** the landscape of the Oligocene in Central North America.
- **Discuss** the changes in animals in North America during the Cenozoic.
- **Identify** the characteristics of primates.
- **Explain** what separates hominids from the other hominoids.

VOCABULARY

primate
hominoid
hominid
Homo sapiens

Figure 24-18 The Badlands of South Dakota may resemble a moon-landscape but they were far from a lifeless plain. In fact, the abundant and diverse mammal fossils found here have inspired some paleontologists to call the Oligocene the Golden Age of Mammals.



Figure 24-19 The woolly mammoth, dire wolf, and the sabre-toothed cat are a few of the Pleistocene animals that evolved abilities to withstand the cold.

PRIMATES AND HUMANS

One of the most difficult problems to overcome in studies of the origin of humans and our relationship to other primates is the scarcity of fossils. This makes this area of study dynamic, partly because the discovery of a single new fossil can dramatically change our understanding.

Primates Primates are distinguished from other mammals by a grasping hand with an opposable thumb and two eyes directed forward that result in stereoscopic vision. Such vision allows primates to judge distance quite accurately. Other primate characteristics include smaller, fewer, and less-specialized teeth than other mammals and a relatively large brain.

Our species, *Homo sapiens*, belongs to a group of primates called hominids. In turn, hominids are part of a larger group called **hominoids** that includes the great apes. The fossil record of hominoids extends back approximately 4.4 million years. What is it that separates a hominid from the other hominoids? The most recognizable feature is that all **hominoids** are bipedal. That is, they have an upright posture resulting from a modification of the hipbone and they walk on two legs. Hominids also have larger brains, smaller canine teeth, and smaller faces than other hominoids, and they use sophisticated tools and have greater manual dexterity.

The Rise of *Homo Sapiens* Tracing the ancestry of **Homo sapiens**, the species to which humans belong, to earlier hominids began in the 1850s, when a fossilized skull was discovered in Neander Tal near Dusseldorf, Germany. *Tal* is the German word for “valley”. Since that time, paleoanthropologists have scoured Earth looking for fossils of hominids in an attempt to piece together the ancestry of *Homo sapiens*.



Update To find out more about hominid fossil finds, visit the Earth Science Web Site at earthgeu.com

What about the fossils from Neander Tal? These hominids are commonly called Neanderthals. Most fossil evidence indicates that Neanderthals were most likely a side branch of *H. sapiens* and not direct ancestors of modern humans. The Neanderthals were hunters that inhabited Europe and the Near East approximately 200 000 to 30 000 years ago. Neanderthals differed from modern humans in a number of ways; differences in their skulls are shown in **Figure 24-20**. Neanderthals had heavy brows, mouths that projected forward, and receding chins. They had short, thick limbs and more massive, muscular bodies. Perhaps most surprising is that they had slightly larger brains than modern humans do. Neanderthals did live in caves and used a variety of tools. There is evidence that they buried their dead and placed items such as tools in their graves.

It may seem strange that scientists do not have a more complete understanding of the relationships among the hominids. After all, the fossil skeleton of one of the earliest known hominid species, *Australopithecus afarensis*, provides evidence that bipedal, upright-walking hominids existed at least 3.5 million years ago. However, compared to the rest of the fossil record, there are relatively few hominid fossils. As a result, our understanding of the evolution of many other groups of animals is much better than our understanding of the evolution of hominids. Subsequently, each new find yields information that could dramatically change previous ideas.

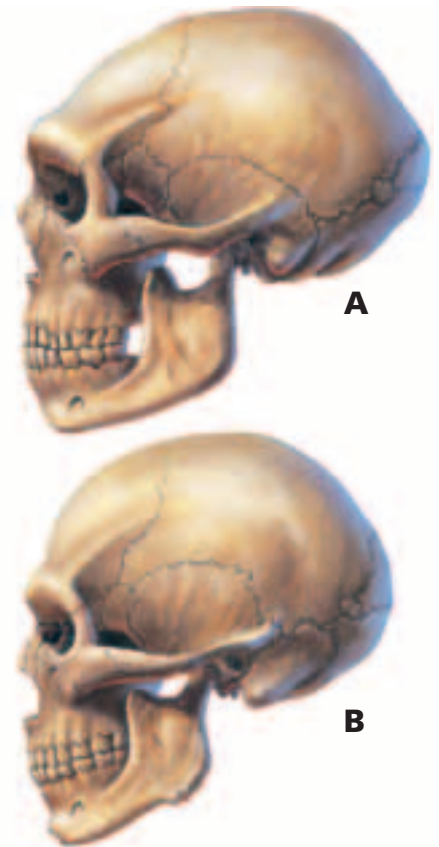


Figure 24-20 A characteristic of Neanderthals is a gap that occurs between the rear teeth and the jaw bone (A). Modern humans do not possess this (B).

SECTION ASSESSMENT

1. What kind of plants dominated the landscape of Central North America during the Oligocene?
2. How did the flora and fauna change in response to climatic changes during the Cenozoic?
3. What characteristics distinguish primates from other mammals?
4. What separates hominids from the other hominoids?
5. Discuss why it is difficult to reconstruct the evolutionary history of hominids.
6. **Thinking Critically** Explain why the evolution of grasses was a significant event for the mammals of central North America.

SKILL REVIEW

7. **Communicating** Suppose you are a journalist. In your science journal, write a press-release describing the recent discovery of a group of Neanderthal hominids. For more help, refer to the *Skill Handbook*.

Huge Appetites

The study of how an organism interacts with its environment is called ecology. Ecology includes how an organism obtains energy from its environment. Animals do this by eating. Determining the diet of modern animals is relatively easy to do. We can observe them in their habitat and watch what they eat, or we can examine their feces. Paleocology is the ecology of ancient organisms. Part of dinosaur paleocology includes determining what and how dinosaurs ate. Imagine how much food some dinosaurs must have eaten!

Preparation

Problem

How do paleontologists tell what types of food different dinosaurs ate?

Hypothesis

What kind of evidence might you use to determine what type of diets dinosaurs ate? What are the diets of different animals today? Think about the characteristics of these different animals. Do most meat eaters share certain characteristics? What about plant eaters? **Form a hypothesis** about the skeletal characteristics of plant eaters and meat eaters.

Objectives

- **Gather** data and **communicate** interpretations about the characteristics of meat eaters and plant eaters.
- **Form conclusions** about the characteristics of plant eating and meat eating dinosaurs.
- **Discover** how sauropods might have shared food resources.

Data Sources

Go to the Earth Science Web Site at earthgeu.com to find links to fossil data on the Internet. You can also visit your library or local natural history museum to gather information about dinosaur diets.



This Late Cretaceous *Tyrannosaurus* is from Alberta, Canada.

Plan the Experiment

1. Find a resource that describes skeletal characteristics of meat-eating and plant-eating dinosaurs. The Earth Science Web Site lists sites with information about dinosaurs.
2. Gather information from the links on the Earth Science Web Site or the library about the environments that these two types of dinosaurs lived in and which dinosaurs lived in the same environments.
3. Design a data table to record your research results. Include categories such as Dinosaur Name, Meat or

Plant Eater, Food Preference, Skeletal Characteristics, Jaw and Teeth Characteristics, and so on.



Triceratops was an herbivore.

Procedure

1. Complete your data table, including all information that you think is important.
2. Go to the Earth Science Web Site at earthgeu.com to post your data.
3. Visit sites listed on the Earth Science Web Site for more information on the diets of dinosaurs.

Conclude & Apply

Sharing Your Data Find this Internet GeoLab on the Earth Science Web Site at earthgeu.com. Post your data in the table provided for this activity. Use the additional data from other students to complete your chart and answer the Conclude and Apply questions.

1. What part of a dinosaur skeleton is most important in determining its diet? Why? What is the likelihood that this part of a skeleton will be preserved?
2. What are some other characteristics associated with dinosaur skeletons

that help paleontologists determine what their diets were like?

3. Which were more abundant, meat-eating dinosaurs or plant-eating dinosaurs? Why?
4. How did sauropods share food resources? Describe the evidence used by paleontologists to determine how sauropods shared food resources.
5. How could the same evidence that is used to determine the diets of dinosaurs be used for other animals?



Model of *Parasaurolophus*, actual dinosaur was 10 m tall.

