

Chapter 23

What You'll Learn

- How the Appalachian and Ouachita Mountains formed.
- When and on what scale three mass extinctions occurred.
- Why coal is common in Pennsylvanian-aged rocks.
- How the development of seeds and eggs affected the evolution of life.

Why It's Important

The tectonic setting of eastern North America provided a hospitable environment not only for a wide variety of animals and plants, but also for the vast swamps that ultimately formed the rich coal deposits of eastern North America.



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

The Paleozoic Era

Discovery Lab

Where is oil found?

Many sedimentary rocks contain oil and water in the pore spaces between their grains. For example, as you will learn later in this chapter, there is abundant oil in the Paleozoic-aged, sedimentary rocks of West Texas. In this activity, you will observe how oil or water can be stored in solid rock.

1. Place an unglazed brick or sandstone sample on your table.

2. Using a dropper, slowly squeeze three to five drops per minute, of water or oil, for ten minutes.

Infer In your science journal, sketch a cross-section of the rock or brick. Include both before and after you added the water to it. Include in your sketches what the inside of the brick might look like. Infer what happened to the water.



SECTION

23.1

The Early Paleozoic

OBJECTIVES

- **Describe** the Cambrian paleogeography of Laurentia.
- **Discuss** the concept of a passive margin.
- **Describe** the Cambrian fauna.

VOCABULARY

paleogeography
passive margin
transgression
regression
Burgess Shale

Clues from the Paleozoic Era help us to understand how the diversity of life developed. Today, the Appalachian Mountains of the eastern United States border a tectonically calm coastline. But this area was much different in the past. The Paleozoic story explains how early life-forms moved from water to land, why the Appalachians exist, and why they contain the vast coal deposits that fueled the industrial revolution. The Paleozoic portion of the geologic time scale is shown in **Figure 23-1** on page 602.

CONTINENTAL SETTING

Geologists refer to the ancient geographic setting of an area as its **paleogeography**. The supercontinent Rodinia, was present at the end of the Proterozoic. By the Cambrian, the ancient North American continent of Laurentia had split off from Rodinia, was located near the equator, and was surrounded by ocean. In addition, it was almost completely covered by a shallow, tropical sea.

Throughout the Cambrian Period, there was no plate tectonic activity on Laurentia. There were no collisional tectonic events, so there were no mountain ranges actively forming at that time. The edge of a continent is called a margin; when there is no tectonic activity

Paleozoic Era	Permian Period	245 M.Y.B.P.
	Pennsylvanian Period	290 M.Y.B.P.
	Mississippian Period	323 M.Y.B.P.
	Devonian Period	362 M.Y.B.P.
	Silurian Period	408 M.Y.B.P.
	Ordovician Period	439 M.Y.B.P.
	Cambrian Period	510 M.Y.B.P.
		540 M.Y.B.P.

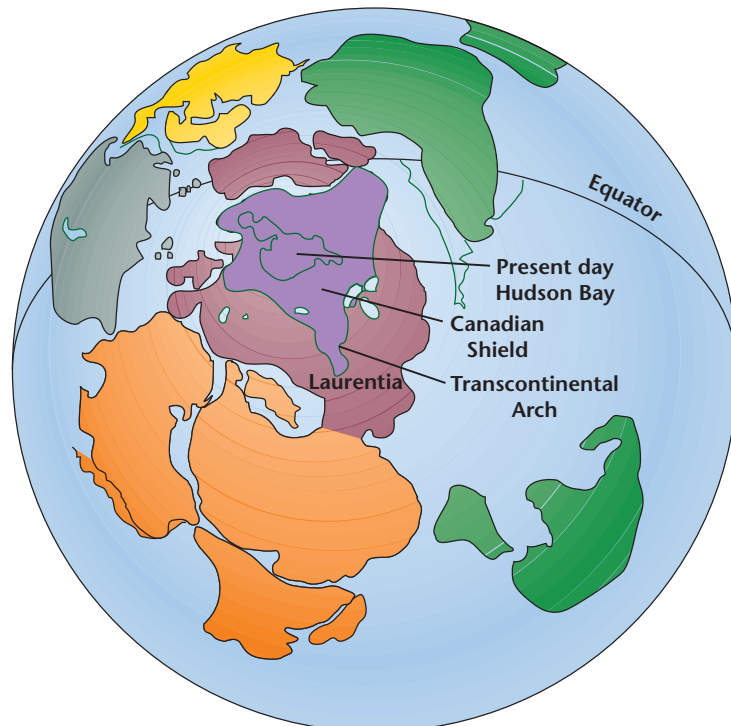
Figure 23-1 The Paleozoic Era spans 290 million years and is divided into seven periods. The rocks of the Paleozoic Era, tell of the great changes in both the tectonic setting and the life-forms that developed during that era.

along a margin, it is called a **passive margin**. Laurentia was completely surrounded by passive margins throughout the Cambrian Period.

Characteristic Sediments The paleogeographic setting of Laurentia, as shown in *Figure 23-2*, set the stage for a characteristic pattern of sandstone-shale-limestone deposits that represent increasing water depth from shore. The exposed land surface was flat, and the floor of the shallow sea that covered Laurentia dipped gently away from the shoreline. On land, the exposed Precambrian rocks were deeply eroded. Large, sandy beaches formed as fragments of quartz were weathered

from the rocks of the Precambrian Shield and transported to Laurentia's shoreline. Clay-sized sediments were carried by strong tides and deposited in slightly deeper water. Carbonate sediment accumulated in even deeper water as organisms whose skeletons were composed of calcium carbonate died and fell to the seafloor. Over time, the sand that had been deposited on the beaches became sandstone, the clay-sized sediments compacted to form shale, and the carbonate sediment became limestone. The most famous location where the sandstone-shale-limestone deposits of the Cambrian are exposed is the Grand Canyon. This sequence is shown in *Figure 23-3*.

Figure 23-2 Laurentia was positioned at the equator during the Early Paleozoic. Strong, tropical storms, much like today's hurricanes, contributed to erosion and formation of sandy beaches. Corals thrived in the warm ocean waters and ultimately contributed to the formation of limestone.



CHANGES IN SEA LEVEL

The sandstone-shale-limestone sequence deposited during the Cambrian was a side-by-side, or lateral, sequence from shallow to deeper water. Why, then, are the layers of sandstone, shale, and limestone stacked one on top of the other in the Grand Canyon? The sediments themselves reflect the energy of the water and often, the water depth. Thus, any changes in sediments may indicate changes in sea level.

A **transgression** occurs when sea level rises and the shoreline moves further inland. Think of a sandy beach. In water slightly deeper than that at the beach, there is clay-rich sediment, and beyond this, in even deeper water, is carbonate-rich sediment. As sea level rises, the water floods inland and the shoreline moves inland. The beach is now located where dry land had been. The area of slightly deeper water where clay-sized sediments are deposited also moves shoreward on top of the old beach. The result of the transgression is deeper-water deposits overlying shallower-water deposits, as shown in *Figure 23-4*.

