CHAPTER 13

# The development of higher life forms

## The age of the reptiles and dinosaurs

*As the vast land mass of Pangaea began to assemble, the interior of the super-continent became drier. Developments that allowed animals to move away from water courses and swampy areas to explore the new regions were favored in the evolutionary process. By about 300 million years ago, a new animal had evolved from the amphibian rootstock. This new creature, with leathery skin and watertight eggs was the first reptile. Over the next 100 million years, two major branches of reptile evolution led to the dinosaurs and to the first mammals. Evolving in step with the changing climate of Earth and developing traits to enable them to exploit an array of environments, these early land animals were amazingly complex and diverse.*

Living on land requires an altogether different set of characteristics to living in water. In this chapter we will follow the evolution of reptiles from the early amphibians, and see how they evolved body characteristics suitable to a dry land environment. We will learn how the evolution of life is inextricably linked to the Earth's climate, and how life has had to constantly adapt to its changing environment. In a relatively stable climate, life forms such as the dinosaurs had the chance to diversify and flourish. We will look at the amazing variety of dinosaurs that dominated the Earth for around 135 million years, and at why they eventually and so suddenly became extinct.

## 13.1 Evolution of the reptile

Through a succession of mutations, traits favorable in the new land environments had begun to evolve in the time of the amphibians. In a world where access to water was becoming more difficult, a tough membrane to seal in body moisture was a trait advantageous for survival. Leathery skin to hold in moisture enhanced the ability of the possessor to venture into the new, drier continental habitats. The development was probably a gradual process. In each clutch of young amphibians the changing environment selected those best able to resist dehydration in order to survive and reproduce. Amphibian eggs, with gelatinous coverings that dried out easily had to be laid in water. Life on land required eggs that were covered with a watertight coating (Figure 13.1). By about 300 million years ago, a new animal had evolved – one that lived entirely on land, possessed a leathery skin and produced eggs resistant to dehydration. The early amphibians had evolved into the first reptiles (Figure 13.2).

Over the next 50 million years, from about 300 to 250 million years ago, as Pangaea grew in size, the reptiles proliferated. The geological changes that occurred during that interval greatly affected Earth's climate. These climatic changes would determine the destiny of the reptiles and their progeny.

As the super-continent Pangaea assembled, the rate of sea-floor spreading diminished and the level of the sea dropped.

Previous page: *Euoplocephalus* (a type of Ankylosaur) with Stygimoloch Group.

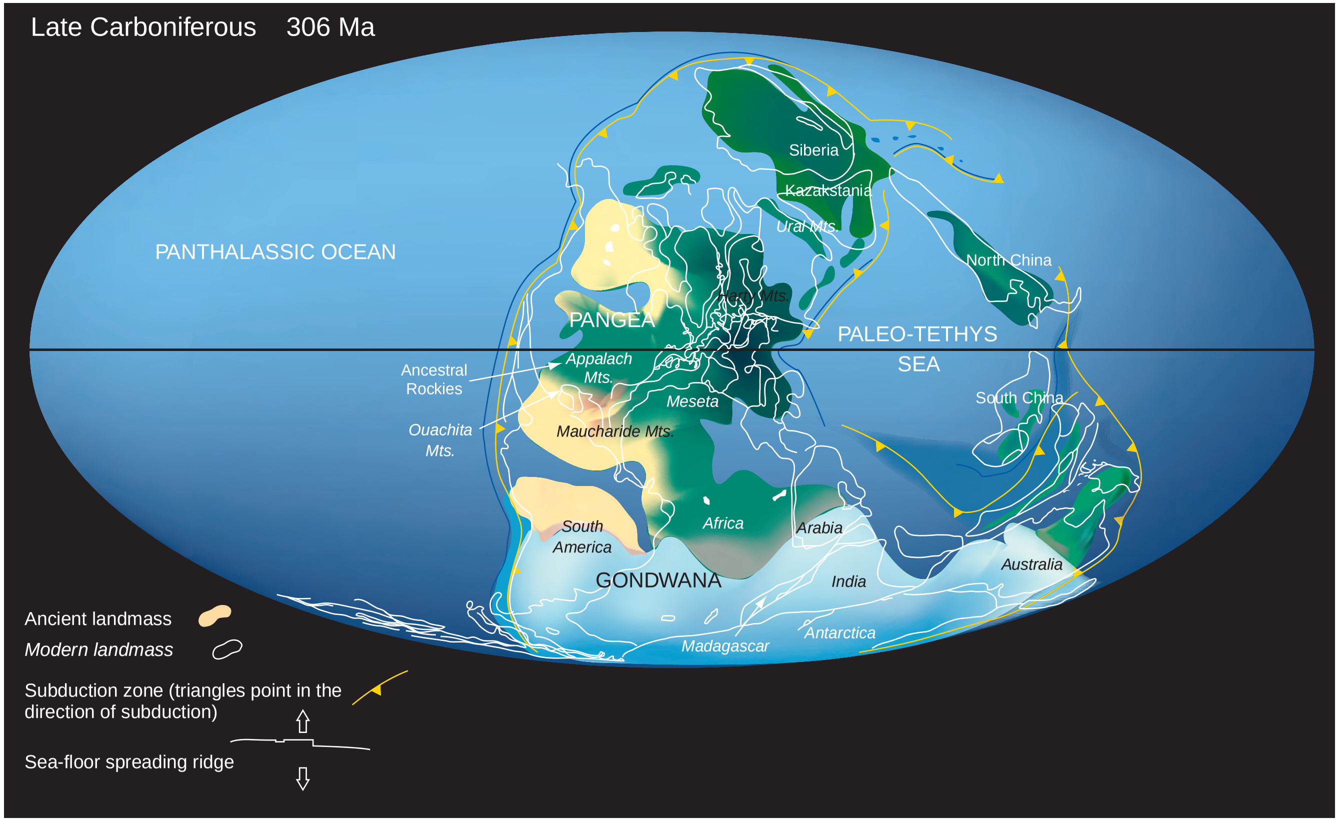



FIGURE 13.3 The configuration of the continents at the time of the Late Paleozoic Ice Age. The position of the large ice sheet on the Gondwana super-continent in the Southern Hemisphere has been inferred from glacial deposits and scratched and grooved rocks dating from this time.

Christopher R. Scotese. PALEOMAP Project, Texas

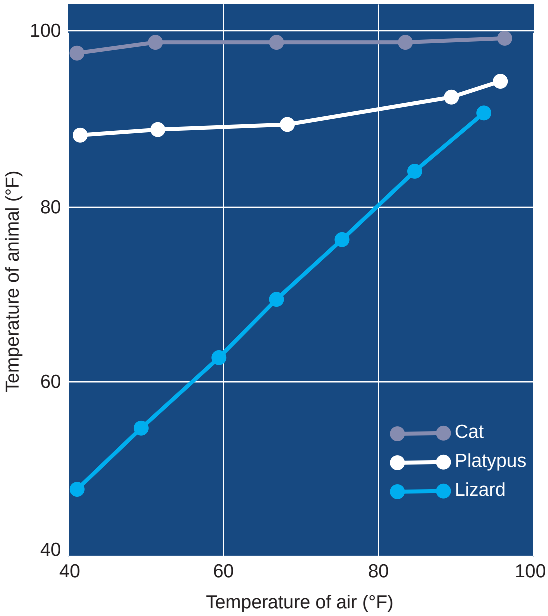



FIGURE 13.4 The meaning of warm-bloodedness. The cat is a typical warm-blooded mammal, with many special ways of keeping its body temperature constant. Sweat glands or panting cool a warm-blooded animal when the air is hot, and the blood vessels under the skin dilate to carry body heat to the surface, where it is lost. Because of these defenses, the temperature of the cat scarcely changes when the air temperature increases from 40 °F to 95 °F (5 °C to 35 °C).

The lizard – a typical reptile – is cold-blooded and lacks the cat's defenses against temperature change. Its body temperature is usually close to the temperature of the outside air. The duck-billed platypus – a link between the mammals and the reptiles – controls its body temperature more effectively than the lizard but not as well as the cat.

chemical reactions needed for cellular activity and growth) even when air temperatures dipped well below freezing. In vertebrates that have developed internal means of regulating their body temperature, this ability is called *endothermy*, as opposed to *ectothermy*, in which an animal has no internal means of regulating its body temperature. These traits are commonly called warm-bloodedness and cold-bloodedness (Figure 13.4).

Modern reptiles are ectotherms – they rely on the heat of the Sun (or a warm patch of ground) to raise their body temperature to a point at which they can become active. At night, or in cool weather, as their body temperature drops, ectothermic animals must retreat temporarily into burrows or hibernate. It seems likely that the early reptiles were also ectothermic. During the cooling that accompanied the Late Paleozoic Ice Age, however, a new kind of animal developed, one that had the beginnings of characteristics that we usually associate with endothermy.

## 13.2 The mammal-like reptiles

About 275 million years ago, the sail-back reptile *Dimetrodon* made its first appearance in the fossil record (Figure 13.5).

FIGURE 13.1 Fossilized reptile egg with a leathery outer shell that allowed it to be laid out of the water.
Mark Mohell and the Australian Department of the Environment, Water, Heritage and the Arts

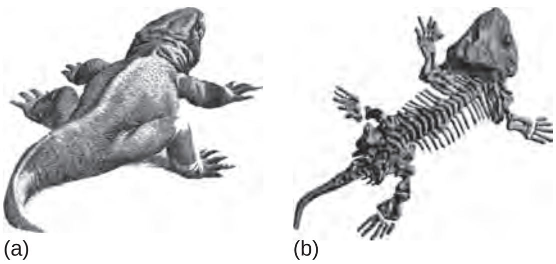



FIGURE 13.2 *Seymouria*, one of the earliest reptiles (about 300 million years ago), reconstructed from a nearly complete fossil skeleton found near Seymour, Texas. The animal was about 20 inches (50 centimeters) long. *Seymouria* is a link between the amphibians and the reptiles.

The climate began to cool. The development and spread of land plants may have contributed to this cooling of global climate. Land plants with deep root systems pump carbon dioxide into the soil, where it accelerates rock weathering. This process increases the rate of removal of carbon dioxide from the atmosphere, tending to cool the climate.

During this time, a large ice cap grew to cover portions of what are today the continents of Antarctica, Australia, southern Africa, southern South America, and the Indian subcontinent. These continents were joined together to form the southern or *Gondwana* portion of the super continent (Figure 13.3). As discussed earlier, the ice sheet reflected more solar energy back to space causing further cooling of the climate.

This major change in climate had an important effect on the course of evolution. Animals living on the margins of the Gondwana ice sheet evolved traits that allowed them to continue to function in cooler climates. Of primary importance is the ability to keep body temperature high (and thus maintain the

FIGURE 13.5 *Dimetrodon* – the sail-back reptile. *Dimetrodon* was distinguished by the large "sail" on its back, which seems to have been an early design for regulation of body temperature. *Dimetrodon* was about 10 feet (3 meters) long.



What was the reason for such a body structure? Scientists now believe that the sail-like structure was designed to help the animal maintain a relatively constant body temperature. During the day the sail could be spread out and turned towards the Sun to collect solar energy. At other times the sail could be pulled back to conserve body heat. The sail-backs had developed a primitive temperature regulation system.

Another piece of evidence that the sail-backs were on the path toward warm-bloodedness is the nature of their teeth. The early reptiles possessed peglike teeth. The teeth of *Dimetrodon*, however, show the first signs of differentiation into cutting teeth toward the front of the jaw, "canine" saber-like teeth at the sides, and flatter, grinding teeth in the back. This is the beginning of a pattern of dentition that was to evolve into the specialized teeth of the mammals. *Dimetrodon* is one of the earliest in the line of so-called *mammal-like reptiles* that eventually gave rise to true mammals.

What was the reason for specialized teeth in the early mammal-like reptiles? The answer may have been that the mammal-like reptiles were developing a higher metabolic rate. Specialized teeth are only needed if an animal must chew its food efficiently. Modern mammals chew their food into small pieces before swallowing. The mammal must digest its food rapidly in order to extract the maximum amount of energy to stoke its internal fires. Modern reptiles, by contrast, swallow their food whole, or bite it off in large chunks. Since they are ectotherms, they have little need to digest their food rapidly. Reptiles remain inactive as they slowly digest their meal.

By about 255 million years ago (in the Late Permian Period) (Figure 13.6), more advanced mammal-like reptiles had evolved. *Cynognathus*, the “doglike” reptile, was even more mammalian (Figure 13.7), with differentiated teeth and a relatively larger brain than that of the earlier reptiles. This animal may have been one of the first to be covered in fur – reptilian scales modified for the purpose of insulation.

The end of the Permian Period (about 250 million years ago) of Earth history was marked by one of the most severe mass extinctions of life seen in the fossil record. In the oceans, more than 90% of the species of life died out. On land, many reptiles and amphibians and large numbers of plants became extinct. The event may have been caused by massive volcanism, or the impact of a large asteroid or comet. Great basaltic lava flows were erupted in Siberia at about this time. Some scientists have reported evidence for a large impact crater off the coast of Australia. The cause of the extinctions, however is still unknown.

## 13.3 The mammals

The first true mammals appear in the fossil record about 200 million years ago (in the Late Triassic Period). They were the size of a mouse (Figure 13.8). The small size of the early mammals is a sign of competition with a more successful group of animals. During the same period in which the mammals were evolving, another kind of animal appeared that was also descended from the ancestral stock of reptiles. The new kind of reptile was the dinosaur.

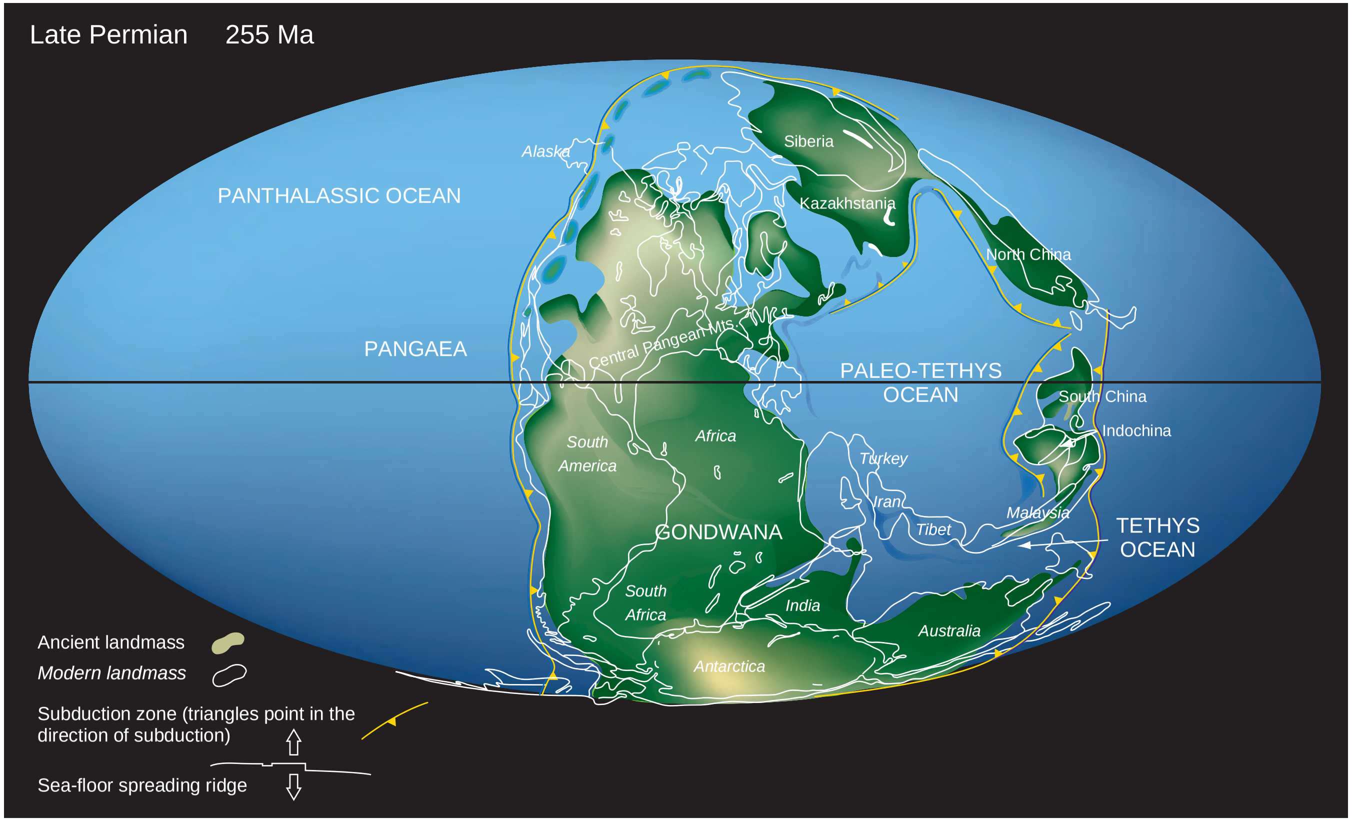



FIGURE 13.6 Reconstruction of the continents about 255 million years ago, in the Late Permian Period, showing the super-continent Pangaea.
Christopher R. Scotese, PALEOMAP Project, Texas

FIGURE 13.7 *Cynognathus* lived about 255 million years ago. Changes in the skeleton of this animal have raised its body well off the ground, although its posture still retains a hint of the sprawling gait characteristic of its reptile ancestors. *Cynognathus* was the size of a wolf. Its teeth were beginning to evolve into the canines and incisors characteristic of modern mammals, and used for biting and tearing the prey into small pieces.

FIGURE 13.8 This early mammal, known as *Morganucodon* (Morning-tooth), lived about 200 million years ago. This small animal was only about 4 inches (10 centimeters) long.
Smithsonian Institution-National Museum of Natural History, Scientific advisor Anna K. Behrensmeyer, sculpture by Gary Staab

In the branch of evolution leading to the dinosaurs, speed and agility were of the essence. These desirable traits were achieved in the dinosaur ancestors by a change in posture, in which the legs no longer sprawled outward to either side but were tucked in, with the body raised off the ground. Still another innovation appeared in the dinosaur line: The ancestral dinosaur, four-footed at the start like other reptiles, gradually evolved a two-legged posture. Their hind limbs became strong and muscular, which gave them additional speed, while their forelimbs were freed for grasping their prey.

These were the early dinosaurs. They were birdlike in appearance, but with the long tail of a lizard. A jaw with a wide gape, and many sharp teeth, completed the picture of an effective carnivore (Figure 13.9).

FIGURE 13.9 This small reptile, about the size of a rooster, the ancestor of the dinosaurs, lived about 225 million years ago.

By permission of Cecilia Barnbaum and Edward E. Chatelain, Valdosta State University

How did it come to pass that the mammals were surpassed by the early dinosaurs? One possibility involves changes in global climate. The line of evolution leading to the mammals originated during a time when Earth's climate was relatively cool. The mammal-like reptiles continued to thrive until inexorably Earth's climate began to change again.

Major shifts occurred at this time in the movements of Earth's plates. Not long after the final assembly of Pangaea, the super-continent began to break apart again. At that time, Pangaea was split by new rift valleys. Volcanic activity was widespread, as new ocean areas formed by sea-floor spreading. The hot, newly minted ocean ridges expanded and drove some of the ocean water onto the continents to create new shallow seas (Figure 13.10). The increased volcanic activity poured carbon dioxide into the atmosphere, and the climate grew warmer.

In the new warmer climate, cold-blooded animals, like the early dinosaurs, could remain active. Warm-bloodedness, once a valuable trait, became a liability since there was less of a need to keep warm, and endotherms must eat often to maintain their high body temperatures. Competition with the dinosaurs led to a trend toward smaller size in the mammal-like reptiles and their mammal descendants. The small mammals were able to hide from their dinosaur predators and scavenge enough food to survive. They were fated to spend the next 135 million years as subordinates in a world ruled by the giant dinosaurs.

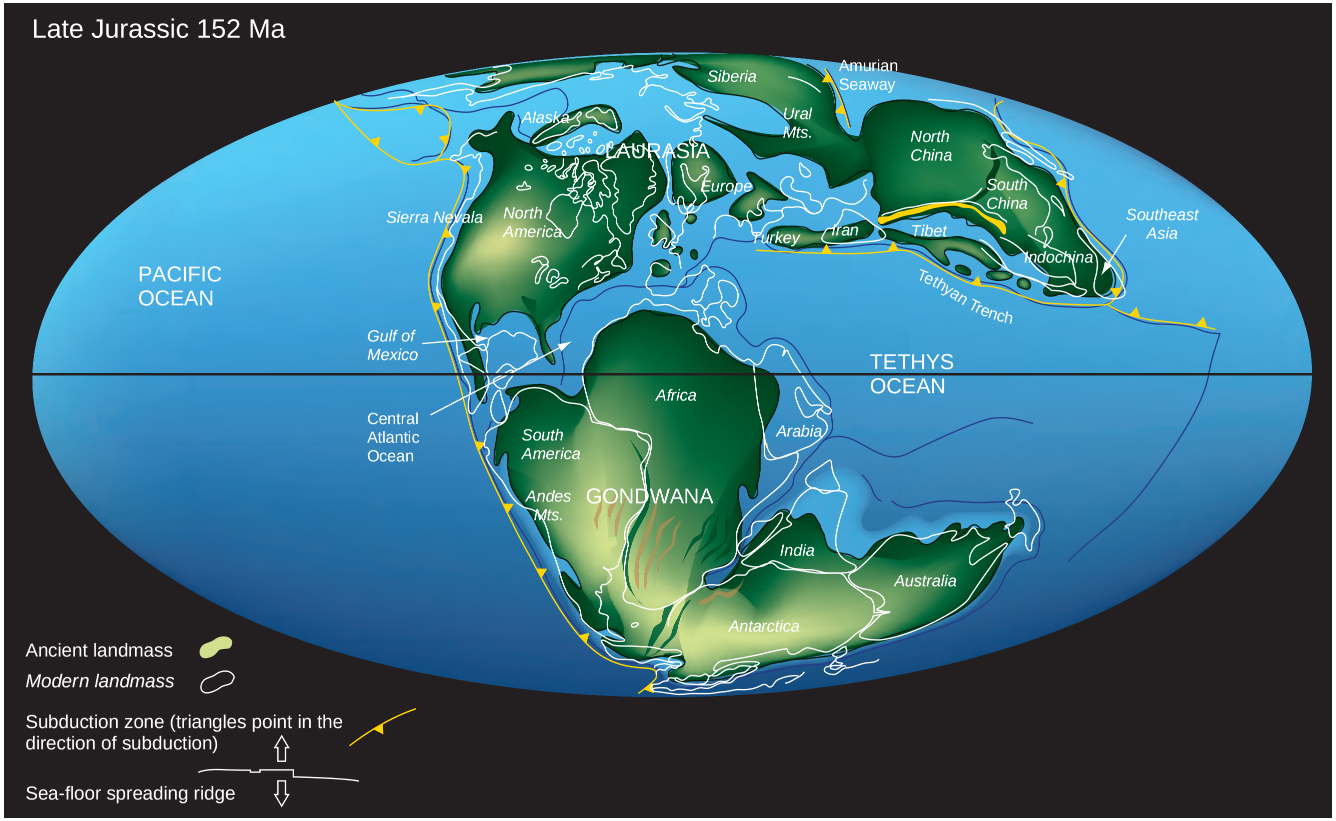



FIGURE 13.10 Continental reconstruction for the Late Jurassic Period, about 152 million years ago. The presence of inland seas and increased atmospheric carbon dioxide from renewed volcanism warmed the Jurassic climate.
Christopher R. Scotese, PALEOMAP Project, Texas

Another factor in the replacement of the mammal-like reptiles by the dinosaurs was a severe mass extinction of life that occurred about 200 million years ago, at the end of the Triassic Period. This event was marked by the disappearance of many forms of life in the oceans, and also led to extinctions of many land-dwelling reptiles. Many lines of reptiles died out; others survived, including the early dinosaurs.

## 13.4 The dinosaurs

For more than 100 million years Earth enjoyed a climate of unparalleled warmth, and the dinosaurs and other reptiles proliferated. They flowered into a variety of creatures that ruled over the air, the sea, and the land. Flying reptiles soared and glided, ready to swoop down on smaller prey; some had wing-spans as great as 50 feet (17 meters) – the size of a small aircraft (Figure 13.11). Giant crocodiles with jaws 6 feet (2 meters) long lurked in the waters; turtles weighing 3 tons paddled across the inland seas of North America (Figure 13.12).

The greatest giants lived on the land. These were the dinosaurs. The earliest dinosaurs were small carnivores, but they rapidly evolved into new forms and many grew larger. By about 200 million years ago, all of the major groups of dinosaurs were in existence. Some of the early bipedal carnivores developed into large meat eaters such as *Allosaurus* by about 150 million years ago (in the Jurassic Period) and eventually into the largest meat-eating dinosaur of all, *Tyrannosaurus rex*, about 70 million years ago (in the Late Cretaceous Period). *Tyrannosaurus rex* grew to a length of 50 feet (17 meters) and a weight of 10 tons, with jaws filled with daggery-like teeth (Figure 13.13).

Among the largest dinosaurs were huge herbivorous dinosaurs like *Apatosaurus* (Figure 13.14). These large plant-eating dinosaurs dropped back onto all four legs and, like the modern-day elephant, were protected by their bulk from most predators. Plant-eaters were also represented by the *Ornithischian* dinosaurs, such as *Stegosaurus* (Figure 13.15), and the armored *Ankylosaurs*. Later, horned dinosaurs such as *Triceratops* (Figure 13.16) and the duck-billed dinosaurs (Figure 13.17) became common.

FIGURE 13.11 During the age of dinosaurs, the flying reptiles flourished. The largest flying reptiles soared on wings with a span of 30 to 50 feet (10 to 17 meters).
Joe Tucciarone and Jeff Polling

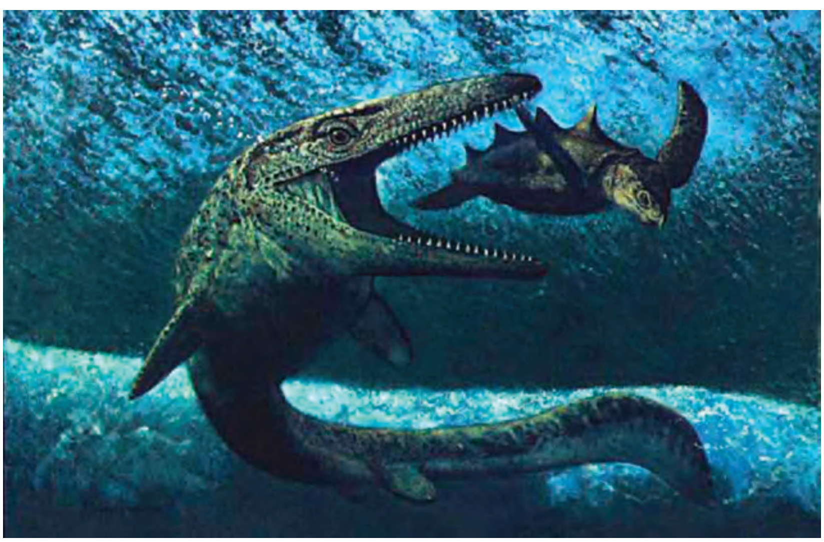


FIGURE 13.12 During the time of the dinosaurs, there were also giant reptiles in the sea. *Mosasaurs* were giant marine reptiles 40 feet (13 meters) long.
Daniel W. Varner

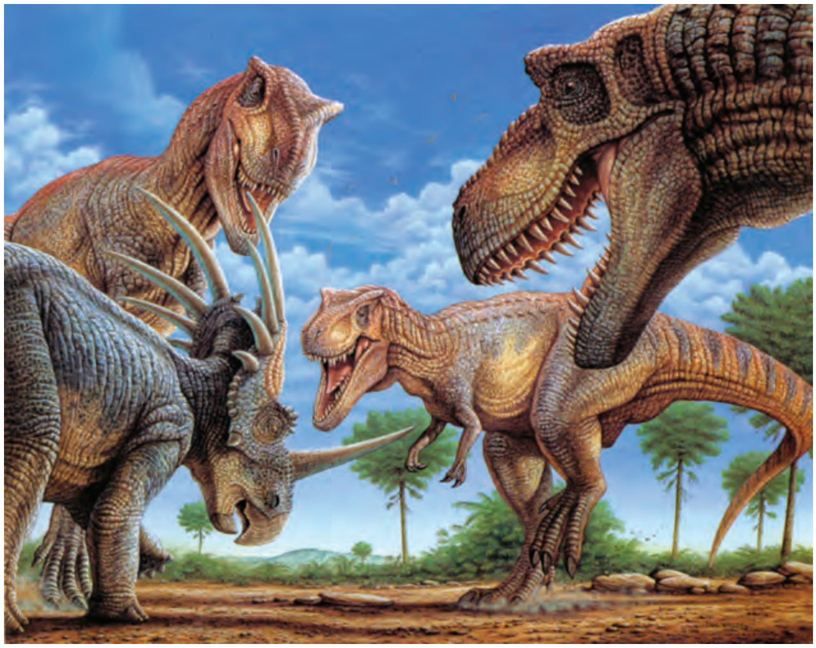


FIGURE 13.13 The meat-eating dinosaur *Tyrannosaurus rex*, with a length of about 50 feet (17 meters), lived during the Late Cretaceous Period (about 70 million years ago). Here, a group of Tyrannosaurs threatens the horned dinosaur *Styracosaurus*.
Phil Wilson

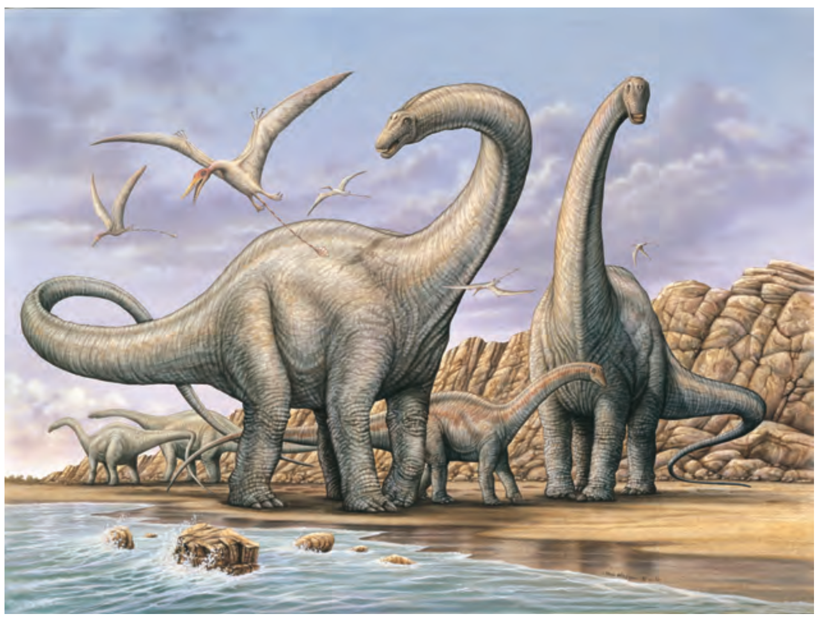


FIGURE 13.14 The largest dinosaurs were plant-eaters, such as 65-foot (20-meter) long *Apatosaurus*. *Apatosaurus* lived in western North America, then a tropical land of forests and swamps, during the Late Jurassic Period about 150 million years ago.
Phil Wilson

One group of the small carnivorous dinosaurs gave rise to the birds. The earliest well-known fossil bird, *Archaeopteryx*, which appeared about 150 million years ago (in the Jurassic Period), had the skeleton of a small dinosaur, including a toothed skull, bony tail, and claws on its wings, but was

FIGURE 13.15 *Stegosaurus*, about 20 feet (7 meters) long, lived in the Late Jurassic Period about 150 million years ago. The plates at the back of this creature may have acted as cooling vents to help maintain a stable body temperature. The large tail spikes clearly were for defense. *Stegosaurus* had a brain the size of a walnut.
Phil Wilson

FIGURE 13.16 *Triceratops*, one of the largest horned dinosaurs, was 15 feet (5 meters) long. *Triceratops* lived during the Late Cretaceous Period about 70 million years ago.
Phil Wilson

covered by true feathers (Figure 13.18). A number of exceptionally well-preserved small, feathered dinosaurs have been found in China, showing that feathers were not an uncommon trait among dinosaurs. Feathers probably evolved for insulation, keeping the small dinosaurs warm during the cool evenings.

FIGURE 13.17 Duck-billed dinosaurs, like this *Hadrosaurus*, were abundant during the Late Cretaceous Period, about 70 million years ago.
Phil Wilson

FIGURE 13.18 *Archaeopteryx*. In the line of reptilian evolution that led to the birds, the edges of the reptile's horny scales became more and more ragged, and gradually the scales changed into feathers. Feathers grew from the forearm to make a wing; they also sprouted from the long, lizardlike tail of the animal. This creature, *Archaeopteryx*, half reptile and half bird, first appeared in the fossil record about 150 million years ago (in the Jurassic Period) and was the ancestor of the modern bird.
Karen Carr

## 13.5 Why were the dinosaurs successful?

The dinosaurs were among the most successful animals ever to walk Earth. For approximately 135 million years these creatures, which ranged from chicken-sized reptiles to the largest land animals of all time, dominated Earth. During this long interval, Earth's climate was particularly warm and equable. Continental areas were free of ice sheets, and most of the world had a tropical or subtropical climate.

For most of this period, large areas of the continents were submerged beneath warm shallow seas. Large amounts of carbon dioxide were added to the atmosphere by increased volcanic activity at mid-ocean ridges and subduction zones.

This created a world with perhaps ten times more carbon dioxide than in the present atmosphere, with a more intense greenhouse effect and warmer climate.

Another factor that led to the warm climatic conditions during the Mesozoic Era was the low relief of the terrain, and the general lack of high mountains. The Appalachians had been worn down by erosion, and the great mountain belts of the modern world – the Himalayas, Rockies, Alps, and Andes – were either in the early stages of their development, or had not yet begun to form. The lack of mountain barriers allowed for the freer circulation of air currents between the equatorial and polar regions. The transport of warm air and warm ocean currents toward the polar regions warmed the climate in these areas, and made for a more even temperature over the planet.

Under such conditions of almost universal warmth and abundant rainfall, lush tropical and subtropical forests and marshlands came to cover large areas of the exposed continents. This environment created conditions in which the dinosaurs flourished. Many of the dinosaurs show evidence of complex mating behavior, parental care, and a social structure in which they lived in large herds and nesting colonies. Some dinosaurs were apparently able to stabilize their body temperatures, either as a result of their large size or relatively high metabolism. But elaborate mammalian types of warm-bloodedness and high intelligence were not required for success in the Mesozoic climate regime.

Beginning about 80 million years ago, however, the environment began to change. The rate of sea-floor spreading began to slow, the ocean ridges partly subsided, and the waters of the shallow seas began to drain back into the deepening ocean basins. The exposure of more land area caused the climate to become cooler and more seasonal. This is because the land absorbs heat in the summer, but loses it rapidly in winter so that the seasons tend to be extreme with cold winters. As weathering rates of the newly exposed continental rocks increased, the carbon dioxide levels in the atmosphere began to fall. Meanwhile, plate movements continued, progressively carrying the continents into higher latitudes and therefore leading to further cooling of the dinosaurs' habitats.

The result of all these factors was the beginning of a global cooling and an increase in seasonality of climate. Some paleontologists believe that the dinosaurs were already too specialized – as a result of 100 million years of rather stable climate conditions – to cope with these ongoing changes in the environment. But the dinosaurs disappeared abruptly 65 million years ago in a dramatic event that was unrelated to the long-term environmental changes (Figure 13.19). More than 75% of the species of life on Earth became extinct at that time.

## 13.6 The End Cretaceous extinction

Sixty-five million years ago, many species of life in the seas, from one-celled algae to giant marine reptiles, became extinct. On land, the dinosaurs vanished, and forest plants were decimated. In the air, the flying reptiles disappeared.

Geologists recognize this mass extinction as marking the end of the Mesozoic Era. Rocks below and older than the boundary belong to the Cretaceous Period, the final chapter in the "Age of Reptiles," and rocks above, and therefore younger than the boundary, are assigned to the Tertiary Period of Earth history, when birds and mammals became dominant.

The cause of this wave of extinction has long been one of the outstanding problems for students of the history of life. Some scientists suggest that the extinctions were abrupt. An abrupt extinction implies some sort of global catastrophe. Other scientists hold that the extinctions happened gradually over millions of years. Such a gradual extinction implies progressive environmental changes over time as the cause.

## 13.7 The Alvarez Hypothesis

One of the best places to study the Cretaceous extinction is in rock layers exposed in the walls of a deep gorge near the medieval Italian town of Gubbio. These layers of limestone are composed of countless shells of tiny floating marine organisms, or plankton, that were deposited on the ancient

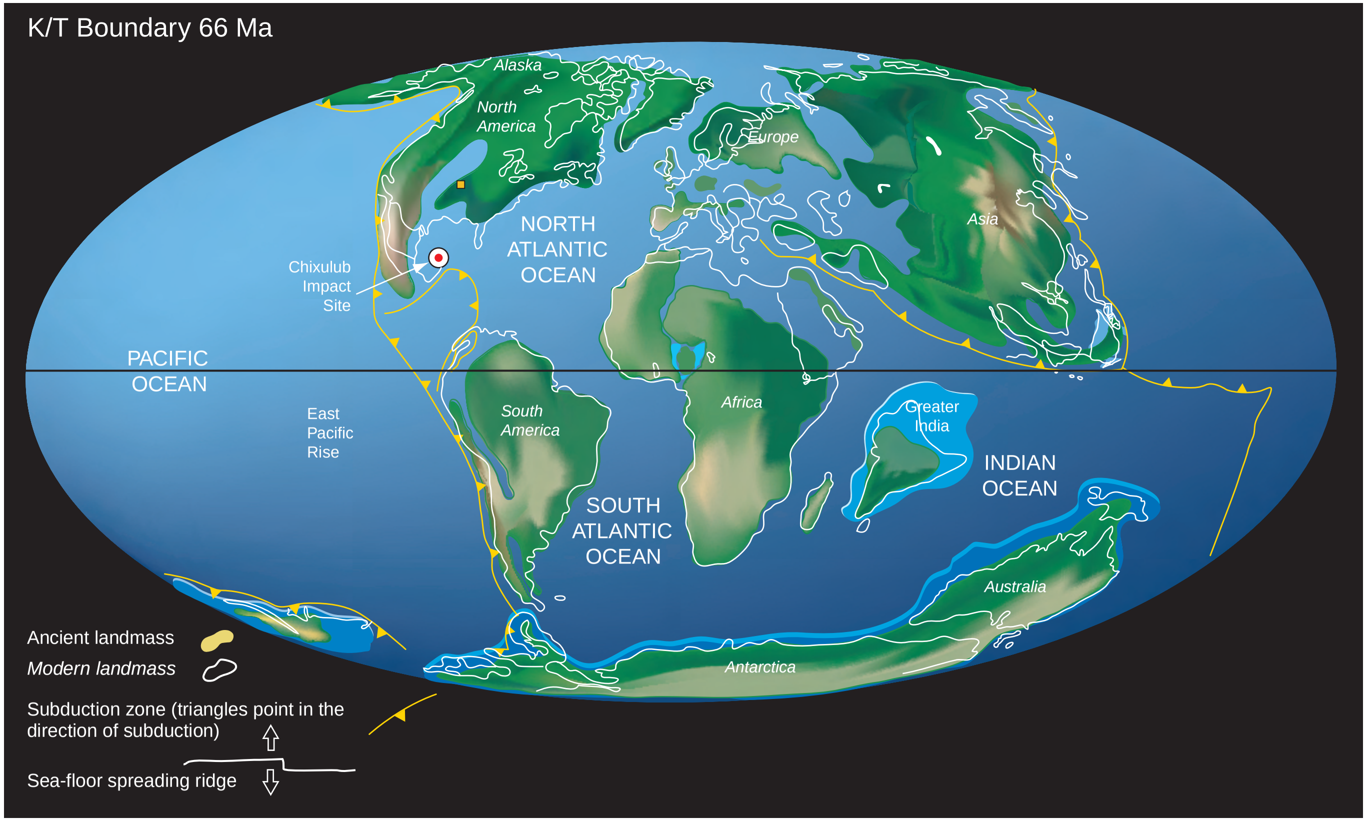



FIGURE 13.19 Reconstruction of continents, for the time of the mass extinction at the end of the Cretaceous Period, 65 million years ago. The continents are still partly flooded with shallow seas. The site of the asteroid impact on the Yucatán Peninsula is shown by the small circle.

Christopher R. Scotese, PALEOMAP Project, Texas

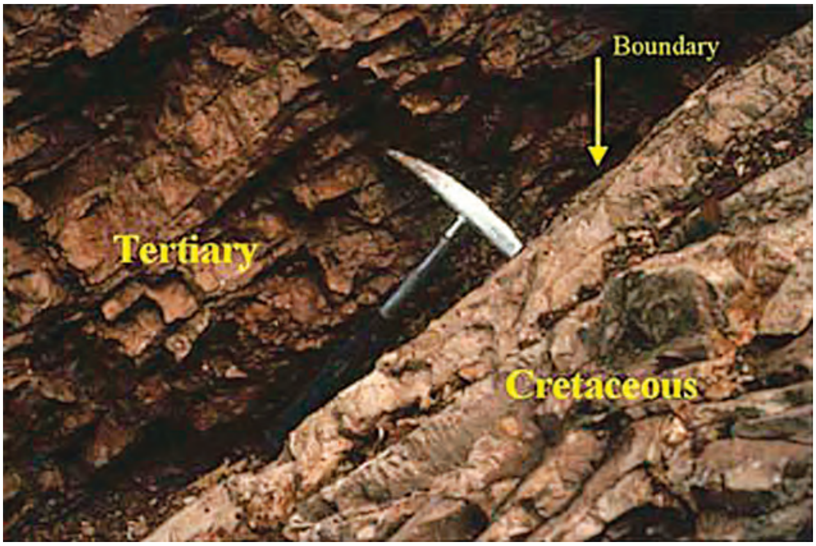



FIGURE 13.20 Photograph of the boundary between the Cretaceous and Tertiary Periods (65 million years ago) in a gorge near the Italian town of Gubbio. Cretaceous limestones are overlain by darker Tertiary limestones. The boundary is marked by a thin layer of clay at the head of the hammer.
M. R. Rampino

sea floor. A drastic change in the fossils in these rock layers occurs at a bed marked by a one-centimeter-thick layer of soft clay (Figure 13.20).

In 1980, a group of scientists from the University of California at Berkeley led by the late Nobel laureate physicist Luis Alvarez and his son Walter, a well-known geologist, discovered that the thin clay layer that was laid down at the time of the extinction event contained high levels of the rare element iridium, a member of the platinum group of elements.

Iridium is a rare element in the rocks of Earth's crust, because iridium has a strong affinity for metallic iron, and most of Earth's complement of iridium sank into the core during the early melting and differentiation of our planet. Most meteorites, and the asteroids and comets from which they come, are almost unmodified pieces of planetary matter, and thus contain their original abundance of iridium.

The Alvarez group's analysis showed that the source for the iridium layer was fallout of the dust produced by the collision of a 6-mile (10-kilometer) diameter asteroid or comet. Such an impact would create a large crater spewing out a global dust cloud of pulverized rock and vaporized asteroid. The mass extinction of life was caused by the dense impact-induced global dust cloud that shut out sunlight, curtailed photosynthesis, and cooled the climate. The same iridium-rich layer has

FIGURE 13.21 Photograph of the 65-million-year-old impact layer in Colorado, in sediments deposited on a river floodplain. The clay layer occurs at the base of a thin bed of coal. Dinosaur footprints are found just below the clay layer, but no dinosaur fossils have ever been found above the layer.
M. R. Rampino

since been found at more than a hundred sites around the world (Figure 13.21).

Many scientists were initially skeptical of these findings. Some suggested that the iridium layer came from a large volcanic eruption, and they showed that some volcanoes, such as those on the island of Hawaii, release iridium brought up from deep within Earth. Massive lava flow eruptions were taking place in India just at the end of the Cretaceous Period, and some scientists still think that these eruptions caused climatic cooling that led to the extinction.

The thin clay layer, however, also contains tiny grains of the mineral quartz with unusual sets of crisscrossing planes (Figure 13.22). Studies show that these quartz grains must have been subjected to the extremely high pressures generated by a large-body impact. The layer has also yielded glassy beads that originated as droplets of molten rock thrown out of the large impact crater.

If a large impact occurred 65 million years ago, then a huge impact crater should exist somewhere on Earth. Calculations and experiments suggested that the crater would be about 20 times the diameter of the impacting object, or about 120 miles (200 kilometers) in diameter. In the 1980s, exploration for deposits of oil and natural gas in Mexico turned up evidence

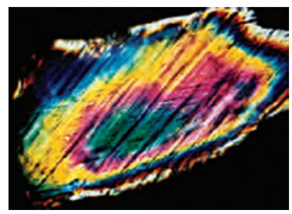
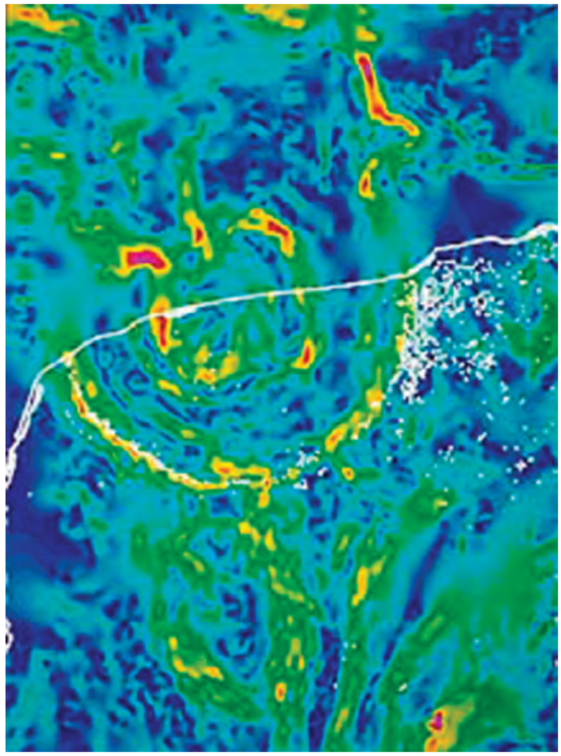


FIGURE 13.22 A sand-sized grain of quartz taken from the clay layer that occurs at the time of the mass extinction, 65 million years ago. The crossing lines are planes in the mineral grain filled with amorphous quartz of extremely high pressure origin.
Richard P. Walker, Shawn T. Smith, and Steven M. Smith, USGS


(a)



(b)

FIGURE 13.23 (a) Location of the large (~100 miles or 160 kilometers in diameter) Chicxulub impact crater (circle) in the Yucatán Peninsula of Mexico. Figure 13.23(b) The Chicxulub crater is imaged by using measurements of the strength of Earth's gravity over the buried crater. The white line is the coastline of the Yucatán Peninsula. Half of the crater is offshore. The white dots are small lakes, or *cenotes*, that occupy sinkholes created by dissolution of limestone along the circular fractures related to the crater.
Alan Hildebrand, University of Calgary

for a large, buried multi-ringed crater underneath the Yucatán Peninsula (Figure 13.23). Drilling at the site revealed melted and shocked debris that formed 65 million years ago. This crater, named Chicxulub after a small town near its center, is the source of the worldwide layer of debris that occurs at the time of the mass extinction.

## 13.8 Mass extinctions in Earth history

The Cretaceous event was one of a number of mass extinctions that punctuate the fossil record of life. The record of extinctions of marine organisms for the past 540 million years shows at least five major mass extinction events (Figure 13.24). Traditionally, these extinction episodes have been attributed to terrestrial causes such as changes in global climate or volcanism. The recognition that the End Cretaceous extinction was caused by an impact leads to the

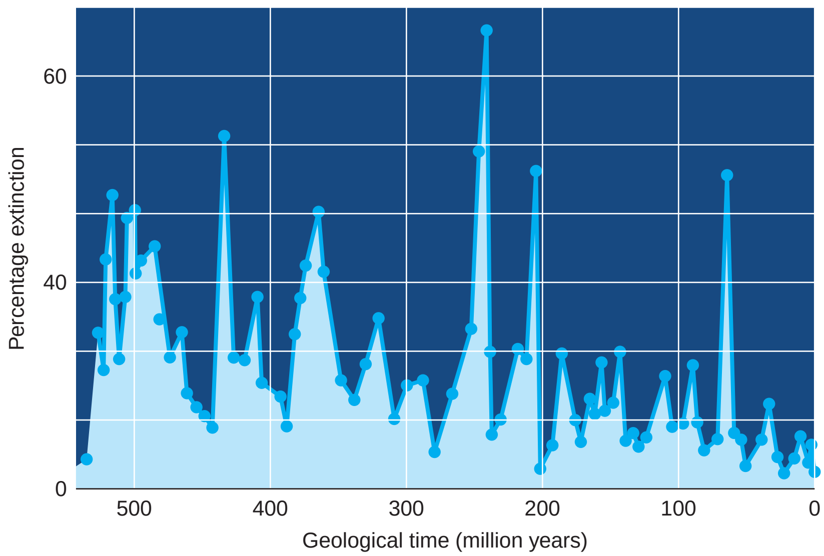



FIGURE 13.24 The record of mass extinctions. The percentage of marine organisms that became extinct at various times during the last 540 million years. The peaks represent extinction events of various magnitudes. The most severe mass extinction occurred at the end of the Permian Period, 250 million years ago. The large extinction peak at 65 million years ago marks the Cretaceous–Tertiary boundary.

question: Could there be a general connection between mass extinctions and impacts?

Astronomical observations of Earth-crossing asteroids and comets, and the records of the inner planets predict that Earth will be hit by a 6-mile (10-kilometer) diameter asteroid or comet – the estimated size of the impactor at the end of the Cretaceous – about once every 100 million years. These observations can be used to predict a record of impact-induced mass extinctions during the past 540 million years. The expected impact history for this time period predicts about five major mass extinctions. This agrees well with the record of extinctions. The result suggests that the record of extinction events could be explained by comet and asteroid impacts. This hypothesis is testable, in principle, by searching for evidence of impacts at extinction episodes.

The discovery of the impact layer at the time of the mass extinction at the end of the Cretaceous prompted the search for impact signatures at other geological boundaries. A widespread iridium anomaly was found at the time of a lesser extinction that occurred about 36 million years ago near the end of the Eocene Epoch of Earth history. Associated with this iridium peak, researchers discovered shocked quartz grains and tiny glass objects called *microtektites*, originally droplets formed when an impact blasts the surface rocks into a molten spray.

Geologists at the US Geological Survey recently found a 50-mile (90-kilometer) diameter crater beneath Chesapeake Bay in the eastern United States that dates from 36 million years ago. A similar large crater of the same age, called Popigaí, was discovered in Siberia. The search for evidence of impact at the times of other mass extinctions is a focus of current research.

## 13.9 Catastrophism

The outcome of this new line of research may be a concept of geological and biological change that relates to Earth's place within the Solar System. At the beginning of the nineteenth century, the doctrine of *catastrophism* was the vogue in geology. According to the catastrophist doctrine, the geological and fossil records were punctuated by sudden breaks, during which great paroxysms of extinction took place. Collisions of comets with Earth were suggested as a possible cause of these traumatic episodes.

James Hutton (1726–97), the Scottish scientist often called the "father of geology," is said to have discovered "deep time" – the realization that geological history represented an almost unimaginable span of time. This concept was utilized by British geologist Charles Lyell (1797–1875) in his influential *Principles of Geology* (published from 1831 to 1833) to propose what became known as the *principle of uniformitarianism*. Lyell argued that, given the great expanse of geological time, slow geological processes were sufficient to explain the major features of the geological record, such as great mountain ranges, volcanic plateaus, deep canyons, and the episodic inundation of the continents by the sea. Catastrophism was rejected as unnecessary and contrary to the geological facts.

According to Lyell, sudden breaks in the geological record should be interpreted as gaps in an incomplete and imperfect rock record, and not as cataclysms in Earth history. The abrupt mass extinctions that seemed to take place at such geological discontinuities were seen as illusions caused by the incompleteness of the rock record. As Lyell wrote, "There must be a perpetual dying out of animals and plants, not suddenly and by whole groups at once, but one after another."

Lyell went further in proposing that the rates of geological processes were slow and relatively constant throughout geological time. There was no room in Lyell's gradualism for catastrophic change.

Geological processes, like volcanic eruptions and earthquakes, vary not only in intensity but also in frequency. Small events are common, whereas larger events are rare. If we consider impacts to be another normal geological process, then we can see that they follow the same pattern. The largest impacts, which have caused mass extinctions, have left their imprint on the history of life and the course of evolution on Earth.

Mass extinctions may be necessary for evolutionary change. In the fossil record, extinctions are commonly followed by periods of rapid evolution and diversification of surviving groups of plants and animals as they evolve to fill environmental niches left open by extinct animals and plants, eventually leading to a much altered biosphere in which new species predominate. Thus, at the end of the Cretaceous, a world dominated by dinosaurs and flying reptiles was transformed into the modern world of mammals and birds.

## 13.10 Summary

By the end of this chapter you should be familiar with the following concepts and topics:

**The development of higher forms of life**

The evolution of reptiles
The mammal-like reptiles
The mammals
The dinosaurs
Evolution of life and Earth's climate
Adaptation of life to its changing environment
The extinction of the dinosaurs – Alvarez Hypothesis
Catastrophism

## Questions

13.1. What was the climate like during the Mesozoic Era (250 to 65 million years ago), and how did this affect the evolution of the vertebrates?

13.2. Describe the circumstances that led to the extinction of the dinosaurs.

13.3. What were mammals like during the era of the dinosaurs?

13.4. What is "catastrophism" in geology?