Weighing a Dinosaur

How do you weigh a dinosaur? Since the last one died 66 million years ago, you can't exactly ask one to step on a scale.

Weight is a much better indicator of overall size than length or height. A python may be longer than an elephant, and a giraffe may be taller, but most people would agree that the heavier elephant was the bigger animal.

How to Weigh a Dinosaur

Two methods have been employed to estimate the weights of dinosaurs. The first uses a formula derived from the cross-sectional area of the leg bones. Since the legs supported the animal, their strength is an approximation of that animal's weight. Heavier animals have thicker bones.

The second method estimates the volume of a dinosaur, then multiplies the volume by the specific gravity. Most living animals have a specific gravity of around 0.9 kilograms per liter, but this can vary from 0.8 to just over 1. But how do you obtain the volume of a dinosaur? Calculating the volumes of simple shapes like cubes and spheres is easy, but dinosaur shapes were not simple.

One way is to measure the volume of an accurate scale model, then multiply that volume by the scale cubed (since the real dinosaur increased in length, width, and height by the scaled amount). The easiest way to obtain the volume is to immerse the model in water and measure how much water is displaced.

Procedure

1. Obtain several waterproof models of dinosaurs. You will also need a ruler, a calculator,

and a graduated cylinder large enough to hold your biggest model.

2. Calculate the scale of each model. Measure the length of the model. The length of the actual dinosaur divided by the length of the model is the scale. Example: a model *Tyrannosaurus* is 30 cm long. A real *Tyrannosaurus* skeleton is 12 meters (1200 cm) long, so the scale is $1/40$.
3. Fill the empty graduated cylinder with enough water to cover the model. Record that amount. Completely submerge the model and record the new level of the water. The difference between the first reading and second is the volume of the model.
4. Multiply the volume of the model by the cube of the scale. The result is the volume of the living dinosaur.
5. Multiply the volume of the living dinosaur by the density of living tissue (about 0.9 g/cc). The result is the weight of the living dinosaur, in grams. Convert that number into kilograms.



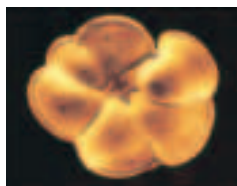
To find out more about dinosaur sizes and weights, visit the Earth Science Web Site at earthgeu.com

CHAPTER 24 Study Guide

Summary

SECTION 24.1

Mesozoic Paleogeography



Main Ideas

- Geologists hypothesize that Pangaea broke apart as heat built up beneath it. Expansion occurred and ultimately resulted in the rifting apart of Pangaea.
- The first orogeny is characterized by igneous intrusions, whereas the second orogeny is characterized by thrust faulting and folding.

Vocabulary

Cordillera (p. 626)

SECTION 24.2

Mesozoic Life



Main Ideas

- The modern marine fauna include crabs, lobsters, shrimps, sponges, sea urchins, modern corals, snails, and clams. The major vertebrate groups of the modern fauna include bony fishes, sharks, aquatic reptiles, and aquatic mammals.
- The oceans contained vast numbers of ammonites that are now index fossils. The most common land plants were cycads, and the dominant land animals were dinosaurs.
- An upright posture distinguishes dinosaurs from other reptiles.

Vocabulary

angiosperm (p. 630)
dinosaur (p. 631)
ectotherm (p.633)
endotherm (p. 633)
iridium (p. 634)
modern fauna (p. 628)
Ornithischia (p. 632)
Saurischia (p. 632)

SECTION 24.3

Cenozoic Paleogeography



Main Ideas

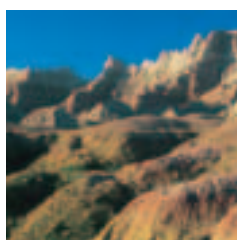
- The Cenozoic tectonism is characterized by vertical normal faulting.
- During the Pleistocene, glaciers extended as far south as the courses of the Ohio and Missouri Rivers.

Vocabulary

Basin and Range Province (p. 637)
Tethys Sea (p. 638)

SECTION 24.4

Cenozoic Life



Main Ideas

- Large mammals evolved to feed on the abundant grasslands that developed during the Cenozoic. As the ice ages approached, many of the mammals that lived on these grasslands became extinct and were replaced by large mammals that were adapted to the cold and arid land south of the glaciers.
- Primates are mammals that developed specialized traits, including a grasping hand with an opposable thumb; stereoscopic vision; smaller, fewer, and less-specialized teeth, and a relatively large brain.

Vocabulary

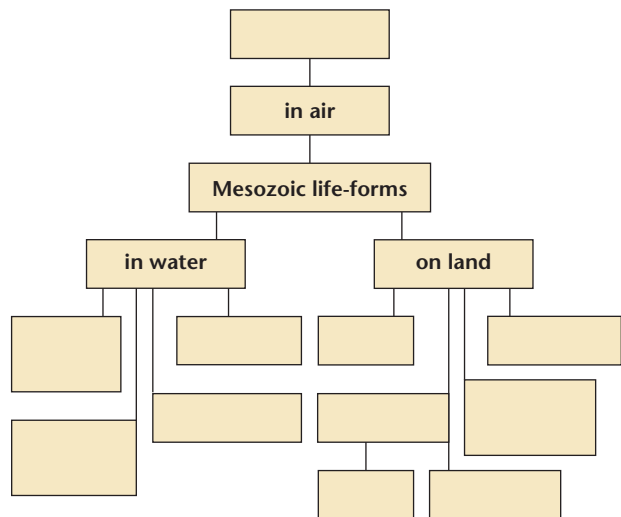
hominid (p. 640)
hominoid (p. 640)
Homo sapiens (p. 640)
primate (p. 640)

CHAPTER 24 Assessment

Understanding Main Ideas

- Which term describes down-dropped blocks of crust bounded by steeply dipping normal faults?
 - volcanic arcs
 - basins
 - red beds
 - batoliths
- What are tiny organisms that float in the oceans and make their own food through the process of photosynthesis called?
 - echinoids
 - gastropods
 - phytoplankton
 - teleosts
- What makes a dinosaur different from other reptiles?
 - Dinosaurs were large.
 - Dinosaurs laid eggs.
 - Dinosaurs were carnivores.
 - Dinosaurs had upright postures.
- The Saurischia were one main group of dinosaurs. What was the other one?
 - Ornithischia
 - Sugoschia
 - Australopithecus*
 - Smilodon*
- Which of the following best describes all theropod dinosaurs?
 - herbivores
 - carnivores
 - omnivores
 - quadrupedal
- Which of the following best describes all sauropod dinosaurs?
 - herbivores
 - carnivores
 - omnivores
 - bipedal
- What seed-bearing, flowering plants first appeared during the Cretaceous?
 - angiosperms
 - phytoplankton
 - prosimians
 - cycads
- What flying reptiles became extinct at the end of the Cretaceous?
 - plesiosaurs
 - mosasaurs
 - ichthyosaurs
 - pterosaurs

- What region in the southwestern United States and North-Central Mexico is characterized by northeast-trending mountains and long, linear valleys?
 - Basin and Range
 - Colorado Plateau
 - Sierra Nevada
 - Mississippi Embayment
- Use the following terms to complete the concept map below: pterosaurs, ichthyosaurs, primitive mammals, reptiles, rudists & corals, cycads, ammonites, angiosperms, dinosaurs, phytoplankton, turtles, mosasaurs, predatory reptiles.



Test-Taking Tip

IF IT LOOKS TOO GOOD TO BE TRUE...

Beware of answer choices in multiple-choice questions that seem ready-made and obvious. Remember that only one answer choice for each question is correct. The rest are made up by the test-makers to distract you. This means that sometimes they look very appealing. Check each answer choice carefully before finally selecting it.

CHAPTER 24 Assessment

11. What mountain range formed as a result of the collision of India with Asia?
 - a. Rocky Mountains
 - b. Andes Mountains
 - c. Himalayan Mountains
 - d. Alps
12. What genus do Neanderthals belong to?
 - a. *Australopithecus*
 - b. *Ardipithecus*
 - c. *Smilodon*
 - d. *Homo*

Applying Main Ideas

13. Discuss how and when the Mid-Atlantic Ridge formed.
14. What evidence indicates that during the Late Triassic and Early Jurassic, western North America was arid?
15. What evidence suggests that dinosaurs were endothermic?
16. How did the paleogeography of Antarctica and Australia affect the climate during the Oligocene?
17. What characteristics separate primates from other mammals?

Thinking Critically

18. Compare the body shapes of ichthyosaurs and plesiosaurs to those of dolphins and whales. What can you conclude about these body shapes?
19. If a meteorite struck Earth at the end of the Cretaceous, does this mean that the impact caused the extinction of the dinosaurs? Explain why or why not.
20. Cite several reasons why the evolutionary history of ammonites is better supported than theories about hominid evolution.
21. Do the characteristics of today's coral reefs suggest that they might become oil reservoirs as the rudist reefs did? Explain.

Standardized Test Practice

1. What characterizes the second orogeny that affected western North America in the Mesozoic Era?
 - a. low-angle faults
 - b. block faults
 - c. igneous intrusions
 - d. clastic wedges

INTERPRETING DATA Use the table below to answer questions 2 and 3.

Mass Extinction Theories

Evidence for meteor impact	Unusually high levels of iridium in Cretaceous-Paleogene boundary sediments; Discovery of Chicxulub crater
Evidence for massive volcanic activity	Volcanic eruptions during the Late Cretaceous in India; Unusually high levels of iridium, soot, and charcoal in Cretaceous-Paleogene boundary sediments

2. How does the presence of iridium at the Cretaceous-Paleogene boundary support the theory of massive volcanic activity?
 - a. Iridium is deposited after a large fire is extinguished.
 - b. Iridium is a common byproduct of combustion reactions.
 - c. Iridium is found in abundance in Earth's core.
 - d. All of the above.
3. Underneath the Chicxulub crater is a large layer of melted rock and a layer of jumbled rocks. Why are these rocks jumbled?
 - a. They have been broken up by water erosion.
 - b. They contain a higher level of iridium.
 - c. They are pieces of the meteorite that broke off upon impact.
 - d. They fell into the crater after the impact.



For a **preview** of geologic time, study this GeoDigest before you read the chapters.
After you have studied geologic time, use the GeoDigest to **review** the unit.

Geologic Time

Fossils and the Rock Record

Geologists have separated Earth's history into divisions based upon the fossil record and organized these divisions into the geologic time scale. The divisions found on the geologic time scale—in descending order of length—are eons, eras, periods, and epochs. The principles of uniformitarianism, original horizontality, superposition, and cross-cutting relationships are used to interpret Earth's rock record—and thus describe our planet's history. Unconformities caused by weathering and erosion or by periods of nondeposition indicate missing layers in the rock record. Fossils are the remains and evidence of plants and animals that once lived on Earth. Fossils preserved in the rock record provide information about past environmental conditions and evolutionary changes in life-forms. They thus help to correlate rock layers from one area to another.

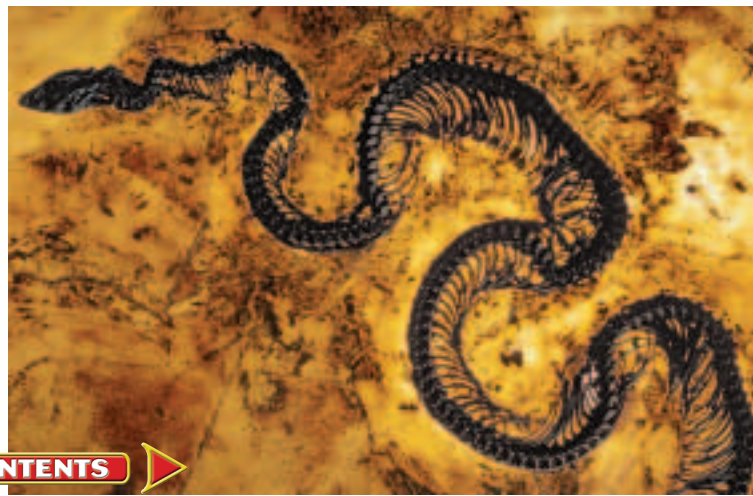
Absolute Age of Rocks Absolute age dating measures the actual age of an object such as a mineral, rock, or fossil. Radioactive dating uses the decay rates of various types of radioactive minerals to determine the actual age of a rock or fossil. Radioactive decay is the random emission of particles from the nucleus of a radioactive atom at a constant rate. The time it takes a radioactive isotope to decay fifty percent of its original mass to a nonradioactive element is known as the mineral's half-life. Tree rings and varves are other methods of determining the dates of events and changes in the environment. Key beds in the rock record that mark

the time of their occurrence include volcanic ash and meteorite-impact debris that spread out over large areas of Earth in a small amount of time.

The Precambrian

Geologists have used radiometric dating to show that Earth must be at least 4.2 billion years old. Because all of the objects in the solar system formed at the same time, and Moon rocks and meteorites are dated at 4.6 billion years old, Earth is assumed to be 4.6 billion years old also. Early Earth was hot because of abundant radioactive isotopes, bombardment by meteorites, and gravitational contraction. Earth's crust formed when the uppermost portion of the mantle cooled. The early crust weathered and formed sediments. Sediment-covered slabs of early crust were subducted and generated magmas with granitic compositions. During the Archaean Eon, granitic crust formed microcontinents. The microcontinents collided with one another throughout the Proterozoic Eon to form the cores of today's continents. Earth's early

Fossil snake



atmosphere and the oceans formed through the process of outgassing. Nearly all of the oxygen in the atmosphere is a result of photosynthesis. Certain minerals oxidize, or rust, in the presence of free oxygen. Proterozoic red beds are sedimentary rock deposits that contain oxidized iron. They are evidence that there was free oxygen in the atmosphere during the Proterozoic Eon.

Early Life on Earth All the ingredients were present on the early Earth to form proteins, which are the building blocks of life. Experiments have demonstrated that amino acids, the molecules that make up proteins, were likely abundant on the surface of early Earth. The first life was likely prokaryotic cells, which are small and contain no nuclei. Eukaryotic cells, which contain nuclei and are generally larger and more complex than prokaryotic cells, emerged later. The first evidence of multicellular organisms are fossils of eukaryotic algae from a 2.1 billion year old banded iron formation in northern Michigan. By about 670 million years ago, the multicellular Ediacaran organisms began to flourish throughout the world.

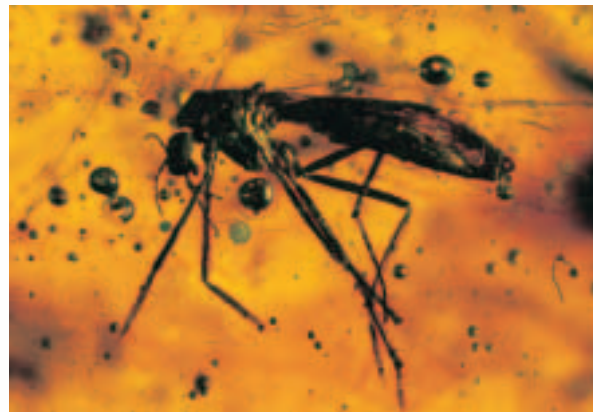
The Paleozoic Era

Early in the Paleozoic, a shallow sea covered the ancient North American continent of Laurentia, which was located near the equator. Laurentia's continental margin was passive—no tectonic activity was occurring. The fauna included many new

Vital Statistics

Half-Lives of Radioactive Isotopes

Carbon 14	5730 (+/- 30) years
Uranium 235	700 million years
Rubidium 87	4.9 billion years
Uranium 238	4.5 billion years



Insect in amber

organisms that evolved during the Cambrian explosion. Fossils of trilobites and articulate brachiopods are common. Sea level changes cause depositional environments to change position laterally. This results in adjacent depositional sequences overlying each other in vertical succession.

Middle Paleozoic Deposits of evaporite minerals such as gypsum, and halite formed in the mid-Paleozoic as areas of ocean water were isolated and evaporated. Collisional tectonism occurred, causing mountain building along active continental margins. Clastic wedges formed as a result of mountain building as deposits of sedimentary rocks formed adjacent to uplifted areas in wedge-shaped formations. Articulate brachiopods, corals, and many other organisms dominated the seas. Fishes evolved as top ocean predators and plants moved onto land. At the end of the Ordovician and in the Late Devonian, large numbers of organisms became extinct in relatively short periods of time. This phenomenon is called a mass extinction.

Late Paleozoic In the Late Paleozoic, continents collided to form Pangaea. Cycles of glacial/interglacial periods during the Pennsylvanian are represented by cyclothems—stacked deposits of

alternating transgressive and regressive rock sequences. The ocean shrank during glacial periods and expanded during interglacial periods. Seeds and the amniote egg developed during the Late Paleozoic, developments that allowed plants and reptiles to move onto dry land. Regression of the ocean and climate change led to a mass extinction at the end of the Permian Period.

The Mesozoic and Cenozoic Eras

Mesozoic Era In the Mesozoic, Pangaea broke up. Geologists hypothesize that the size of the supercontinent led to a heat buildup and expansion of the landmass, resulting in rifting that broke it up. Two orogenies occurred. The first orogeny is characterized by igneous intrusions whereas the second orogeny is characterized by thrust faulting and folding. Ammonites were prevalent in the Mesozoic ocean; the most common land plants were cycads; and the dominant land animals were dinosaurs. High levels of iridium, and the Chicxulub structure in the rocks at the Cretaceous-Paleogene boundary indicate that a meteorite hit Earth at the end of the Cretaceous Period. This meteorite may have led to the extinction of the dinosaurs. Dinosaurs are distinguished from reptiles by their upright posture. Birds may be descended from dinosaurs. The fossil *Archaeopteryx*, which contains features of both dinosaurs and birds, is cited as evidence for the relationship. The fossils of reptiles are distinguished from the fossils of mammals by tooth shape, and the number of lower jawbones.

Cenozoic Era The major orogeny of the Cenozoic is characterized by vertical normal faulting. During the Pleistocene ice ages, glaciers extended as far south as the courses of the Ohio and Missouri rivers. By the Oligocene, grassy savannas covered much of Central North America. Large



Fossil bat

mammals evolved to feed in these abundant grasslands. As the ice ages approached, many grazers became extinct and were replaced by large mammals that were adapted to cold and arid climates. Primates emerged during the Cenozoic. Primates are mammals that developed specialized traits such as a grasping hand with an opposable thumb; smaller, fewer, and less specialized teeth; stereoscopic vision; and a relatively large brain.

FOCUS ON CAREERS

Paleoecologist

Paleoecologists study the ecology of ancient animals and plants.

Where did a fossil specimen live?

What did it eat? What ate it?

What were the limiting factors in its environment? Paleontology,

biology, and ecology are put

together to complete pictures of

ancient environments. Curiosity

and patience are essential to a

paleoecologist, but advanced

degrees are also required.

ASSESSMENT

Understanding Main Ideas

- What feature, caused by weathering and erosion or by periods of nondeposition, indicates missing layers in the rock record?
 - uniformitarianism
 - unconformity
 - horizontality
 - cross-cutting
- What is the random emission of particles from the nucleus of a radioactive atom at a constant rate called?
 - radioactive minerals
 - half-life
 - radioactive decay
 - uranium
- What formed when the uppermost portion of Earth's mantle cooled?
 - meteorites
 - radioactive isotopes
 - sediment
 - Earth's crust
- Earth's early atmosphere and the oceans formed through what process?
 - photosynthesis
 - free oxygen
 - outgassing
 - Proterozoic red beds
- The first life on Earth was a small cell with no nucleus called what?
 - a prokaryotic cell
 - a eukaryotic cell
 - algae
 - Ediacaran organisms
- What forms when areas of ocean water are isolated and evaporate?
 - collisional tectonism
 - clastic wedges
 - evaporite minerals
 - brachiopods
- What sequence represents alternating glacial/interglacial periods during the Pennsylvanian?
 - cyclothem
 - amniote egg
 - clastic wedges
 - microcontinent
- What were the most common land plants of the Mesozoic?
 - ammonites
 - conifers
 - cycads
 - embayments
- Which of these land features was prominent in Central North America during the Oligocene?
 - grasslands
 - forests
 - primates
 - glaciation
- Which of the following is a trait of primates?
 - more-specialized teeth
 - smaller brain
 - hooves
 - stereoscopic vision

Fossil
conifer cone

Thinking Critically

- Put the following geologic time divisions in order from shortest to longest: period, eon, epoch, era.
- Describe why early Earth was hot.
- Discuss how paleontologists distinguish reptiles from mammals in the fossil record.