A **regression** occurs when sea level falls and causes the shoreline to move seaward. This results in shallow-water deposits overlying deeper-water deposits. A stacked sequence of limestone-shale-sandstone is evidence of a regression. As sea level rises or falls, sediments that are lateral to each other become stacked one on top of another.

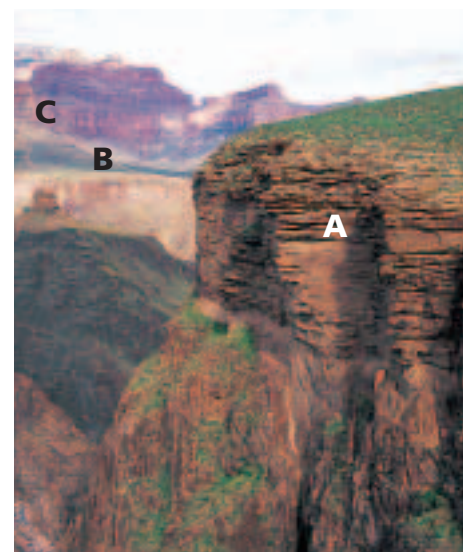
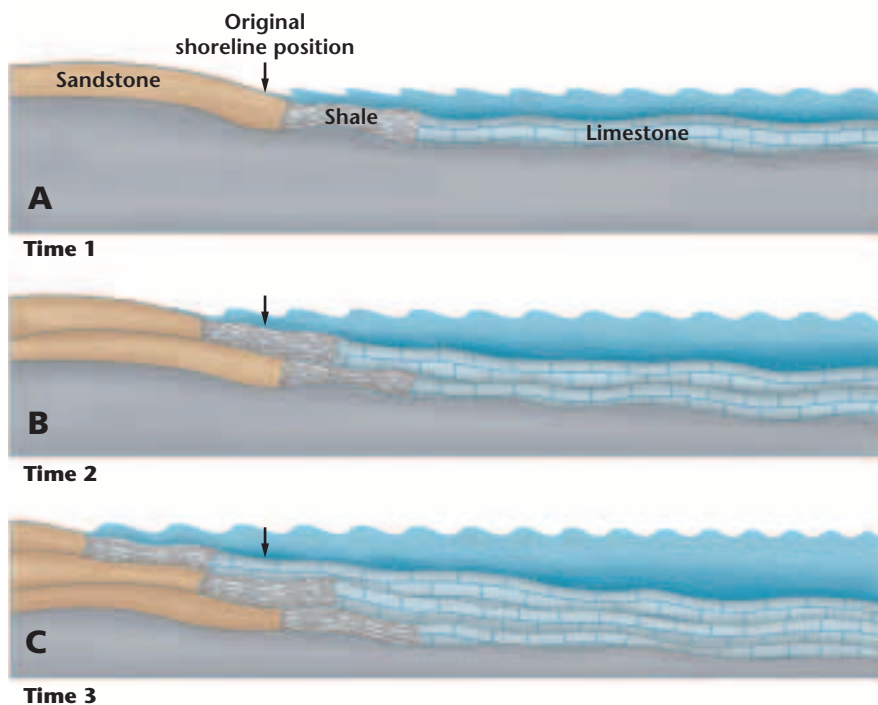


Figure 23-3 This sequence of rocks is evidence of a rise in sea level during the Cambrian. The beach environment that existed during the Cambrian is preserved in the Tapeats Sandstone (**A**). Slightly deeper water is represented by the Bright Angel Shale (**B**). The fossiliferous Muav Limestone represents the deepest, off-shore environment (**C**).

Figure 23-4 Time 1—sand is deposited at the shoreline and shale and limestone are deposited farther out (**A**). Time 2—sea level has risen, the shoreline has moved inland and shale is deposited at the original shoreline position (**B**). Time 3—sea level has risen again and limestone is deposited at the original shoreline position. The result is a sedimentary sequence of sandstone–shale–limestone (**C**).

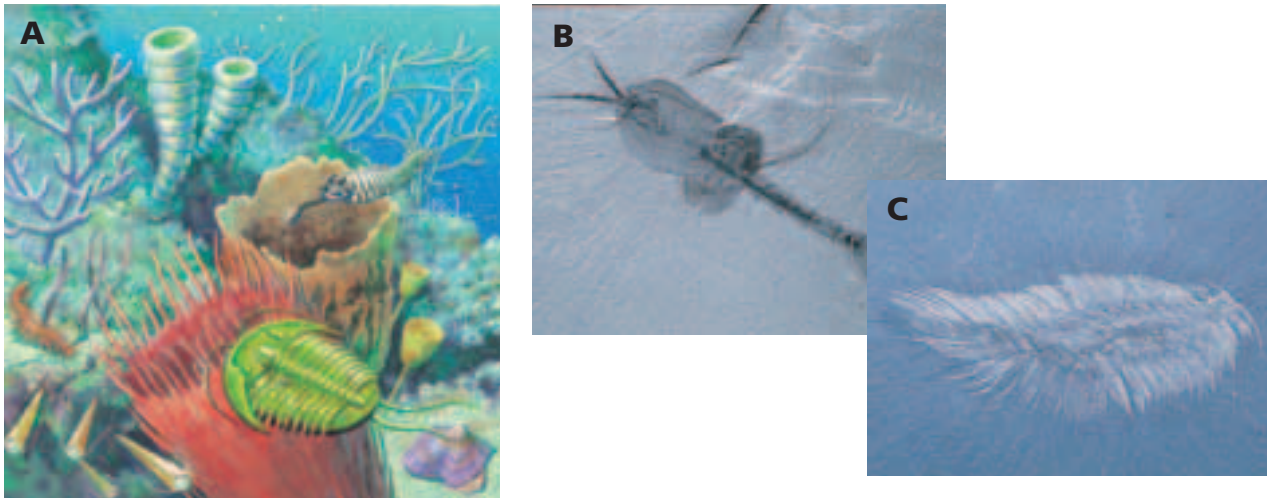


Figure 23-5 The Burgess Shale fauna were found in an isolated quarry near the town of Field, British Columbia. The unusual organisms lived a quiet life in the absence of predators **(A)**. *Waptia fieldensis* was an arthropod **(B)**. *Canadia spinosa* was a polychaete or bristle worm **(C)**.

You have learned that these distinct sequences of rock are the result of changes in sea level. While sea level was changing throughout the Paleozoic, so were the types of plants and animals that lived in the seas.

EARLY PALEOZOIC LIFE

There was such an increase in diversity and abundance of life-forms near the beginning of the Cambrian Period that some call this the Cambrian “explosion.” Organisms representing all but one of the major marine groups appeared at this time. The development of mineralized skeletons or hard parts also mark the Cambrian explosion.

Some of the best fossilized Cambrian organisms come from the **Burgess Shale**, in the Canadian Rocky Mountains. A spectacular array of soft-bodied organisms, as well as organisms with hard parts, are preserved. This deposit includes wormlike animals of unknown affinity and many other animals that do not fit into any living phylum, as shown in *Figure 23-5*.

SECTION ASSESSMENT

1. What was the paleogeography of Laurentia during the Cambrian?
2. What is a passive margin?
3. Briefly describe the significance of the Cambrian fauna.
4. Describe how sedimentary sequences change when sea level lowers.
5. **Thinking Critically** If there were a major ice age today, explain the effect it would

have on the sediments that are currently being deposited in the oceans and at sea level.

SKILL REVIEW

6. **Communicating** In your science journal, explain the relationship between the meanings of the words Cambrian *explosion* and the *explosion* of an object. For more help, refer to the Skill Handbook.

The passive margin that existed around Laurentia continued into the Early Ordovician Period. The paleogeography of Laurentia, as shown in **Figure 23-6A**, was still equatorial, with the paleo-equator running from approximately modern-day New Mexico through Minnesota.

SEA LEVEL CHANGES AGAIN

Sea level rose during the Early Ordovician and, once again, a beach environment covered much of Laurentia's margins. The base of the rock layers that were deposited is marked throughout much of central North America by the pure quartz sand of the St. Peter Sandstone, shown in **Figure 23-7** on page 606. The sandstone is overlain by minor amounts of shale and by extensive limestone deposits. These limestone deposits contain a tremendously diverse array of organisms, including the first corals that built organic reefs.

Organic reefs are structures composed of carbonate skeletons made by living organisms. Corals require warm, clear, shallow water of normal marine salinity in order to thrive. For this reason, they are confined to latitudes between 30° north and south of the equator. During the Middle Ordovician, corals and a group of sponges called stromatoporoids became common and began to build reefs in the shallow sea that covered Laurentia.

Reefs affect the environments in which they grow. They commonly form in long, linear mounds parallel to islands or continents, where they absorb the energy of waves that crash against them on their oceanward side. This protects the environments behind reefs from the waves' energy. The calm areas behind reefs, are called lagoons.

OBJECTIVES

- **Describe** the Middle Paleozoic paleogeography.
- **Explain** the concept of an active margin and the formation of a clastic wedge.
- **Describe** the Middle Paleozoic fauna.
- **Define** the concept of mass extinction.

VOCABULARY

Taconic Orogeny
Caledonian Orogeny
Acadian Orogeny
Antler Orogeny
Paleozoic fauna
vascular plant
mass extinction

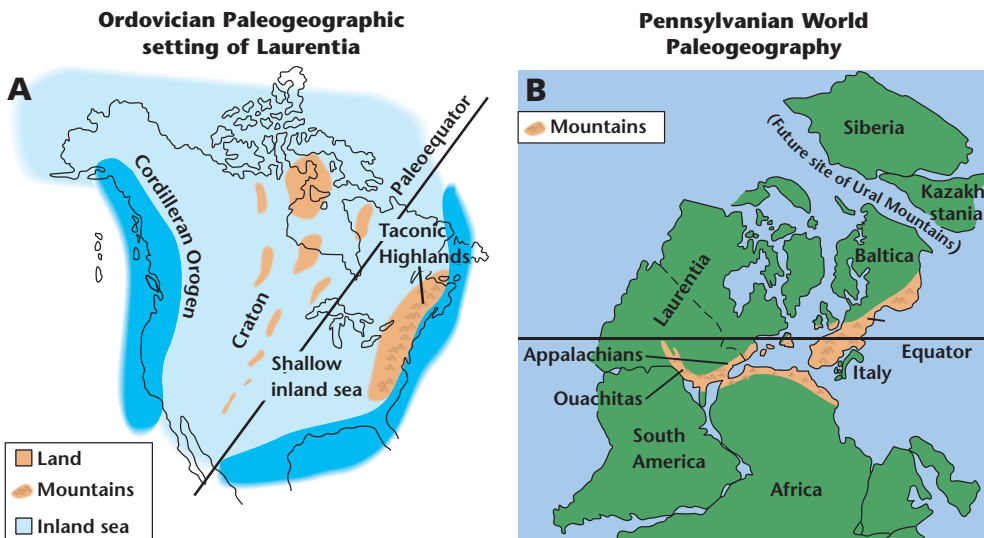


Figure 23-6 Laurentia was positioned across the equator during the Early Ordovician. The Taconic Orogeny formed the Taconic Highlands along Laurentia's eastern margin (**A**). Orogenic activity continued during the Pennsylvanian. Mountains formed along the line of collision. All of the continents were assembled as one supercontinent, Pangaea (**B**).



Figure 23-7 Glass is made from silica sand such as the very pure and clear St. Peter sandstone.

Here fragile organisms can thrive as shown in **Figure 23-8**. Reefs also can restrict water flow from the lagoon to the ocean. The shallow, quiet water in lagoons warms in the tropical sunlight and water evaporates at a high rate. When this happens, lagoon waters may become oversaturated with calcium and sodium. These elements combine with other elements or compounds in the water and precipitate out of solution as evaporite minerals such as gypsum and halite.

The Great Lakes area of North America contains huge deposits of Silurian-aged evaporite minerals that are mined commercially. Surrounding many of these evaporite deposits are reefs that almost certainly played a role in restricting the flow of water, thus making conditions right for the deposition of evaporite minerals. In the Michigan Basin, periodic restriction and deposition of evaporites resulted in deposits of halite and anhydrite more than 700 m thick! The Ohio Basin and the Appalachian Basin also were sites of evaporite deposition during the Late Silurian. **Figure 23-9** shows the locations of these basins. Today, these evaporite deposits are important sources of gypsum, which is used to make plaster and drywall, and halite, which is mainly used as road salt.

MIDDLE PALEOZOIC TECTONICS

During the Middle Ordovician, an ocean-continent collisional boundary, an active margin, developed in what is now eastern North America. As shown in **Figure 23-6A**, this resulted in a mountain building event called the **Taconic Orogeny**, named for the Taconic

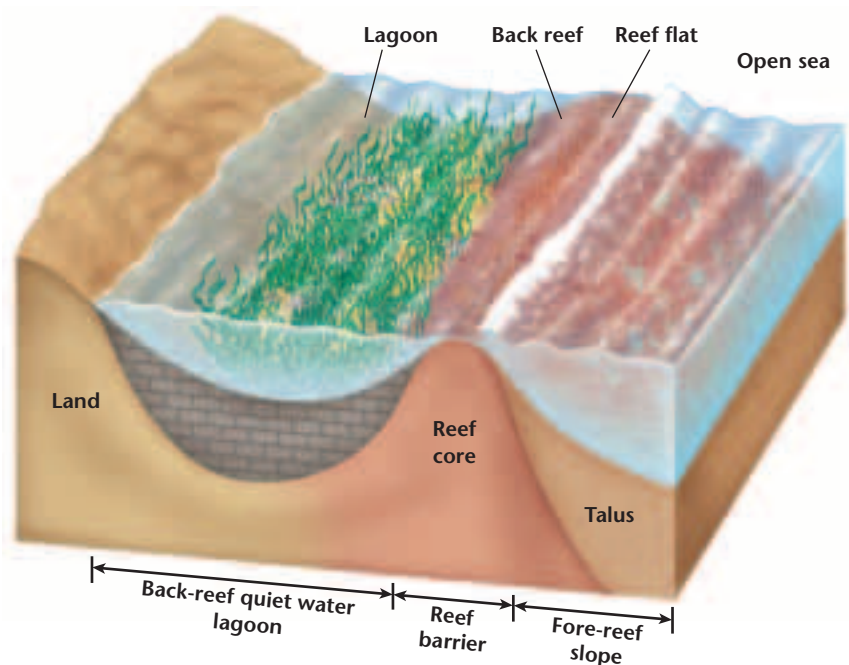


Figure 23-8 The sheltered, quiet water behind a coral reef is an ideal place for fragile organisms to thrive.



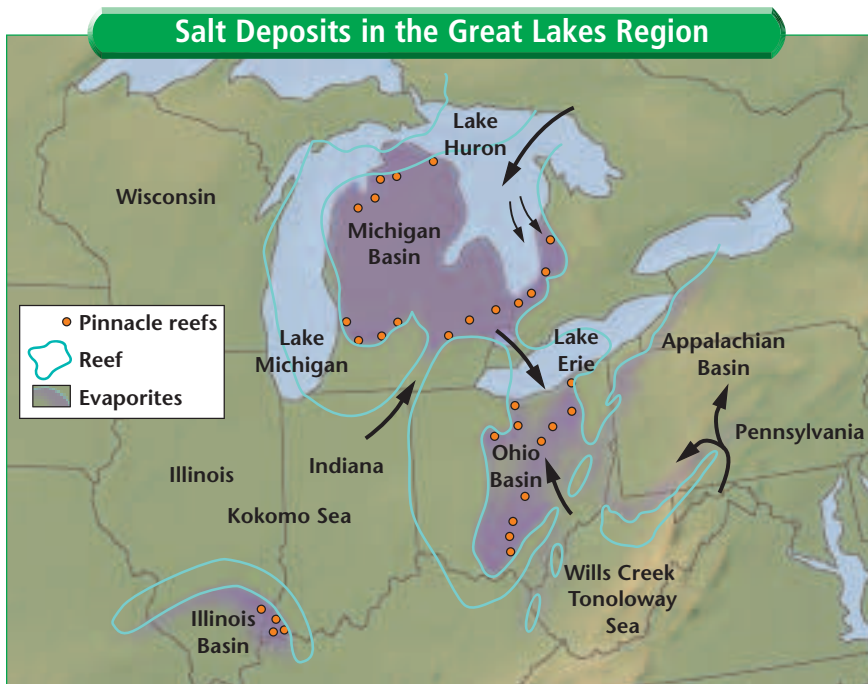


Figure 23-9 The barrier reefs that grew within these basins most likely restricted the flow of water from time to time. This, coupled with increased evaporation, resulted in the formation of halite and other evaporite minerals.

Mountains of eastern New York State. A series of volcanic islands also formed as a result of this mountain building event.

How do we know that this Taconic Orogeny occurred? Geologists look for clues and evidence in the rocks like detectives at a crime scene. One form of evidence is angular unconformities. Rocks that are older than the Middle Ordovician of eastern New York are tilted at a different angle than those of the younger Silurian rocks. This means that something, such as a tectonic collision, tilted the rocks after the Middle Ordovician but before the Silurian. Volcanic activity also provides evidence of the Taconic Orogeny. Lava flows and volcanic ash deposits that are Middle-to-Late Ordovician in age exist in present-day eastern North America. There are also igneous intrusions and regional metamorphic features that have been radiometrically dated as being between 480 and 440 million years old. The final piece of evidence of the Taconic Orogeny is the wedge of sediment, some of which is shown in **Figure 23-10**, that formed as the mountains from the Taconic Orogeny eroded. In a cross section, such a deposit has a triangular wedge shape, and is called a clastic wedge.

Orogenies and Deformation Tectonism continued during the Late Silurian and into the Devonian when Laurentia collided with Baltica, an ancient continent that consisted of what are now northern Europe and Russia west of the Ural Mountains. This collision joined Laurentia and Baltica into a larger continent known as Laurasia, pictured in **Figure 23-6B** on page 605.

Figure 23-10 Erosion and transport of material from rising mountains to the east resulted in the formation of these coarse-grained, layered deposits. They are part of a large clastic wedge called the Queenston Delta and are exposed in Genesee Gorge in Letchworth State Park, NY.





Figure 23-11 These rocks were deformed and faulted during the collisional events of the Taconic and Acadian Orogenies.

This collisional tectonic event, known as the **Caledonian Orogeny**, closed the ocean that had separated these two continents. Shortly after Baltica collided with Laurentia, a microcontinent called Avalonia, which is now Newfoundland, collided with the southeastern margin of Laurasia. This tectonic event, known as the **Acadian Orogeny**, affected the same general area as the Ordovician Taconic Orogeny. The deformation caused by the Acadian Orogeny added folds, faults, and igneous intrusions to the already deformed rocks of the Taconic Orogeny. **Figure 23-11** shows some of the complex folds that resulted. During the Late Devonian and into the early Mississippian, the passive western margin of Laurentia was affected by a collisional tectonic event called the **Antler Orogeny**. It was most likely caused by a microcontinent or island arc that collided with what is now western North America, as shown in **Figure 23-12**. As you will learn in the next chapter, one of the problems with interpreting the Paleozoic geology of western North America is that it has been complicated by numerous younger orogenic events.

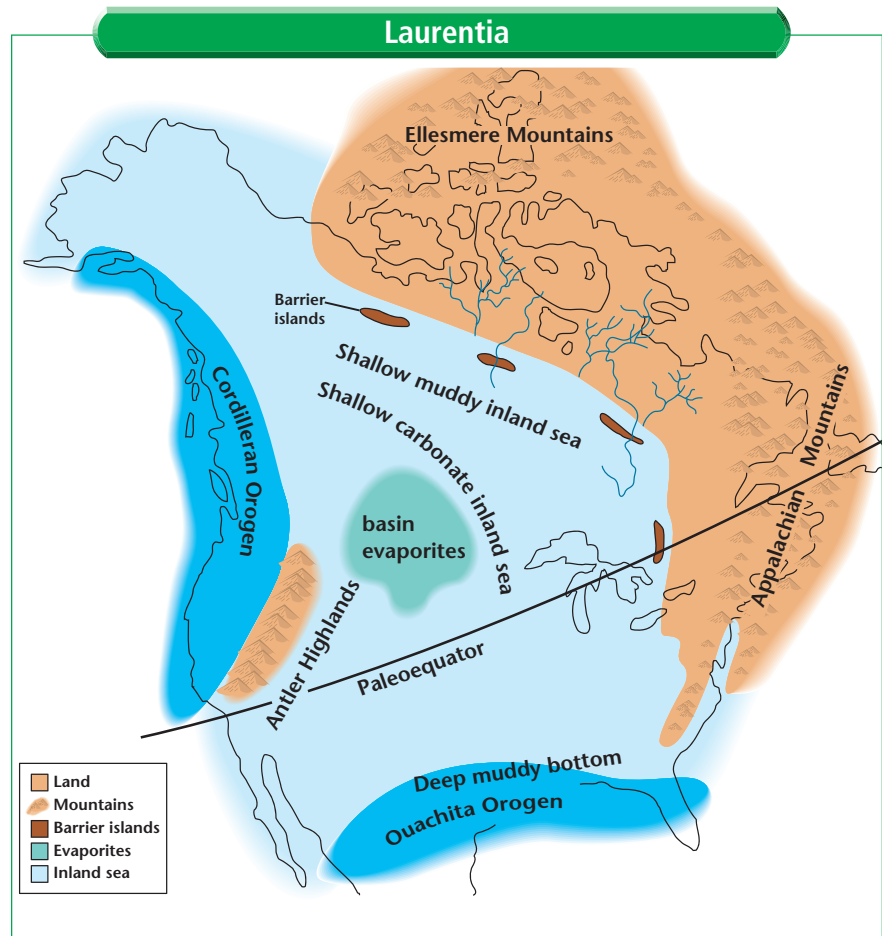


Figure 23-12 The mountains of the Antler Orogeny bordered an inland sea to the east. The collision of a microcontinent with Laurentia is thought to be the cause of the orogeny.

MIDDLE PALEOZOIC LIFE

The Middle Paleozoic seas were dominated by animals that are collectively called the **Paleozoic fauna**. The animals that dominated the Cambrian seas were replaced during the Early Ordovician by a variety of new organisms. Representatives of the Paleozoic fauna are shown in *Figure 23-13*.

Biologists have observed that modern corals deposit thin layers of carbonate, called growth lines, to their skeletons each day. Seasonal variations in length of day cause yearly changes in the spacing of these growth lines. The Devonian horn coral, *Heliophyllum*, pictured in *Figure 23-13D*, displays these types of growth lines. Based upon the spacing and number of growth lines in a cycle, paleontologists have deduced that, during the Devonian, the days were about 22 hours long and there were about 400 days in a year. The corals thus indicate that Earth was rotating more rapidly during the Paleozoic and, like a top, has been slowing ever since. You will calculate the lengths of days of other periods in the *Problem-Solving Lab* on page 610.

LIFE MOVES TO LAND

The seas were not the only places where life was developing during the Middle Paleozoic. For the first time in the history of life on Earth, land was colonized. Fossilized plant parts and spores suggest that some form of land plant existed during the Late Ordovician. **Vascular plants** have tissue for circulating water and nutrients through their stems and leaves. It was the development of this tissue that allowed plants to spread out on land. Fossils that undisputedly represent vascular plants are found in Early Silurian rocks. These plants were small, leafless, grew along the ground, and reproduced by spores.

New Plants Emerge By the Late Devonian, three important groups of vascular spore-bearing plants were living on land. One group, the ferns, still thrive today. The second group, the sphenopsids, were joint-stemmed plants. A modern species of sphenopsid is the horsetail or scouring rush, shown in *Figure 23-14*, whose common name is derived from its use by early plains settlers to scour their dishes. The last group is the lycopods. The leaves of the lycopods grew directly from their stems, leaving diamond-shaped scars on the fossilized stems.

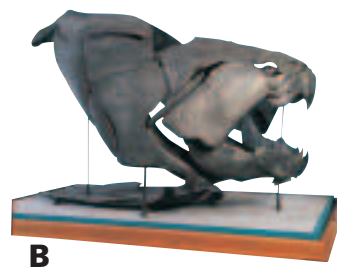
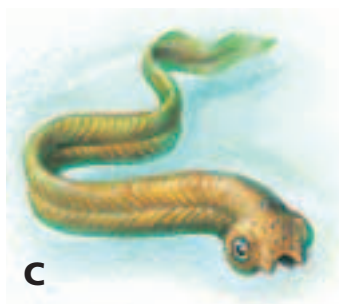
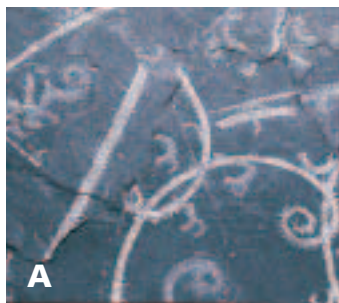


Figure 23-13 Graptolites lived in shallow, marine waters (A). The Early Paleozoic fishes had internal skeletons of cartilage. This *Dunkleosteus*, from Ohio was a top predator in the Devonian Seas (B). Conodonts were eel-like swimmers whose only hard parts were tooth-like structures. They are excellent index fossils because they are widespread, existed during a short period of time, and have distinct characteristics (C). The growth lines on this Devonian horn coral, *Heliophyllum*, help determine the length of a Devonian year (D).

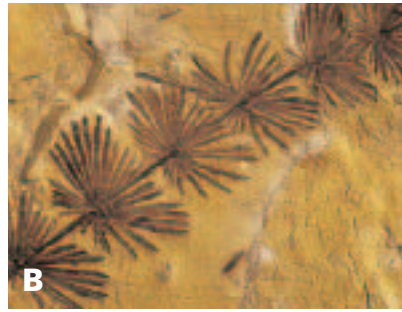


Figure 23-14 This modern horsetail (A) and this fossil horsetail from Italy (B) exhibit strikingly similar features such as the individual joints and clusters of leaves along the stem. This fossil fern is from Piesberg, Germany (C).

During the Late Devonian, the seed ferns developed. The most important aspect of these plants was the development of seeds. Seeds contain their own moisture and food source. They are covered by a hard coating that prevents drying and protects them. Seeds allowed plants to spread out and colonize dry land. Until the development of the seed, plants required water to complete their reproductive cycles. Thus, with the development of seeds, the surface of the continents was changed forever.

MASS EXTINCTIONS

Two of the greatest extinction events in Earth's history occurred during the Middle Paleozoic. When an unusually large number of organisms become extinct over a relatively short period of geologic time, it

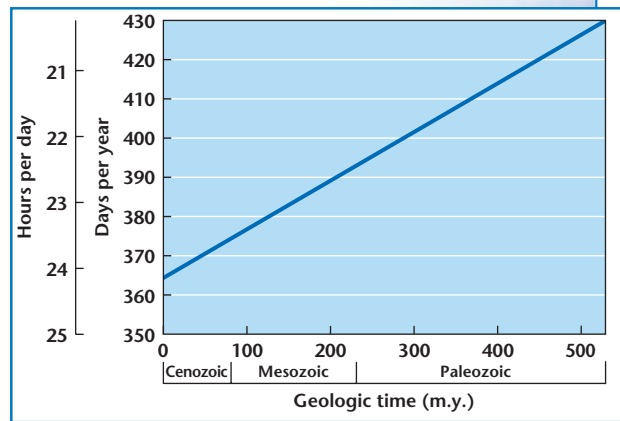
Problem-Solving Lab

Interpreting Graphs

Determine the length of a Paleozoic day Geologists study the shapes and compositions of fossil organisms to interpret how and in what types of environments they lived. Fossils can even be used to interpret climatic changes. For example, rugose corals exhibit lines on their shells that represent yearly growth cycles. Ultimately, paleontological data such as this can be used to interpret the past and to predict future events. Use the figure at the right to answer the following questions.

Analysis

1. How many hours were in a day 400 million years ago?



2. How many hours were in a day 200 million years ago?

Thinking Critically

3. When will there be 24.5 hours in a day?

is called a **mass extinction**. The first mass extinction occurred at the end of the Ordovician Period. Approximately 57 percent of all marine genera became extinct. Those that survived suffered large but not complete losses in their numbers of species and genera.

What caused the Late Ordovician mass extinction? One clue is that there are Late Ordovician glacial deposits preserved in what is now northern Africa. Another clue is that species that were adapted to warm environments were the hardest hit. Geologists hypothesize that an episode of global cooling, plus the rapid lowering of sea level that accompanied the glaciations, caused the extinction of many species that were adapted to warm environments.

Global Cooling and Overturning A second mass extinction occurred during the late Devonian when approximately 50 percent of the marine genera were wiped out, including many species of corals and stromatoporoids. Again, the polar communities were not severely affected. Was global cooling again the cause? There is evidence that glaciation occurred on some continents at this time. The cooling of Earth's atmosphere may have caused a tremendous disturbance in the ocean system. This created overturning, a process in which oxygen-poor, deep ocean water rises up, creating surface waters that contain little or no oxygen.

Evidence of overturning exists in the form of black shale. Black sediment indicates a lack of oxygen. Black shale deposits from the Late Devonian are common worldwide, and therefore, suggests that the seawater at that time contained reduced amounts of oxygen. The lack of oxygen in the water stressed the organisms to the point at which many species became extinct.



Update To find out more about present-day extinctions, visit the Earth Science Web Site at earthgeu.com

SECTION ASSESSMENT

1. Where was Laurentia positioned on Earth during the Middle Paleozoic?
2. Explain how evaporite deposits formed during the Middle Paleozoic.
3. What kinds of evidence do geologists use to determine whether an area was subjected to an orogeny?
4. What were the common causes of the Late Ordovician and Late Devonian mass extinctions?
5. **Thinking Critically** In Chapter 19, you learned about different kinds of faults. What kinds of faults would you expect to have been associated with the Acadian Orogeny? Why?

SKILL REVIEW

6. **Recognizing Cause and Effect** Explain how the appearance of land plants led to the appearance of land animals.



OBJECTIVES

- **Describe** the formation of Pangaea.
- **Explain** how cyclothem formed.
- **Identify** the importance of amniote eggs.
- **Discuss** the causes of the Late Permian mass extinction.

VOCABULARY

Gondwana
 cyclothem
 Ouachita Orogeny
 Ancestral Rockies
 Alleghenian Orogeny
 amniote egg

During the Late Paleozoic, the supercontinent Pangaea formed. In the previous section, you learned that Laurentia, Baltica, and the microcontinent Avalonia were joined together by the end of the Devonian. **Figure 23-15** shows how, as a result of similar collisional events, South America, Africa, India, and Antarctica joined to form the large continent in the southern hemisphere called **Gondwana**.

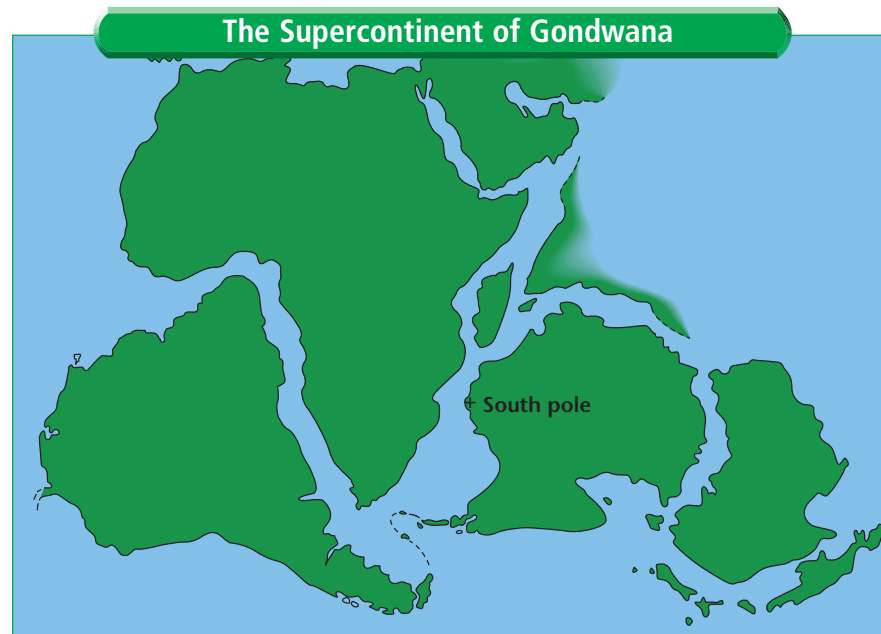
SEA LEVEL AND DEPOSITION

The Late Paleozoic began with Laurasia still covered by a shallow tropical sea. This setting provided the perfect environment for the deposition of carbonate sediment. Thus, Mississippian rocks throughout North America are predominantly limestone. The end of the Mississippian was marked by a major regression of the sea.

The Pennsylvanian Period began with a slow transgression. The sediments that were deposited have quite different characteristics from those of the underlying Mississippian carbonates. The Pennsylvanian and Permian rocks in central and eastern North America are predominantly river and delta deposits.

The Pennsylvanian Period is known for the coal deposits that accumulated in heavily vegetated lowland swamps. As you have learned, coal forms through the compaction of plant material. Why

Figure 23-15 The mountain building and subsequent erosion that occurred as Gondwana formed resulted in the formation of clastic wedges in front of the mountains. The mountain building events are sometimes referred to as the Gondwanan Orogeny.



are coal deposits not common in older rocks? The answer lies in the development of plant life on land. Not enough plant material had accumulated on land to form significant coal deposits until the Mississippian. Because a shallow sea covered Laurasia during the Mississippian, and because coal deposits generally form on land, there are few Mississippian-aged coal deposits in North America.

Cyclothems Pennsylvanian rocks in North America display a repeating cyclic pattern of sediments stacked one on top of another. Such a sequence as pictured in *Figure 23-16* is called a **cyclothem**. Cyclothems record two changes in sea level. A regression is represented by layers of marine limestone, and sandstone. A transgression is represented by sandstone, clay, coal, shale and marine limestone. In some parts of Laurentia, as many as 40 to 50 of these sequences were stacked one on top of the other. What could have caused the seas to transgress and regress 50 times? Most geologists hypothesize that glaciation was responsible. Glaciers grow by the accumulation of snow. Most of the water that freezes into snow comes from the evaporation of seawater. Thus, when glaciers are growing, sea level is falling. Gondwana was located in part over the south pole during the Pennsylvanian and large, glacial ice sheets developed on land. It is likely that glaciers grew during cooler periods during the Pennsylvanian and caused sea level to drop, which, in turn, caused a regression. The glaciers partially melted during warmer periods and caused sea level to rise, which resulted in a transgression. In this way, numerous cyclothems were deposited one on top of the other.

REEFS AND EVAPORITES

During the Permian, much of what is now eastern North America was dry land and a shallow sea covered most of what is now western North America. A spectacular fossilized barrier reef complex was formed during the Permian in what is now western Texas, southeastern New Mexico, and northern Mexico. Sponges and algae built this reef complex, known as the Great Permian Reef Complex, the remains of which are shown in *Figure 23-17* on page 614. Because these barrier reefs restricted the flow of water, large evaporite deposits formed behind the reefs during the Middle and Late Permian.

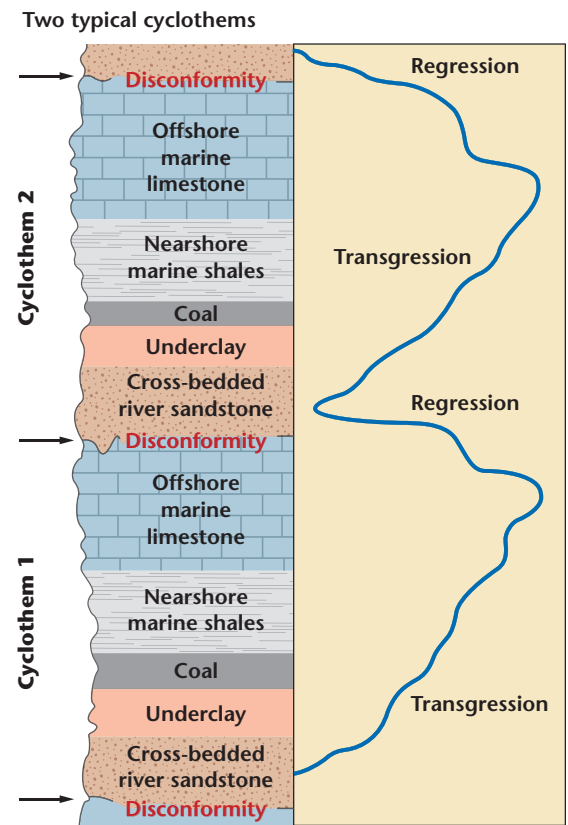


Figure 23-16 The general rock sequence of a cyclothem from base to top, is sandstone-clay-coal-shale-limestone.

Figure 23-17 The best exposure of the Great Permian Reef Complex is at Guadalupe Mountains National Park in West Texas.



ENVIRONMENTAL CONNECTION

Figure 23-18 These rocks are part of the Fountain Formation, a unit whose sediments were derived from erosion of Pennsylvanian-aged arkoses. As a result of continued faulting, the layers are standing literally on end.



These evaporites and the Great Permian Reef Complex are very important deposits. As you learned in the *Discovery Lab* at the beginning of this chapter, pore spaces in rocks and sediment can be filled with oil or water. The pore spaces in Permian reefs and in the surrounding coarse-grained rocks are filled with oil making these reefs important oil reservoirs. The evaporites associated with these reefs are important for a different reason. The thick salt deposits have very low permeability and, thus, virtually no liquids move through them. This makes them an excellent environment for long-term storage of nuclear waste. In the thick salt deposits in southeastern New Mexico, a large facility has been built for the disposal of various kinds of nuclear waste.

CONTINENTAL COLLISIONS AND MOUNTAIN BUILDING

The Late Paleozoic was a time of active mountain building. Gondwana collided with the southeastern margin of Laurasia during the **Ouachita Orogeny**. The Ouachita Orogeny formed the Ouachita Mountains of Arkansas and Oklahoma and the mountains in the Marathon area of West Texas.

The collision between Gondwana and Laurasia was so intense that it caused the crust to uplift inland as far as present-day Colorado. Geologists call the mountain range that formed the **Ancestral Rockies**. Large vertical faults lifted the Paleozoic rocks more than 2 km. The uplifted rocks eventually eroded and were deposited as red sandstone beds. The most famous of these deposits are the beautiful exposures at Garden of the Gods in Colorado Springs, shown in *Figure 23-18*.

As the collision between the two supercontinents continued, it closed the ocean that separated Gondwana from Laurasia. The part of Gondwana that is now Africa began to collide with Laurasia during the Late Pennsylvanian, causing the **Alleghenian Orogeny**.





Figure 23-19 This fossil crinoid is from the Silurian **(A)**. Living crinoids feed by spreading out their arms to catch and filter food particles from the water and pass them down to their mouths through grooves in their arms **(B)**.

It continued through the Permian along the southeastern margin of Laurasia. The Alleghenian Orogeny was the last of the three major mountain-building events to affect what is now eastern North America and resulted in the formation of the Appalachian Mountains. Pangaea had formed. This is summarized in *Figure 23-6B* on page 605.

LATE PALEOZOIC LIFE

The invertebrate marine organisms that flourished during the Middle Paleozoic continued to dominate the marine environment. One group, the crinoids, shown in *Figures 23-19A* and *B*, became dominant during the Mississippian. Crinoids were so abundant that some Mississippian limestones are made almost entirely of fossilized crinoid stem fragments.

Changes in the Ocean Following the extinction of many fishes during the Late Devonian, sharks and other ray-finned fishes, some of which still exist today, became more abundant. Lobe-finned fishes appeared during the Late Devonian, but became more abundant during the Late Paleozoic. Their club-shaped fins were supported by thick bones that made it possible for some of these fishes to walk on land. Of the three groups of lobe-finned fishes, two of them, the lungfishes and the coelacanths, are still living today. The third group of lobe-finned fishes gave rise to the amphibians.

On land, the true ferns, sphenopsids, lycopods, and seed ferns that appeared during the Late Devonian had thoroughly

Figure 23-20 A reconstruction of the life-forms on land during the Late Paleozoic.



Collisions and Shelves

Model the difference in continental shelf area between individual continents and one supercontinent.

Procedure

1. Using 250 g of modeling clay, make a sphere and flatten it into a disk that is 1/2 cm thick. This represents a craton.
2. Divide another 250 g of clay into 2 equal spheres and flatten them as above.
3. Roll 250 g of modeling clay into 3 long cylinders with 1/2 cm diameters. Wrap the cylinders around the edges of the clay disks. These represent continental shelves.
4. Using the formula $\text{area} = \pi r^2$, calculate the area of the large craton and the area of the large craton plus the continental shelf. Subtract the craton area from the total area. This equals the area of the continental shelf.
5. Repeat step 4 for each of the small models.

Analyze and Conclude

1. Which has more shelf area, two small continents or one large continent? Why?
2. Tropical oceans contain the greatest diversity of animals. If there is only one supercontinent how does this further limit the amount of habitat space?
3. Explain how reduced habitat space, Pangaea, and the mass extinction at the end of the Permian are related.

invaded the low, swampy land of the Pennsylvanian as illustrated in **Figure 23-20**. The warm, wet lowlands that developed at the base of the newly formed Appalachian Mountains was a perfect environment for plants to grow in and ultimately gave rise to the great coal swamps of the Pennsylvanian. They were a breeding ground for insects as well as plants. In fact, the largest insects that ever lived were preserved in coal swamps, including cockroaches that reached more than 10 cm in length and centipedes that were longer than 30 cm. The largest of all was a dragonfly with a 74-cm wingspan.

The coal swamps also housed amphibians. Although they were most likely sluggish and ate only fish, insects, vegetation, and smaller amphibians, they were the top carnivores on the land. Amphibians have one major limitation: they must lay their eggs in water because their eggs have no protective coating to prevent them from drying out on land. Thus, although early amphibians could colonize the land, they had to remain close to a source of water. Sometime during the Late Mississippian, this dependence on water was overcome. Reptiles that evolved from the early amphibians developed a new type of egg, the **amniote egg**. It has a shell that protects the embryo, which is surrounded by a liquid-filled sac that contains a food sac and a waste sac. Early reptiles were small, agile, and had more advanced teeth and jaws than amphibians. During the Permian, the more rapidly moving and stronger reptiles became abundant on land and displaced the amphibians as the top land carnivores.

THE PERMIAN MASS EXTINCTION


The largest mass extinction in the history of life on Earth defines the end of the Paleozoic Era. It is called the Permo-Triassic Extinction Event and it marks the end of

nearly 95 percent of all species including trilobites. You will learn more about this event in the *Science & the Environment* feature at the end of this chapter.

In contrast to the mass extinctions of the Middle Paleozoic, this extinction did not affect only the marine animals. Many of the terrestrial organisms that thrived in the swamps of the Late Paleozoic became extinct as well. More than 65 percent of the amphibians and reptiles did not survive, nor did almost one third of all insects. What could have caused such a widespread catastrophe?

A Major Marine Regression One possible cause of the Permian-Triassic Extinction Event was a major marine regression. Now, as then, most marine animals live in the relatively shallow water called the continental shelf. When sea level is high, the entire continental shelf is flooded, and there is quite a large area where marine animals can live. During regression, however, the continental shelf can become very narrow, leaving little space on the continental shelf for marine animals to live. This situation would have been particularly critical when there was only one continent. You learned about the consequences of reduced continental shelf space in the *MiniLab* on the previous page.

The end of the Paleozoic was a stressful time for life on Earth. Marine habitats shrank as a result of the major regression that occurred around Pangaea. Whether additional stresses were acting on life at that time is not known. What is known, however, is that regardless of the ultimate cause, life on Earth was irrevocably changed at the end of the Paleozoic.



Using Math

Calculating Percentages Is Earth currently in the middle of a mass extinction? If ten million species exist today, and 5.5 species extinctions occur every day, calculate how many years it would take for 96 percent of the species living today to become extinct.

SECTION ASSESSMENT

1. Explain the geologic events that resulted in the formation of Pangaea.
2. What is the relationship between cyclothem and glaciation?
3. What do scientists hypothesize were the main causes of the Late Permian mass extinction?
4. **Thinking Critically** In the previous section, you learned about the development of the seed. In this section, you learned about the development of the amniote egg. Explain the similarities between

these two important developments in the history of life on Earth.

SKILL REVIEW

5. **Concept Mapping** Reorganize the events below into an events chain that describes the formation of Pangaea. Ouachita Orogeny occurs; Ancestral Rockies uplifted; North America joined to Gondwana; Pangaea formed; Part of Gondwana collides with eastern Laurasia; Alleghenian Orogeny occurs; Part of Gondwana collides with SE Laurasia.

Symmetry, Shape and Shells

Brachiopods and bivalves have been present in Earth's oceans since the Cambrian. Both have two shells and live in marine environments. But the similarity ends there. How can you tell the two apart? Oysters are bivalves that are known for the pearls they secrete inside their shells. Can you distinguish an oyster from a brachiopod? If you were searching for pearls, you would want to know how!

Preparation

Problem

Distinguish between brachiopods and bivalves and interpret the environment where a brachiopod lived based on its shell.

Materials

fossil brachiopods (4), each belonging to a different species
fossil bivalves (4), each belonging to a different species
paper
pencil

Objectives

In this GeoLab you will:

- **Determine** if a fossil is a brachiopod or a bivalve.
- **Describe** the symmetry of fossil brachiopods and bivalves.
- **Infer** the environment in which different fossil brachiopods lived.

Safety Precautions

Always wear safety goggles and an apron in the lab.



FOSSIL DATA

Specimen	Brachiopod or Bivalve	Deeper water, low energy environment or shallow water, high-energy environment
1		
2		
3		

Procedure

1. Design a data table like the one above. You may choose to add more columns to record additional data.
2. Examine the fossils provided by your teacher.
3. Determine where the plane of symmetry is for each specimen. An organism that can be divided into two nearly identical halves has bilateral symmetry.
4. Identify the specimens as brachiopods or bivalves based on their symmetry and record this in your data table. