CHAPTER 32

Mammals

A collared anteater carries her young on her back. **Like all mammals, anteaters have hair, breathe air, and nurse their young with milk.**

Inquiry Activity

How are teeth adapted to processing different foods?

Procedure

1. Put on plastic gloves. Examine a mammal tooth. Describe the shape of the tooth.
2. Based on the tooth's structure, try to infer whether the mammal ate mainly plants or other animals.
3. Repeat steps 1 and 2 for other mammal teeth.
4. Wash your hands with soap and warm water before leaving the lab.

Think About It

1. **Classifying** Sort the teeth into different groups based on their structure. Explain how you classified the teeth.
2. **Inferring** Describe what type of food you think each type of tooth is adapted to processing. Explain your reasoning.

It is late January in the Appalachian Mountains. In a rocky den beneath the snowdrifts, a black bear has just given birth. Two tiny cubs are nursing on their mother's rich milk. It is bitterly cold outside, but the mother's dense fur and thick layer of body fat keep her and her cubs comfortably warm. When spring arrives, the hungry bears will emerge from the den. For the next two years, the cubs will follow their mother as she teaches them to search for food and defend themselves.

Bears are mammals, members of the class Mammalia. All mammals are characterized by two notable features: hair and mammary glands. In female mammals, **mammary glands**—the feature for which mammals are named—produce milk to nourish the young. **In addition to having hair and the ability to nourish their young with milk, all mammals breathe air, have four-chambered hearts, and are endotherms that generate their body heat internally.**

Guide for Reading

Key Concepts

- What are the characteristics of mammals?
- When did mammals evolve?
- How do mammals maintain homeostasis?

Vocabulary

mammary gland
subcutaneous fat
rumen
diaphragm
cerebral cortex

Reading Strategy: Asking Questions Before you read, rewrite the headings in the section as *how, why,* or *what* questions about mammals. As you read, write brief answers to these heading questions.

Evolution of Mammals

Neither mammary glands nor hair are preserved in the fossil record. But mammals have several other characteristics that help scientists to identify mammalian fossils. These characteristics include a lower jaw consisting of a large, teeth-bearing bone connected directly to the skull by a joint; complex teeth that are replaced just once in a lifetime; and distinctive features of the limbs and the backbone.

Mammals are descended from ancient reptiles. According to the fossil record, the ancestors of modern mammals diverged from ancient reptiles during the Carboniferous Period. For millions of years, various mammal-like reptiles lived alongside other reptile groups.

The first true mammals appeared during the late Triassic Period, about 220 million years ago. These mammals were very small and probably resembled modern tree shrews, like the one in **Figure 32–1**. While dinosaurs ruled the Cretaceous Period, from about 145 to 65 million years ago, mammals were generally small and remained out of sight. These mammals were probably nocturnal, or active at night.

After the disappearance of the dinosaurs at the end of the Cretaceous Period, mammals underwent a burst of adaptive radiation. They increased in size and occupied many new niches. In fact, the Cenozoic Era, which followed the Cretaceous Period, is usually called the Age of Mammals. Three major groups of mammals had evolved by the beginning of the Cenozoic Era. Surviving members of these groups include today's monotremes, marsupials, and placental mammals.

Figure 32–1 **The first mammals appeared on Earth about 220 million years ago.** They may have resembled this tree shrew from Madagascar, shown here clutching a beetle. Like this tree shrew, early mammals probably ate insects.

▲ **Figure 32–2** **As endotherms, mammals are capable of adjusting their body heat internally.** When they get too warm, some mammals, such as this gray wolf cub, pant to rid their bodies of excess heat.

Form and Function in Mammals

The mammalian body has adapted in varied ways to a great many habitats. As a member of this class of chordates, you may be familiar with some of these adaptations.

Body Temperature Control Like birds, mammals are endotherms; their bodies can generate heat internally. Mammals and birds—especially small ones—have a much higher metabolic rate than most other chordates. The high rate of metabolism helps mammals generate body heat. Mammals also have external body hair that helps them keep warm. Hair is part of the integumentary system, which is the outer covering of the body—the skin and all structures associated with the skin. **Subcutaneous** (sub-kyoo-TAY-nee-us) **fat,** which is a layer of fat located beneath the skin, also helps conserve body heat.

Many mammals have sweat glands that help cool the body. Sweating is regulated by an internal negative feedback mechanism, which you learned about in Chapter 26. When its internal body temperature becomes too high, the mammal begins to sweat. The evaporation of the sweat then cools the body. The mammal then stops sweating. Mammals that lack sweat glands, like the wolf in **Figure 32–2**, often pant to rid themselves of excess heat. **The ability of mammals to regulate their body heat from within is an example of homeostasis.** This ability also allows mammals to move about in the cold, while most other animals would seek shelter.

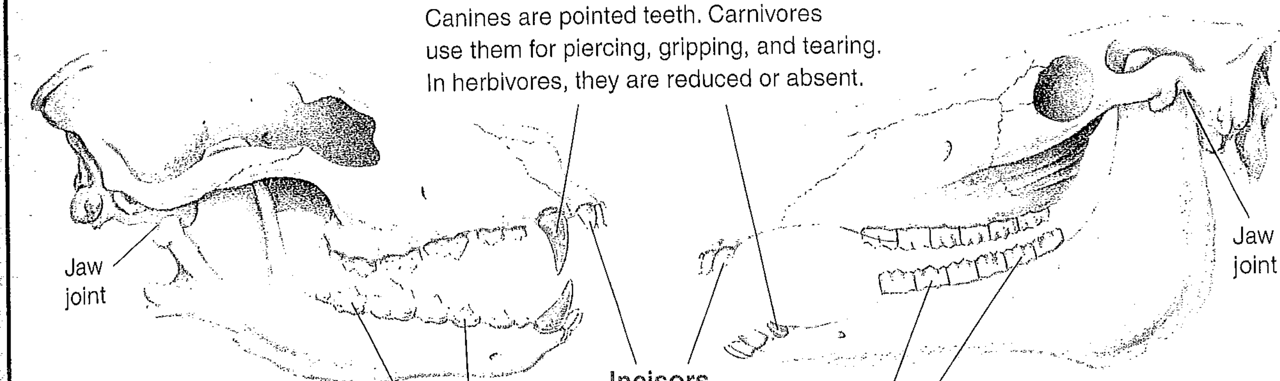
Feeding Because of its high metabolic rate, a mammal must eat nearly 10 times as much food as a reptile of the same size to maintain homeostasis. Some mammals, such as rabbits and giraffes, eat only plants. Others, including cats and weasels, are meat-eaters. Bears and humans are omnivores, consuming all types of food. Certain whales, like the one in **Figure 32–3**, are filter feeders.

Early mammals ate insects. **As mammals evolved, the form and function of their jaws and teeth became adapted to eat foods other than insects.** The joint between the skull and lower jaw became stronger than that of reptiles. This joint allowed mammals to evolve larger, more powerful jaw muscles and different ways of chewing.

▶ **Figure 32–3** The teeth of certain whales, such as this humpback, have been replaced by huge, stiffened plates called baleen. The fringed baleen strains out small animals and plankton from the mouthfuls of water that the whale takes in. **Inferring**

FIGURE 32–4

The specialized jaws and teeth of mammals are adapted for different diets. Carnivorous mammals use sharp canines and incisors to grip and slice flesh from their prey. Their jaws usually move up and down as they chew. Herbivorous mammals use flat-edged incisors to grasp and tear vegetation, and flattened molars to grind the food. Their jaws generally move from side to side.



Modern mammals have specialized teeth—incisors, canines, molars, and premolars—which you can see in **Figure 32–4.** Observe that the structure of carnivores' teeth is different from that of herbivores' teeth. Mammals' teeth enable food to be processed efficiently. The more efficiently an animal can obtain and process its food, the more energy it can obtain.

A mammal's digestive tract breaks down and absorbs the type of food that it eats. Because digestive enzymes can quickly break down meat, carnivores have a relatively short intestine. Tough, fibrous plant tissues take much more time to digest, so most herbivores have a much longer intestine.

Many herbivores also have specialized digestive organs to break down plant matter. Cows and their relatives have a stomach chamber called the **rumen,** in which newly swallowed plant food is stored and processed. The rumen contains symbiotic bacteria that digest the cellulose of most plant tissues. After some time, the grazer regurgitates the food from the rumen into its mouth. The partially digested food is chewed and swallowed again. After several cycles, it moves through the rest of the stomach and into the intestines.

CHECKPOINT *What is the function of a rumen?*

Word Origins

The word **incisor** comes from the Latin word *incidere,* which means "to cut." **In surgery, what is an incision?**

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Respiration All mammals, even those that live in water, use lungs to breathe. These lungs are controlled by two sets of muscles. Mammals inhale when muscles in the chest lift the rib cage up and outward, increasing the volume of the chest cavity. At the same time, a powerful muscle called the **diaphragm** (DY-uh-fram) pulls the bottom of the chest cavity downward, which further increases its volume. As a result, air is pulled into the lungs. When the chest muscles lower the rib cage and the diaphragm relaxes, the volume of the chest cavity decreases. This action pushes air out of the lungs.

Circulation The mammalian circulatory system is divided into two completely separate loops with a four-chambered heart, shown in **Figure 32–5.** The right side of the heart receives oxygen-poor blood from all over the body and pumps it to the lungs. After picking up oxygen in the lungs, blood returns to the left side of the heart. This oxygen-rich blood is then pumped through blood vessels to the rest of the body. The two separate circuits—one to and from the lungs, and the other to and from the rest of the body—efficiently transport materials throughout the body.

Excretion Mammals have highly developed kidneys that help control the composition of body fluids. Mammalian kidneys extract nitrogenous wastes from the blood in the form of urea. Urea, other wastes, and water combine to form urine. From the kidneys, urine flows to a urinary bladder, where it is stored until it is eliminated. **The kidneys of mammals help maintain homeostasis by filtering urea from the blood, as well as by excreting excess water or retaining needed water.** They also retain salts, sugars, and other compounds the body cannot afford to lose. Because they are so efficient at controlling and stabilizing the amount of water in the body, the kidneys enable mammals to live in many habitats, such as deserts, in which they could not otherwise survive.

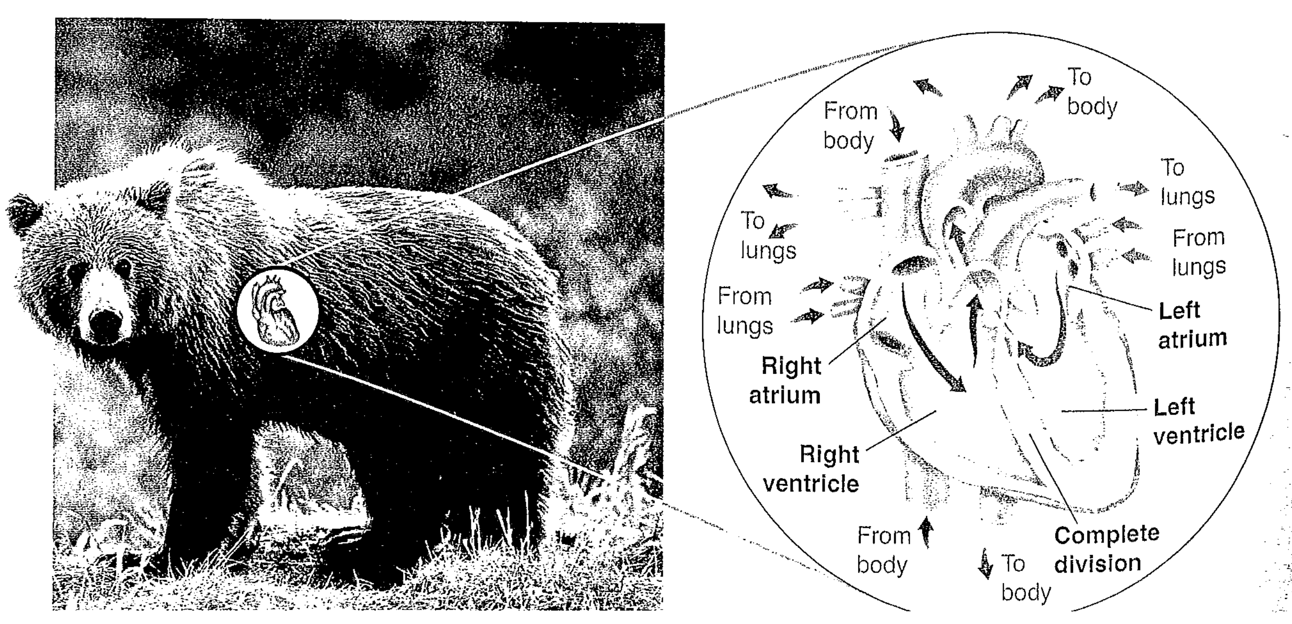


Figure 32–5 All mammals, including this brown bear, have a four-chambered heart that pumps blood in two separate circuits around the body. **Interpreting Graphics** *According to the diagram, which chamber receives blood that is low in oxygen?*

Response Mammals have the most highly developed brains of any animals. As you can see in **Figure 32–6,** the brain consists of three main parts: the cerebrum, the cerebellum, and the medulla oblongata. The cerebrum makes possible such complicated behaviors as thinking and learning. The cerebellum controls muscular coordination. The medulla oblongata regulates involuntary body functions, or those that are not under conscious control, such as breathing and heart rate.

A mammal's cerebrum contains a well-developed outer layer called the **cerebral cortex,** which is the center of thinking and other complex behaviors. Some activities, such as reading this textbook, are possible only with the human cerebral cortex. However, mammals other than humans also exhibit complex behaviors, such as storing food for later use.

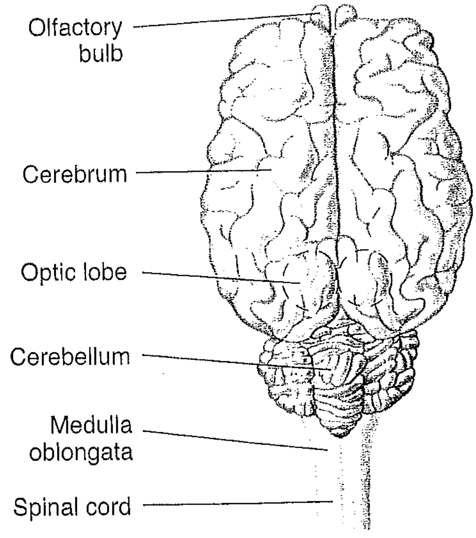
Mammals rely on highly developed senses to detect and respond to stimuli from their external environment. Many mammals have well-developed senses of smell and hearing. You probably know, for example, that dogs can easily identify people by their particular scent. Although mammalian ears all have the same basic parts, they differ in their ability to detect sound. For example, dogs, bats, and dolphins can detect sounds at much higher frequencies than humans can. In fact, bats and dolphins can find objects in their environment using the echo of their own high-frequency sounds. Other mammals, such as elephants, can detect sounds at much lower frequencies.

Many mammals have some color-sensing structures in their eyes, yet the ability to distinguish colors may vary among different species. Color vision is most useful to diurnal animals—those that are active during daylight. Although mammals such as cats can detect color, they may not see the full range of colors that humans and some other primates can.

✓CHECKPOINT *What is the function of the cerebral cortex?*

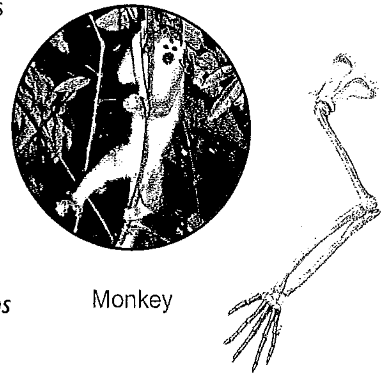
Chemical Controls The nervous system is not the only system that controls body processes. Mammals, like other vertebrates, have endocrine glands that are part of an endocrine system. Endocrine glands regulate body activities by releasing chemicals called hormones that affect other organs and tissues. Hormones produced by a gland in a mammal's neck, for example, help regulate the amount of calcium in the bones. Hormones are carried by the blood to the organs that they affect.

Fighting Disease All organisms live in an environment that contains disease-causing microorganisms, or pathogens. The immune systems of mammals and other vertebrates function to protect animals from disease. When mammals do get sick, their immune systems help them recover. Mammalian immune systems consist of barriers, such as the skin, that prevent pathogens from entering the body. In addition, specialized cells and chemicals recognize and destroy pathogens.

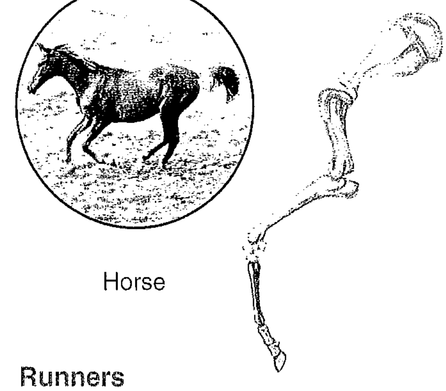


▲ **Figure 32–6** Mammals have large brains in proportion to their body size. Most of the brain is taken up by an enlarged cerebrum, which contains a well-developed cerebral cortex. **Inferring** *How would a large cerebrum be advantageous to a mammal?*

Figure 32–7 The limbs and digits (fingers and toes) of many mammals are adapted to their particular way of life. Note the variety of lengths and shapes of the limb bones that different mammals use for movement. Homologous bones are the same color in all the drawings. **Applying Concepts** *Which structure shown in this figure would most closely resemble the limbs and digits of a whale?*



Climbers
Climbing mammals have long, flexible fingers and toes that can grasp vines and branches. They also have a flexible wrist joint.

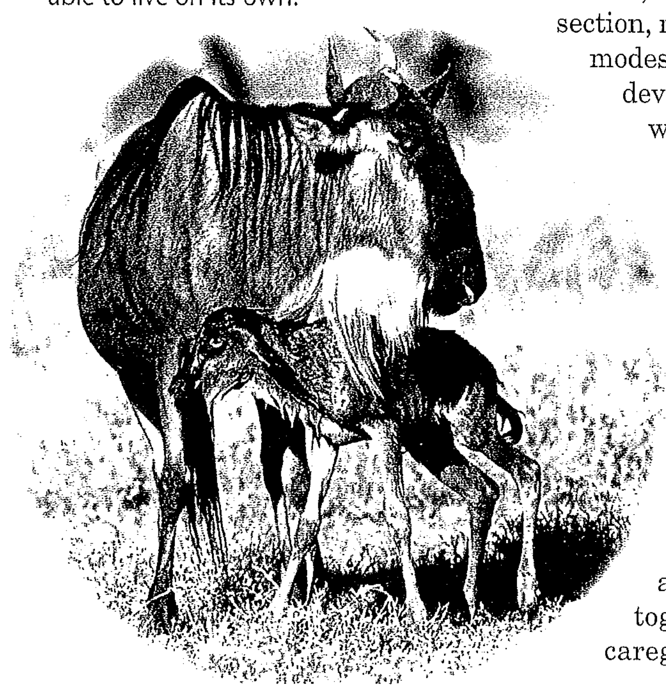


Runners
Running mammals need long limbs that can absorb shock. These animals have lost the side digits on their front and back feet. They stand on the tips of their remaining toes, which are called hooves.

Movement Mammals have evolved a variety of adaptations that aid in movement, including a backbone that flexes both vertically and side to side. This flexibility allows mammals to move with a bouncing, leaping stride. Shoulder and pelvic girdles have become more streamlined and flexible, permitting both front and hind limbs to move in a variety of ways.

Compare the adaptations of mammalian limbs shown in **Figure 32–7.** Variations in the limb bones and muscles allow mammals to run, walk, climb, burrow, hop, pounce, swing, fly, leap, and swim. Depending on their lifestyle, mammals may use any number of these methods to move about.

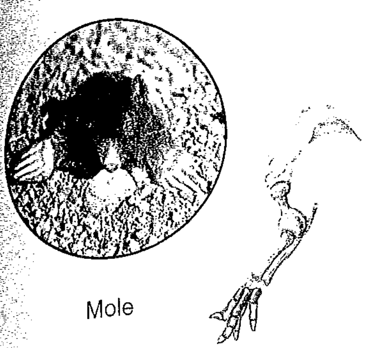
▼ **Figure 32–8** Still wobbly, a newborn wildebeest rises to its feet minutes after birth. Its mother will nurse and protect the calf until it is able to live on its own.



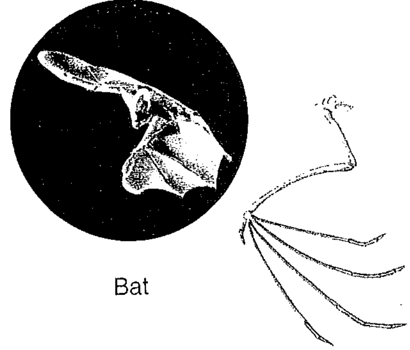
Reproduction Mammals reproduce by internal fertilization. The male deposits sperm inside the reproductive tract of the female, where fertilization occurs. As you will learn in the next section, mammals are classified into three groups, based on their modes of development and birth. Regardless of the mode of development, all newborn mammals, such as the newborn wildebeest in **Figure 32–8,** feed on their mother's milk.

Young mammals generally need care when they are born and for a long time afterward. During this period, they are cared for by one or both parents. Maternal care is an important mammalian characteristic, and the bond between mother and young is very close. Males of many species also play a role in caring for the young. Parental care helps ensure that young mammals will survive and reproduce. Mammalian parental behavior is an adaptation that is the result of natural selection and other evolutionary processes.

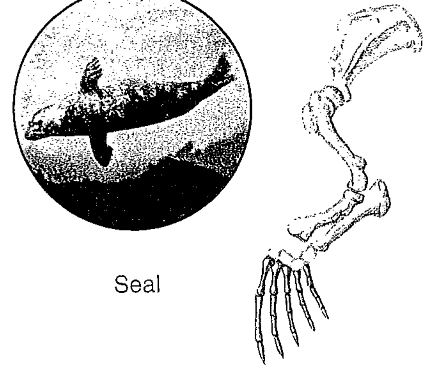
The duration and intensity of parental care varies among different species. Some mammals have a prolonged period when the young and the mother live together. During that period, the juvenile learns from its caregiver the behaviors it needs to survive.



Diggers
Digging mammals have strong, thick claws, especially on their front feet. Their limbs are short and stocky, with large projections that anchor powerful muscles.



Flyers
The arms and hands of bats are modified to support flaps of skin that form wings.



Swimmers
Swimming mammals concentrate most of their movement between the arm and shoulder girdle. Their limbs are modified into broad, flat paddles, with the bones of their hands or feet extended to make a flipper.

Some mammal species, such as lions and elephants, live in groups in which the young may be cared for by adults other than the parents. Group living provides young mammals with the opportunity for complex social interaction among adults and juveniles.

Interrelationships of Organ Systems In mammals and other animals, organ systems are interdependent in order to maintain a homeostatic environment. All body systems depend on the circulatory system to transport materials. The respiratory system, for example, ensures that oxygen enters the lungs, but the blood carries oxygen to body cells. Similarly, blood carries waste products to the kidneys, which remove the waste products from the body. Nerve impulses from cells in the nervous system carry information to and from organs in every body system. The bones of the skeletal system could not grow and maintain themselves without calcium and other materials that enter the body through the digestive system. An animal's organ systems work together to meet the needs of the body as a whole.

32–1 Section Assessment

1. **Key Concept** Name the characteristics that are common to all mammals.
2. **Key Concept** When did mammalian ancestors diverge from the other reptiles?
3. **Key Concept** List two ways in which mammals maintain homeostasis.
4. What is the function of the endocrine system?
5. **Critical Thinking Comparing and Contrasting** Compare the functions of the respiratory and circulatory systems. Then, explain how the structure of a mammal's heart helps these two systems work together to deliver oxygen to body cells.

Focus on the BIG Idea

Structure and Function
Compare the structure of a mammal's brain to that of a fish, as shown in Chapter 30, **Figure 30–14.** What structures are more prominent in each animal's brain? How might these differences relate to the way the animals live?

32–2 Diversity of Mammals

Guide for Reading

Key Concepts
- How do the three groups of living mammals differ from one another?
- How did convergent evolution cause mammals on different continents to be similar in form and function?

Vocabulary
monotreme
marsupial
placenta

Reading Strategy: Summarizing As you read, make a list of the major groups of mammals. Write several sentences describing the characteristics of each group. Then, give an example for each.

The class Mammalia contains about 4500 species, and the diversity of these species is astonishing. From a tiny mouse nibbling its way along a corncob to an African elephant uprooting a gigantic tree with its tusks and trunk, mammals have the greatest range of size of any group of vertebrates.

As you have read, tooth structure is one characteristic that scientists use to classify mammals. Mammals are also classified by the number and kinds of bones in the head. But the most important way to categorize living mammals is by the way they reproduce and develop.

The three groups of living mammals are the monotremes (MAHN-oh-treemz), the marsupials (mahr-SOO-pee-ulz), and the placentals. These three groups differ greatly in their means of reproduction and development.

Monotremes and Marsupials

Monotremes lay eggs. Marsupials bear live young, but at a very early stage of development. All monotremes are grouped in a single order, while marsupials are split into several different orders.

Monotremes Members of the **monotremes,** or egg-laying mammals, share two notable characteristics with reptiles. In monotremes, the digestive, reproductive, and urinary systems all open into a cloaca that is similar to the cloaca of reptiles. In fact, the name *monotreme* means "single opening." Reproduction in monotremes also resembles reproduction in reptiles more than other mammals. As in reptiles, a female monotreme lays soft-shelled eggs that are incubated outside her body. The eggs hatch into young animals in about ten days. Unlike young reptiles, however, young monotremes are nourished by their mother's milk, which they lick from pores on the surface of her abdomen.

Only three species of monotremes exist today: the duckbill platypus, shown in **Figure 32–9,** and two species of spiny anteaters, or echidnas. These animals are found in Australia and New Guinea.

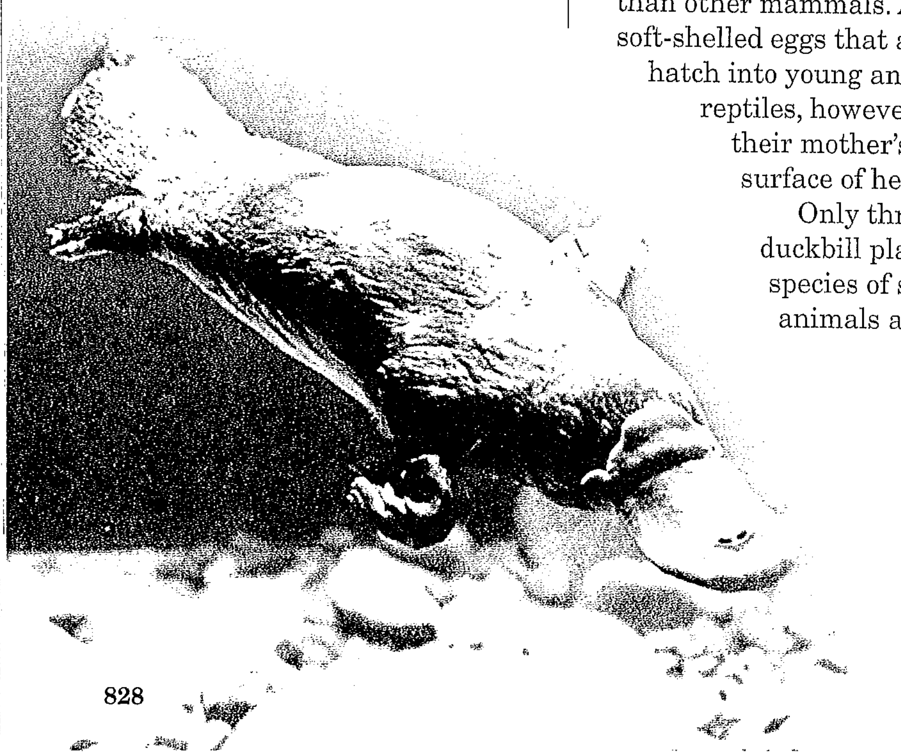


Figure 32–9 **Like all monotremes, the platypus lays eggs that hatch outside the body but nourishes its young with milk produced in mammary glands.** The unusual snout of this duckbill platypus can sense electromagnetic signals put out by the muscles of other animals. The platypus uses its sensitive snout to locate prey, such as worms and mollusks, that burrow in the sediments.

Marsupials Kangaroos, koalas, and wombats are examples of **marsupials**—mammals bearing live young that usually complete their development in an external pouch. When marsupials reproduce, the fertilized egg develops into an embryo inside the mother's reproductive tract. The embryo is born at a very early stage of development. It crawls across its mother's fur and attaches to a nipple. In most species of marsupials, the nipples are located in a pouch called the marsupium (mahr-SOO-pee-um) on the outside of the mother's body. Marsupials are named after this structure. Once inside the marsupium, the embryo, looking much like the one in **Figure 32–10**, spends several months attached to the nipple. It will continue to drink milk in its mother's pouch until it grows large enough to survive on its own.

✓CHECKPOINT *How does a marsupial differ from a monotreme?*

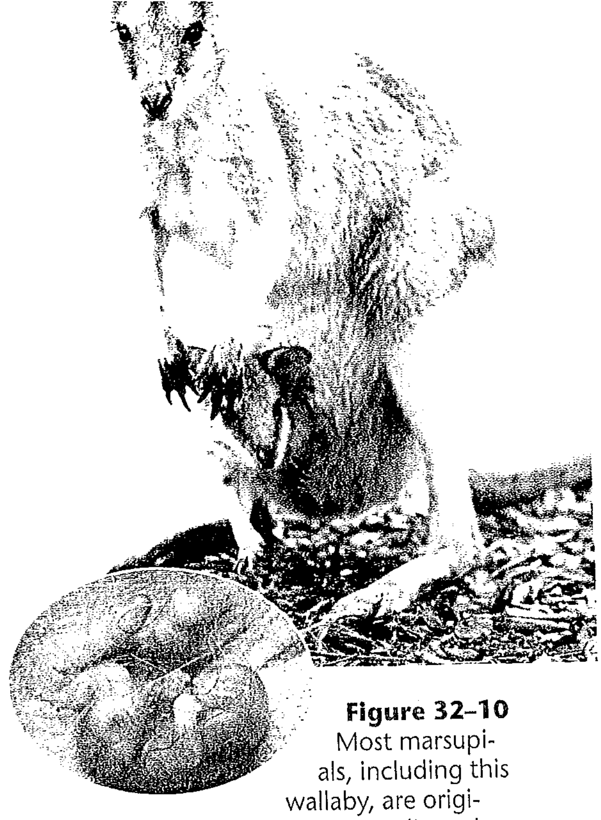
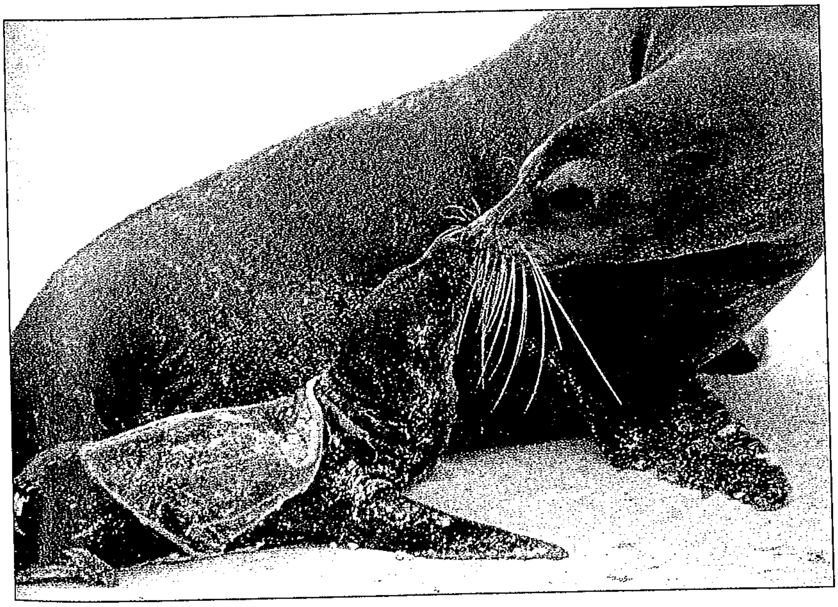


Figure 32–10 Most marsupials, including this wallaby, are originally from Australia and New Guinea. **Marsupials bear live young that usually complete their development in a pouch.** The pink, newborn wallaby (inset) is still an embryo but will soon grow into a "joey" that resembles a small adult.

Placental Mammals

Placental mammals are the mammals with which you are most familiar. Mice, cats, dogs, whales, elephants, humans, and the sea lions in **Figure 32–11** all fall within this category. This group gets its name from an internal structure called the **placenta,** which is formed when the embryo's tissues join with tissues from within the mother's body.

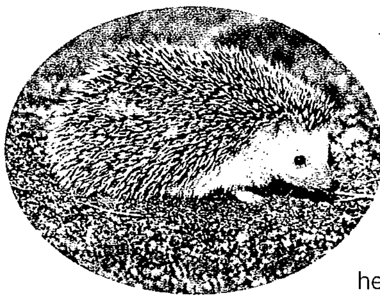
In placental mammals, nutrients, oxygen, carbon dioxide, and wastes are exchanged efficiently between embryo and mother through the placenta. The placenta allows the embryo to develop for a much longer time inside the mother—from a few weeks in mice and rats to as long as two years in elephants. After birth, most placental mammals care for their young and provide them with nourishment by nursing. **Figure 32–12**, on the following pages, describes the main orders of placental mammals.



◀ **Figure 32–11** The California sea lion is an example of a placental mammal. **In placental mammals, nutrients, oxygen, carbon dioxide, and wastes are exchanged between embryo and mother through the placenta.**

Figure 32–12 Orders of Placental Mammals

The 12 orders of mammals shown on these pages contain the vast majority of living placental species. **Classifying** *How are perissodactyls similar to artiodactyls? How are the two orders different?*



◀ INSECTIVORES

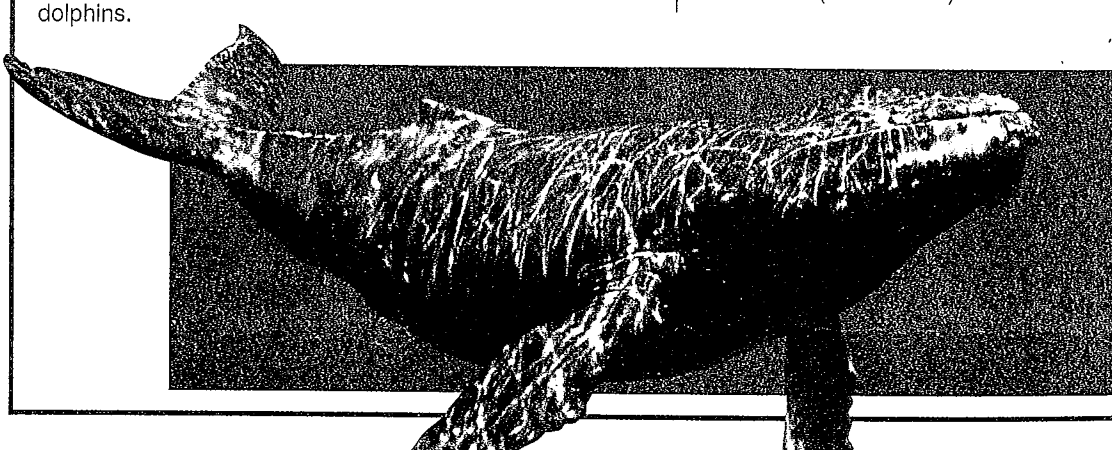
These insect eaters have long, narrow snouts and sharp claws that are well suited for digging. *Examples:* shrews, hedgehogs (shown here), moles.

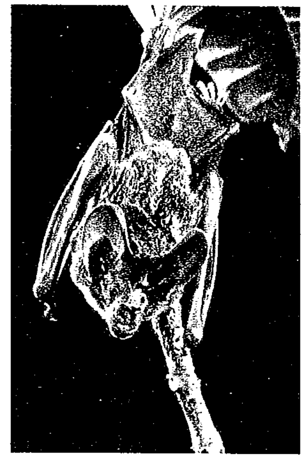
▼ SIRENIANS

Sirenians are herbivores that live in rivers, bays, and warm coastal waters scattered throughout most of the world. These large, slow-moving mammals lead fully aquatic lives. *Examples:* manatees, dugongs (shown here).

▼ CETACEANS

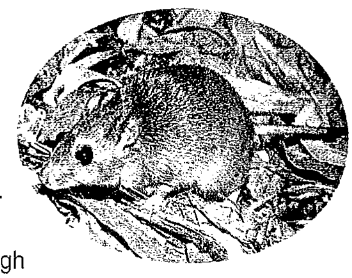
Like sirenians, cetaceans—the order that includes whales and dolphins—are adapted to underwater life yet must come to the surface to breathe. Most cetaceans live and breed in the ocean. *Examples:* humpback whales (shown here), narwhals, sperm whales, beluga whales, river dolphins.





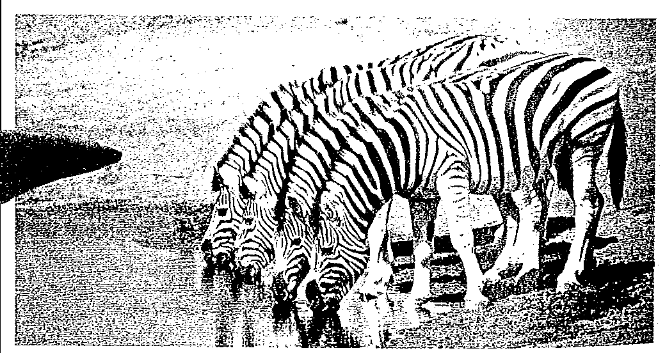
◀ CHIROPTERANS

Winged mammals—or bats—are the only mammals capable of true flight. Bats account for about one-fifth of all mammalian species. They eat mostly insects or fruit and nectar, although three species feed on the blood of other vertebrates.



RODENTS ▶

Rodents have a single pair of long, curved incisor teeth in both their upper and lower jaws, which they use for gnawing wood and other tough plant material. *Examples:* mice, rats (shown here), voles, squirrels, beavers, porcupines, gophers, chipmunks, gerbils, prairie dogs, chinchillas.

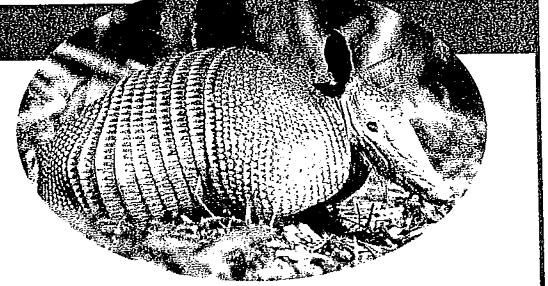


▲ PERISSODACTYLS

This order contains hoofed animals with an odd number of toes on each foot. *Examples:* horses, tapirs, rhinoceroses, and zebras (shown here).

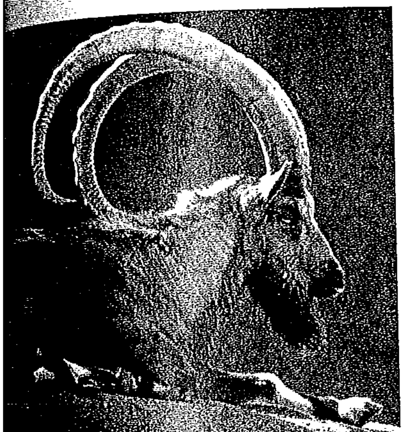
▲ CARNIVORES

Many mammals in this order, such as tigers and hyenas, stalk or chase their prey by running or pouncing, then kill the prey with sharp teeth and claws. Some animals in this group eat plants as well as meat. *Examples:* dogs, foxes, bears, raccoons, walruses (shown here).



▲ XENARTHRANS

Most of the mammals in this order have simple teeth without enamel, and a few have no teeth at all. *Examples:* sloths, anteaters, armadillos (shown here).



◀ ARTIODACTYLS

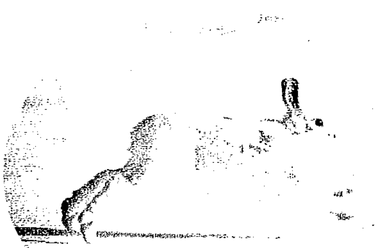
These hoofed mammals have an even number of toes on each foot. Like perissodactyls, this order contains mostly large, grazing animals. *Examples:* cattle, sheep, goats, pigs, ibex (shown here), giraffes, hippopotami, camels, antelope, deer, gazelles.

◀ PRIMATES

Members of this order are closely related to the ancient insectivores but have a highly developed cerebrum and complex behaviors. *Examples:* lemurs, tarsiers, apes, gibbons, macaques (shown here), humans.

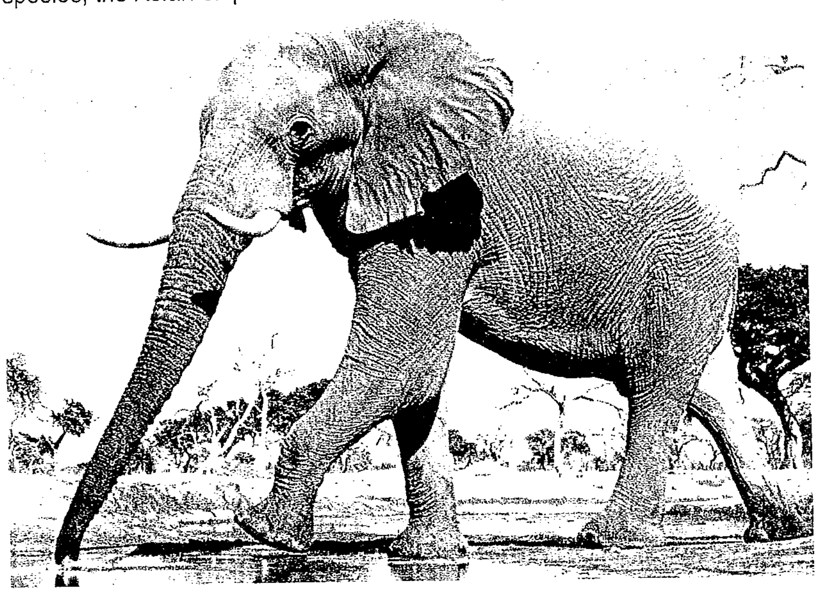
▼ PROBOSCIDEANS

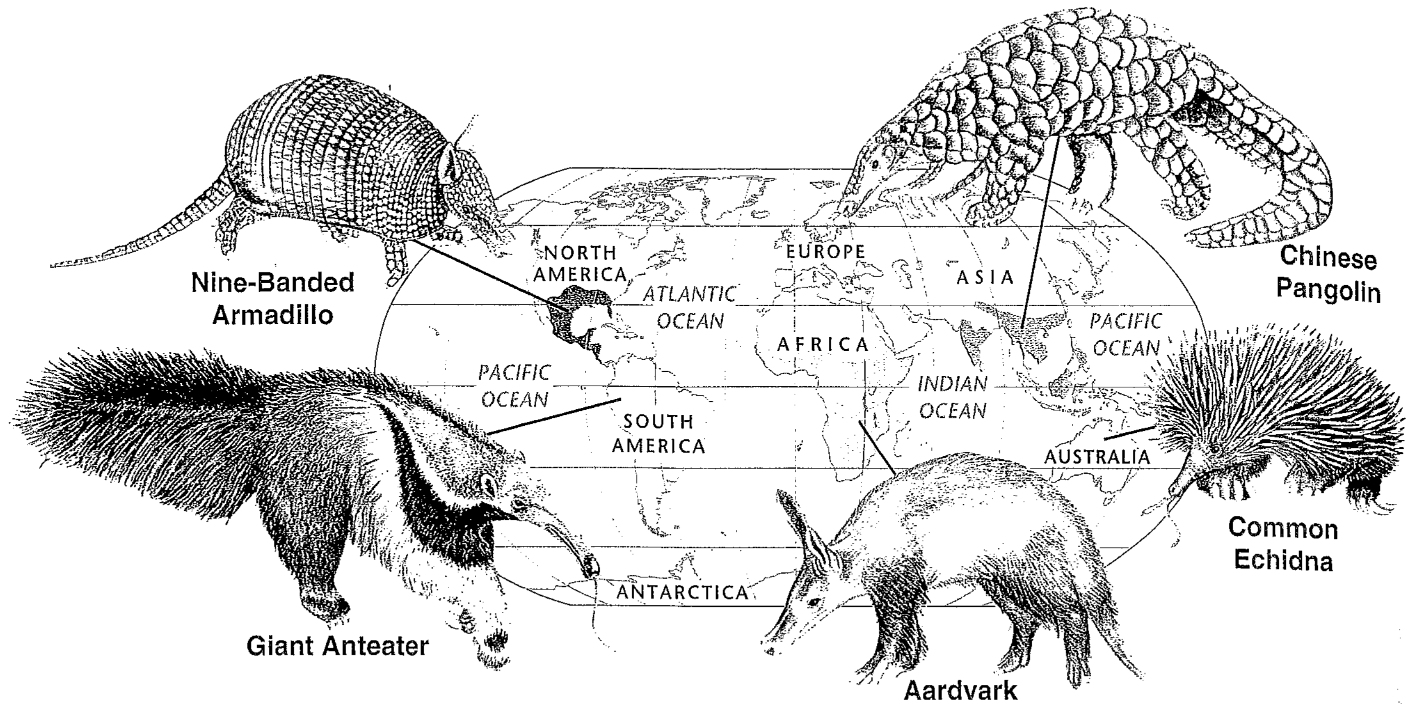
These are the mammals with trunks. Some time ago, this order went through an extensive adaptive radiation that produced many species, including mastodons and mammoths, which are now extinct. Only two species, the Asian elephant and this African elephant, survive today.



▲ LAGOMORPHS

Like rodents, members of this order are entirely herbivorous. They differ from rodents by having two pairs of incisors in the upper jaw. Most lagomorphs have hind legs that are adapted for leaping. *Examples:* Snowshoe hares (shown here), rabbits.





▲ **Figure 32–13** **Similar ecological opportunities on different continents have resulted in convergent evolution among these and other mammals.** Mammals that feed on ants and termites evolved not once but five times in different regions. Powerful front claws; a long, hairless snout; and a tongue covered with sticky saliva are common adaptations in these insect-eating animals.

Biogeography of Mammals

The history of Earth's geography has helped shape today's mammals. During the Paleozoic Era, the continents were one large landmass, and mammals could migrate freely across it. But as the continents drifted farther and farther apart during the Mesozoic and early Cenozoic Eras, ancestors of mammal groups were isolated from one another. Each landmass took with it a unique array of mammal groups.

Similar ecological opportunities on the different continents have produced some striking examples of convergent evolution in mammals. Thousands of kilometers apart, mammals such as those in **Figure 32–13** evolved similar adaptations in form and function. When some of the landmasses merged in the late Cenozoic Era, mammals dispersed and intermingled in new habitats. Living mammals reflect the diversity that resulted from these events.

32–2 Section Assessment

1. **Key Concept** Name the three groups of living mammals and describe the ways each develops.
2. **Key Concept** With regard to mammals, what was the result of continental drift?
3. What is the function of the placenta?
4. List the major orders of placental mammals.
5. What characteristic distinguishes lagomorphs from rodents?
6. **Critical Thinking Inferring** How are powerful front claws and sticky tongues useful adaptations in mammals that feed on ants?

Thinking Visually

Comparing and Contrasting
Create a compare-and-contrast table that describes the characteristics of monotremes, marsupials, and placental mammals. Include characteristics that they share as well as ways in which they differ.

32–3 Primates and Human Origins

Our own species, *Homo sapiens*, belongs to the order that also includes lemurs, monkeys, and apes. Carolus Linnaeus named our order Primates, which means "first" in Latin.

What Is a Primate?

Just what are primates "first" in? When the first primates appeared, there was little to distinguish them from other mammals besides an increased ability to use their eyes and front limbs together to perform certain tasks. As primates evolved, however, several other characteristics became distinctive.

Primates share several important adaptations, many of which are extremely useful for a life spent mainly in trees. **In general, primates have binocular vision, a well-developed cerebrum, relatively long fingers and toes, and arms that can rotate around their shoulder joints.** The gibbon in **Figure 32–14** shows many of these characteristics.

Fingers, Toes, and Shoulders Primates normally have five flexible fingers that can curl around objects. Most also have flexible toes. Flexible digits (fingers and toes) enable many primates to run along tree limbs and swing from branch to branch with ease. Primates' arms are well adapted to climbing because they can rotate in broad circles around a strong shoulder joint. In most primates, the thumb and big toe can move against the other digits. The presence of this adaptation allows many primates to hold objects firmly in their hands or feet.

Well-Developed Cerebrum The large and intricate cerebrum of primates—including a well-developed cerebral cortex—enables them to display more complex behaviors than many other mammals. For example, many primate species have elaborate social behaviors that include adoption of orphans and even warfare between rival primate troops.

Guide for Reading

Key Concepts
- What characteristics do all primates share?
- What are the major evolutionary groups of primates?
- What is the current scientific thinking about hominid evolution?

Vocabulary
binocular vision
prosimian
anthropoid
prehensile
hominoid
hominid
bipedal
opposable thumb

Reading Strategy: Finding Main Ideas Before you read, draw a line down the center of a sheet of paper. On the left side, write down the main topics about primates and human origins. On the right side, note supporting details and examples.

◀ **Figure 32–14** A white-handed gibbon displays several primate characteristics as it swings from tree to tree. **Like all primates, the gibbon has flexible fingers and toes and has arms that can rotate in broad circles around the shoulder joint.**

Quick Lab

Is binocular vision useful?

Material paper crumpled into a ball

Procedure

1. Throw the paper ball to your partner, who should try to catch the ball with one hand. Record whether your partner caught the ball.
2. Now have your partner close one eye. Repeat step 1.

Analyze and Conclude

1. **Using Tables and Graphs** Exchange results with other groups. Make a bar graph for the class data comparing the results with both eyes open and one eye shut.
2. **Drawing Conclusions** How is binocular vision useful to primates?

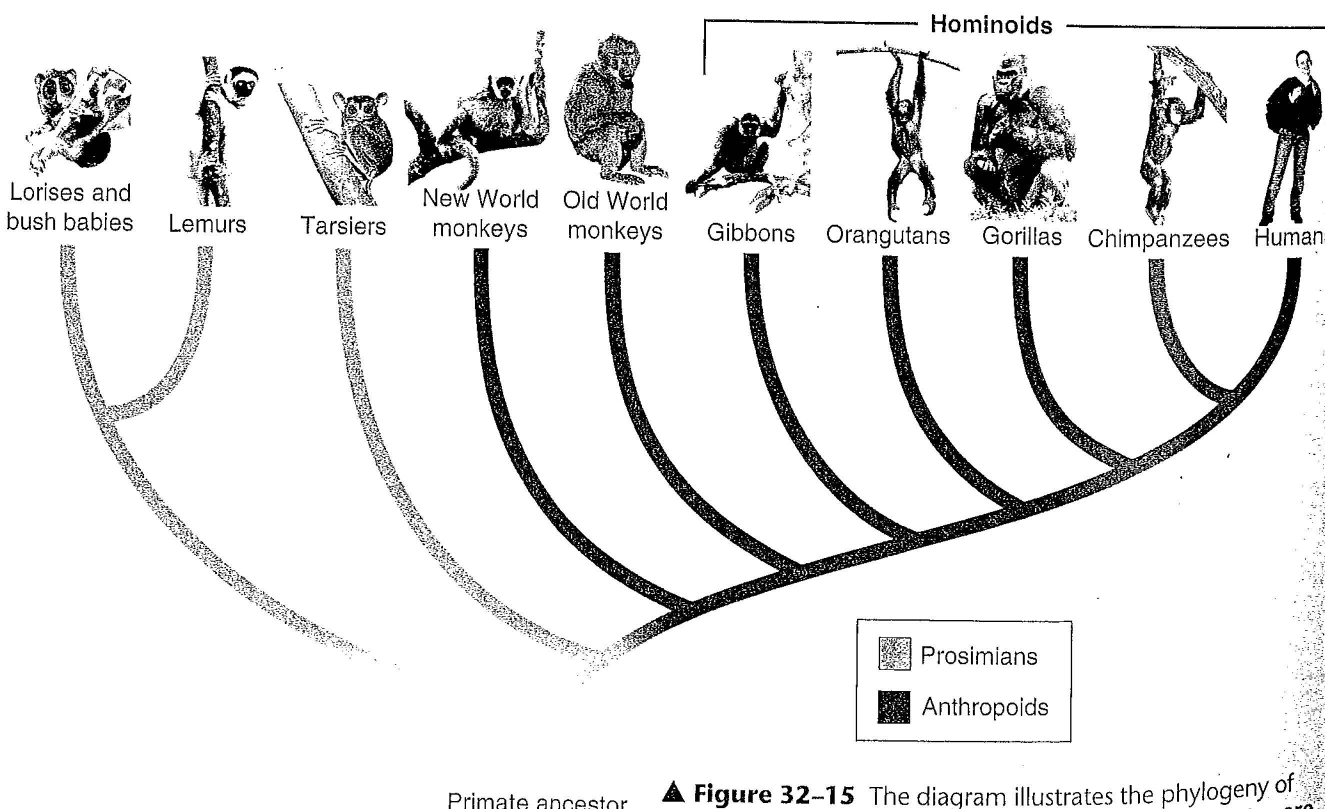
Binocular Vision Many primates have a flat face, so both eyes face forward with overlapping fields of view. This facial structure gives primates excellent binocular vision. **Binocular vision** is the ability to merge visual images from both eyes, thereby providing depth perception and a three-dimensional view of the world. This is a handy adaptation for judging the locations of tree branches, from which many primates swing.

Evolution of Primates

Humans and other primates evolved from a common ancestor that lived more than 65 million years ago. Early in their history, primates split into several groups. **Primates that evolved from two of the earliest branches look very little like typical monkeys and are called prosimians (proh-SIM-ee-unz). Members of the more familiar primate group that includes monkeys, apes, and humans are called anthropoids (AN-thruh-poydz).** Refer to **Figure 32–15** as you read about the phylogenetic relationships among these groups.

Prosimians With few exceptions, **prosimians** alive today are small, nocturnal primates with large eyes that are adapted to seeing in the dark. Many have doglike snouts. Living prosimians include the bush babies of Africa, the lemurs of Madagascar, and the lorises and tarsiers of Asia.

CHECKPOINT *What is a prosimian?*



▲ **Figure 32–15** The diagram illustrates the phylogeny of modern primates. **The two main groups of primates are prosimians and anthropoids.**

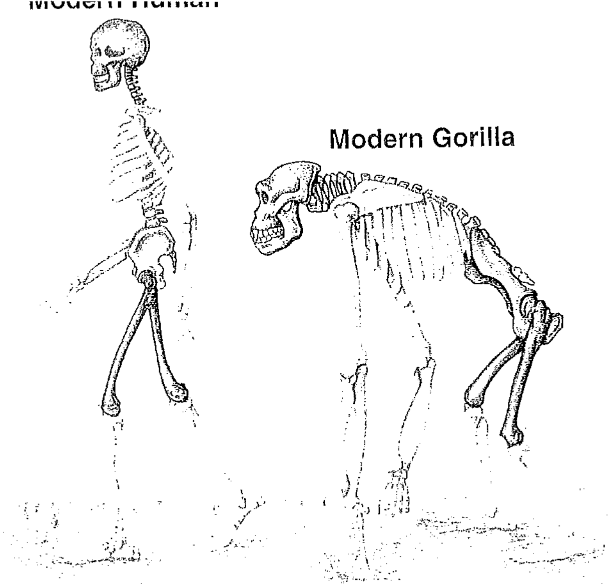
Anthropoids Humans, apes, and most monkeys belong to a group called **anthropoids,** which means humanlike primates. This group split very early in its evolutionary history into two major branches. These branches became separated from each other as drifting continents moved apart. One branch, found today in Central and South America, is called the New World monkeys. (After Columbus's voyage to America, Europeans began to use the term *New World* to refer to North and South America.) New World monkeys, which include squirrel monkeys and spider monkeys, live almost entirely in trees. These monkeys have long, flexible arms that enable them to swing from branch to branch. New World monkeys also have a long, prehensile tail. A **prehensile** tail is a tail that can coil tightly enough around a branch to serve as a "fifth hand."

The other anthropoid group, which evolved in Africa and Asia, includes the Old World monkeys and great apes. Old World monkeys, such as langurs and macaques (muh-KAHKS), spend time in trees but lack prehensile tails. Great apes, also called **hominoids,** include gibbons, orangutans, gorillas, chimpanzees, and humans. Recent molecular studies confirm that chimpanzees are humans' closest relatives among the great apes. Humans and chimps share an astonishing 98 percent of their DNA!

Hominid Evolution

Between 6 and 7 million years ago, the hominoid line gave rise to a branch that ultimately led to the ancestors and closest relatives of modern humans. The **hominid** family, which includes modern humans, displayed several distinct evolutionary trends. Fossil evidence shows that as hominids evolved over millions of years, they became able to walk upright and developed thumbs adapted for grasping. They also developed large brains.

The skull, neck, spinal column, hipbones, and leg bones of early hominid species changed shape in ways that enabled later species to walk upright. **Figure 32–16** shows some ways in which the skeletons of modern humans differ from those of gorillas. The evolution of this **bipedal,** or two-foot, locomotion was very important, because it freed both hands to use tools. Meanwhile, the hominid hand evolved an **opposable thumb** that enabled grasping objects and using tools.



Comparing Human and Gorilla Skeletons

Modern Human	Modern Gorilla
Skull atop S-shaped spine	Skull atop C-shaped spine
Spinal cord exits at bottom of skull	Spinal cord exits near back of skull
Arms shorter than legs; hands do not touch ground during walking	Arms longer than legs; hands touch ground during walking
Pelvis is bowl-shaped	Pelvis is long and narrow
Thigh bones angled inward, directly below body	Thigh bones angled away from pelvis

▲ **Figure 32–16** Modern hominids walk upright on two legs; gorillas use all four limbs. **Comparing and Contrasting** *According to the chart and illustration, what are the other differences between humans and gorillas?*

▲ **Figure 32–17** Between 3.8 and 3.6 million years ago, members of a species of *Australopithecus* made these footprints at Laetoli in Tanzania. The footprints show that hominids walked upright millions of years ago.

Hominids also displayed a remarkable increase in brain size. Chimpanzees, our closest living relatives among the apes, have a brain size of 280 to 450 cubic centimeters. The brain of *Homo sapiens,* on the other hand, ranges in size from 1200 to 1600 cubic centimeters! Most of the difference in brain size results from an enormously expanded cerebrum—the "thinking" area of the brain.

Early Hominids Paleontologists have unearthed a treasure trove of hominid species. At present, most paleontologists agree that the hominid fossil record includes at least these genera—*Ardipithecus, Australopithecus, Paranthropus, Kenyanthropus,* and *Homo*—and as many as 20 separate species. This diverse group of hominid fossils covers roughly 6 million years. All these species are relatives of modern humans, but not all of them are human ancestors. To understand that distinction, think of your family. Your relatives may include aunts, uncles, cousins, parents, grandparents, and great-grandparents. Of these, only your parents, grandparents, and great-grandparents are your ancestors.

Almost a third of all known hominid species have been discovered in the last 20 years. This shows how rapidly knowledge of hominid fossils is growing. It also explains why hominid evolution is both fascinating and confusing. What once looked like a simple "human family tree" now looks more like a dense, branching shrub. Many questions remain about how fossil hominids are related to one another and to humans. Let's examine a few of the most important discoveries.

Biology and History

Human-Fossil Seekers

The study of human origins is an exciting search for our past. To piece together this complicated story requires the skills of many scientists.

1812

Georges Cuvier

Cuvier, a French zoologist, rejects the idea of evolution based on a lack of evidence in the fossil record. He is noted for saying "Fossil man does not exist!" He believed species were static and unchanging.

1868

Edouard Lartet
Henry Christy

French geologist Lartet and English banker Christy unearth several ancient human skeletons in a rock shelter called Cro-Magnon in France. These hominid fossils are the first to be classified as *Homo sapiens.*

1886

Marcel de Puydt
Max Lohest

De Puydt and Lohest describe two Neanderthal skeletons found in a cave in Belgium. Their detailed description of the skeletons shows that Neanderthals were an extinct human form, not an abnormal form of modern human.

1800 — 1850 — 1900

Australopithecus One early group of hominids, members of the genus *Australopithecus,* lived from about 4 million to a million years ago. These hominids were bipedal apes that spent at least some time in trees. The structure of their teeth suggests a diet rich in fruit. Some *Australopithecus* species seem to have been human ancestors, while others formed separate branches off the main hominid line.

The best known species is *Australopithecus afarensis*—described from a remarkably complete female skeleton, nicknamed Lucy, who stood only about 1 meter tall. The humanlike footprints shown in **Figure 32–17,** which are between 3.8 and 3.6 million years old, were probably made by members of the same species as Lucy. Since *Australopithecus* fossils have small brains, the Laetoli footprints show that hominids walked bipedally long before large brains evolved.

Paranthropus Three later species, which grew to the size of well-fed football linebackers, were originally placed in the genus *Australopithecus*. However, they are now usually placed in their own genus, *Paranthropus.* The known *Paranthropus* species had huge, grinding back teeth. Their diets probably included coarse and fibrous plant foods like those eaten by modern gorillas. Most paleontologists now place *Paranthropus* on a separate, dead-end branch of our family tree.

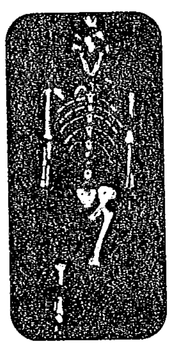
CHECKPOINT *What are the characteristics of* Paranthropus*?*

Discovery Education To find out more about human history, view track 6 "Mummies: Ties to the Past" on the *BioDetectives* DVD.

Writing in Science

You have found Mary Leakey's journal and noticed that the entry for her discovery of the footprints at Laetoli is missing. Write an entry for the journal as she would have, describing the events of the day and her initial reaction to the find.

1924
Raymond Dart
Dart, an Australian anatomist, finds an early hominid fossil—a nearly complete skull of a child—in South Africa. This specimen was placed in a new genus called *Australopithecus.*

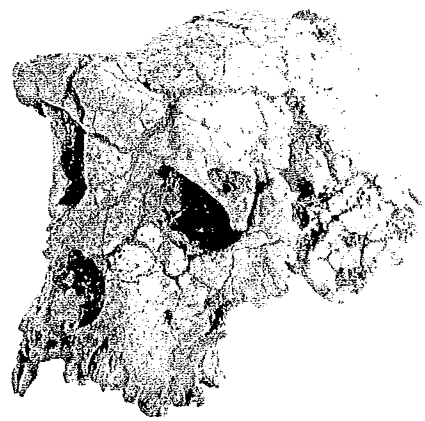


1974
Donald Johanson
An American paleontologist and his team find 40 percent of a skeleton of *Australopithecus*, which they call Lucy, in the Afar region of Ethiopia. The skeleton is about 3.2 million years old.

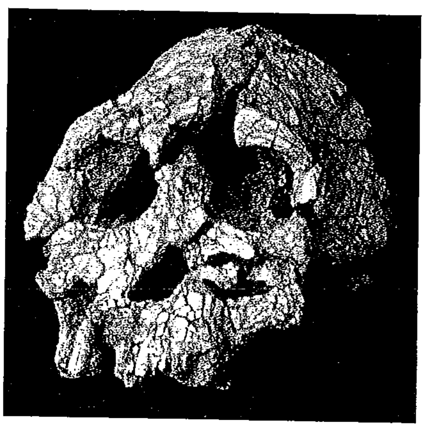
1978
Mary Leakey
Leakey, a British anthropologist, discovers a set of 3.6 million-year-old fossil hominid footprints at Laetoli in Tanzania. The footprints provide evidence that early hominids walked erect on two legs.

1999
Douglas Wallace
Wallace and fellow geneticists create a family tree of human evolution based on their studies of mitochondrial DNA, which is passed only from mother to child.

1900 1950 2000



Sahelanthropus tchadensis



Kenyanthropus platyops

Homo erectus

▲ **Figure 32–18** Paleontologists' interpretations of hominid evolution are based on the study of fossils such as these skulls. *Sahelanthropus* may be the earliest known hominid. **Observing** *Which of these skulls most closely resembles the skull of a modern human?*

Recent Hominid Discoveries Early in 2001, a team led by paleontologist Meave Leakey announced that they had uncovered a skull in Kenya. Its ear structures resembled those of chimpanzees, and its brain was rather small. Yet some of its facial features resembled those of fossils usually placed in the genus *Homo*. Paleontologists put this skull in a new genus, *Kenyanthropus*. *Kenyanthropus* is shown in the middle in **Figure 32–18.** Evidence indicates that this species existed at the same time as *A. afarensis.*

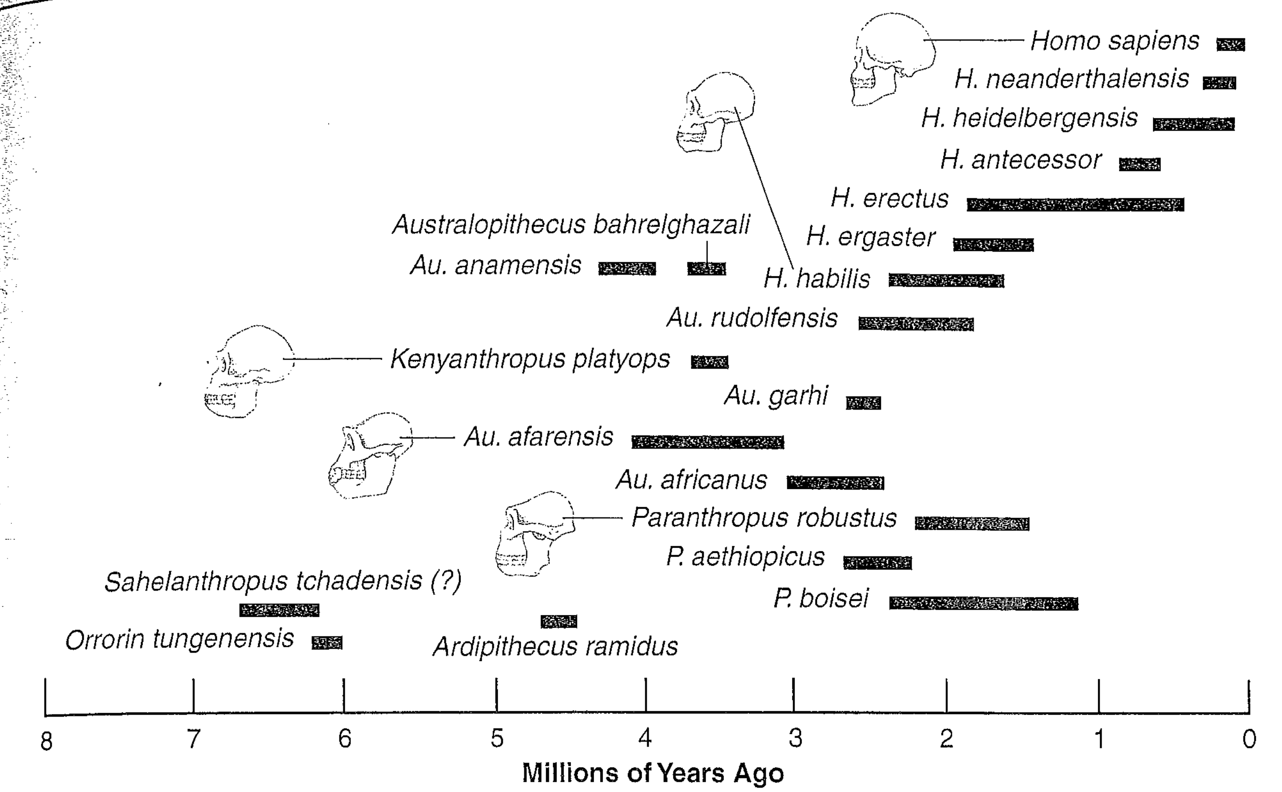
Then, during the summer of 2002, paleontologists working in the desert in north-central Africa announced the discovery of an even more startling skull. This fossil skull, tentatively called *Sahelanthropus,* is nearly 7 million years old. If scientists agree that *Sahelanthropus* is indeed a hominid, it would be a million years older than any hominid previously known.

Sahelanthropus had a brain about the size of a modern chimp, yet its short, flat face is more like that of a human. In fact, this skull seems more humanlike in certain ways than Lucy (*A. afarensis*), who lived several million years later. While most hominid fossils have been discovered in eastern Africa, *Sahelanthropus* was discovered much farther to the west. This suggests that there may be many more fossil hominids to be found in widely separated parts of Africa.

✓CHECKPOINT *What is* Kenyanthropus platyops*?*

Rethinking Early Hominid Evolution Together with other recent fossil finds, the discovery of *Kenyanthropus* and *Sahelanthropus* has dramatically changed the way paleontologists think about hominid evolution. Researchers once thought that human evolution took place in relatively simple steps in which hominid species, over time, became gradually more humanlike. **It is now clear that hominid evolution did not proceed by the simple, straight-line transformation of one species into another. Rather, like the evolution of other mammalian groups, a series of complex adaptive radiations produced a large number of species whose relationships are difficult to determine.** Which hominids are true human ancestors? Which are just relatives? And how are all those species related to one another and to modern humans? At present, no one can answer these questions.

So what is known about hominid evolution? As shown in **Figure 32–19,** the hominid fossil record now dates back nearly 7 million years, close to the time that DNA studies suggest for the split between hominids and the ancestors of modern chimpanzees. In addition, there are many known fossil hominid species, several of which display a confusing mix of primitive and modern traits. It will probably take many years of work to more fully understand this fascinating and complex story.



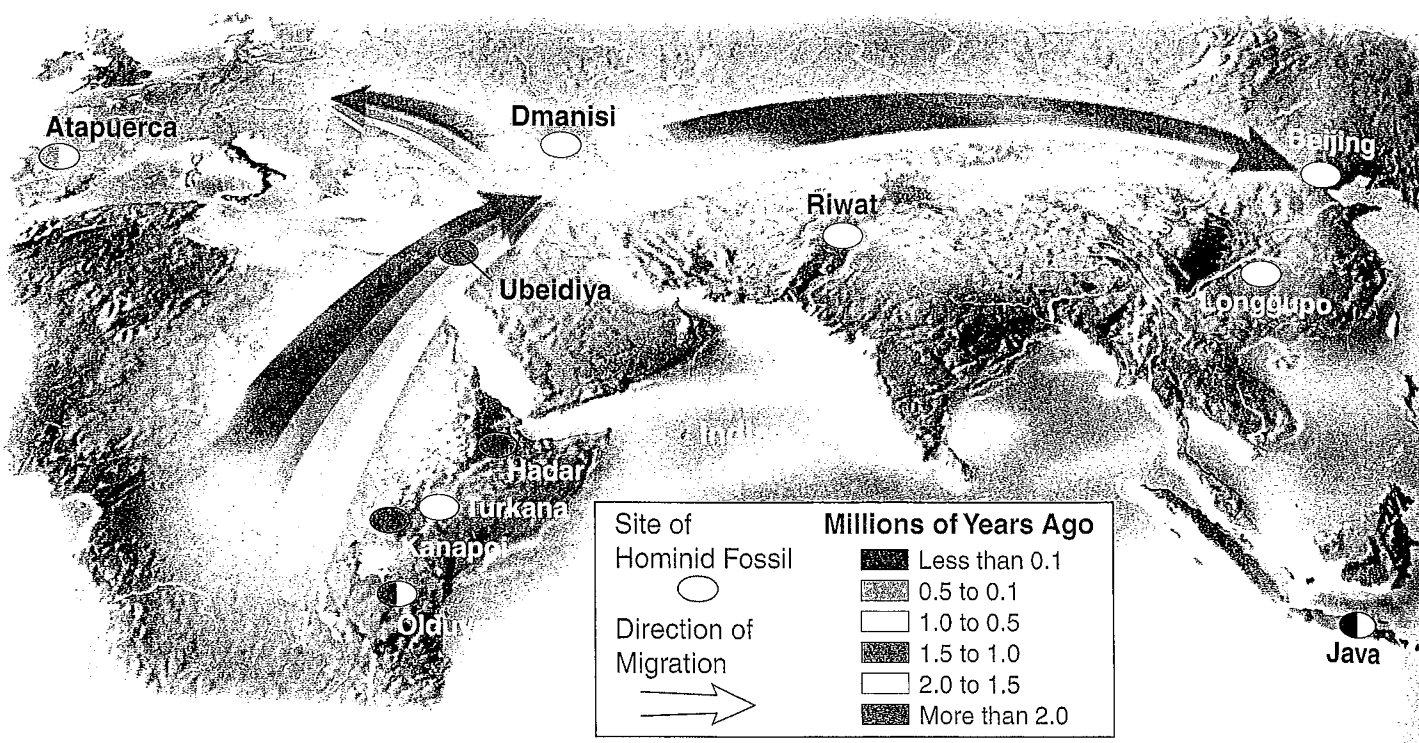
▲ **Figure 32–19** The diagram shows fossil hominids and the time ranges during which they may have existed. The time ranges are likely to change as paleontologists gather new data. The question mark after *Sahelanthropus tchadensis* indicates that scientists are not yet certain that this species is a hominid. Paleontologists do not yet have enough information to know how hominid species are related. **It is now clear that hominid evolution did not proceed by the simple, straight-line transformation of one species into another.** Current hypotheses about early stages of human evolution recognize the incompleteness of the data.

The Road to Modern Humans

The hominids that have been mentioned so far, such as *Paranthropus* and *Australopithecus,* all lived millions of years before modern humans. When did our species, *Homo sapiens,* appear? As you can see in **Figure 32–19**, other species in our genus existed before *H. sapiens,* and at least two other species in the genus *Homo* existed at the same time as early humans. As is the case with earlier hominid fossils, paleontologists still do not completely understand the history and relationships of species within our own genus.

The Genus *Homo* About 2.5 million years ago, a new kind of hominid appeared. Its fossils show that it resembled modern humans enough to be classified in the genus *Homo.* Because these fossils were found with tools made of stone and bone, researchers called the species *Homo habilis* (HAB-ih-lus), which means "handy man."

Homo habilis was the first of several species in our genus to arise in Africa. About 2 million years ago, a species larger than *H. habilis* appeared. It had a bigger brain and downward-facing nostrils that resembled those of modern humans. Today, most researchers call the African fossils of this species *Homo ergaster.* At some point, one or more species in the genus *Homo* began migrating out of Africa through what is now the Middle East. That species may have been *H. ergaster* or a closely related species named *Homo erectus*.



▲ **Figure 32–20** Data show that relatives and ancestors of modern humans left Africa several different times. But when did early hominids leave Africa, and how far did they travel? By comparing the mitochondrial DNA of human populations around the world and by continuing to study the fossil record, scientists hope to improve our understanding of the complex history of *Homo sapiens*.

Out of Africa—But Who and When? Researchers agree that our genus originated in Africa. But many questions remain. When did hominids first leave Africa? Did more than one species make the trip? Which of those species were human ancestors and which were merely relatives? Fossil data and molecular evidence suggest that hominids left Africa in several waves as shown in **Figure 32–20.** By a million years ago, migrants from Africa had crossed Asia and reached China and Java, and populations of *H. erectus* were living in several places across Asia.

Many researchers have hypothesized that *H. erectus* was the first of our genus to leave Africa. Two recently discovered fossil skulls may offer additional evidence that *H. erectus* did leave Africa and migrate long distances. The skulls, which strongly resemble African *H. erectus* fossils and are about 1.75 million years old, were discovered in the country of Georgia, which is north of Turkey and far from Africa.

However, other evidence makes the situation less clear. Another 1.75-million-year-old skull found in Georgia resembles 1.9 million-year-old *Homo habilis* skulls from Kenya. Does this skull indicate that *H. habilis* left Africa before *H. erectus*? The scientific jury is still evaluating the evidence.

Paleontologists are also unsure exactly where and when *Homo sapiens* arose. One hypothesis, the multi-regional model, suggests that modern humans evolved independently in several parts of the world from widely separated populations of *H. erectus*. Another hypothesis, the out-of-Africa model, proposes that modern humans evolved in Africa between 200,000 and 150,000 years ago, migrated out to colonize the world, and replaced the descendants of earlier hominid species. Scientific debate and the search for more data continue.

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Modern *Homo sapiens*

The story of modern humans over the past 500,000 years involves two main groups. The earliest of these species is now called *Homo neanderthalensis,* named after the Neander Valley in Germany where their remains were first found. Neanderthals, as they are commonly called, flourished from Europe through western Asia between about 200,000 and 30,000 years ago. Evidence from Neanderthal sites in Europe and the Middle East suggests that they not only made stone tools but also lived in organized social groups.

The other group is anatomically modern *Homo sapiens*—in other words, people whose skeletons look like those of modern humans. These *H. sapiens,* who probably arose in Africa, appeared in the Middle East around 100,000 years ago. They joined Neanderthals who had been living in that region for at least 100,000 years. As far as anyone can tell, Neanderthals and *Homo sapiens* lived side by side in what is now Israel, Lebanon, Syria, and Turkey for around 50,000 years, using similar tools and living in remarkably similar ways.

That situation may have changed dramatically around 50,000–40,000 years ago. According to one hypothesis, that's when some populations of *H. sapiens* seem to have fundamentally changed their way of life. They used new technology to make more sophisticated stone blades, and made elaborately worked tools from bones and antlers. They produced spectacular cave paintings, such as the one in **Figure 32–21.** These *Homo sapiens* buried their dead with elaborate rituals. In other words, these people began to behave like modern humans. About 40,000 years ago, one such group, known as Cro-Magnons (kroh-MAG-nunz), appeared in Europe.

By 30,000 years ago, Neanderthals had disappeared from Europe—and from the Middle East as well. How and why they disappeared is not yet known. But since that time, our species has been Earth's only hominid.

▲ **Figure 32–21** This ancient cave painting from France shows the remarkable artistic abilities of Cro-Magnons. **Inferring** *How might these painted images be related to the way in which these early humans lived?*

32–3 Section Assessment

1. **Key Concept** List five anatomical characteristics that most primates share.
2. **Key Concept** Describe the major primate groups and explain how they are related phylogenetically.
3. **Key Concept** Explain the way that paleontologists currently view hominid evolution.
4. Compare and contrast hominids and other hominoids. How are they similar? Different?
5. **Critical Thinking Applying Concepts** How did the separation of the continents contribute to the development of New World and Old World monkeys?

Writing in Science

Explanatory Paragraph
Write a paragraph explaining how the structure of primates' fingers, toes, and shoulders are adaptations that help with survival. *Hint:* To prepare to write, make a table that describes the structures in the left column and then lists the advantages of those structures in the right column.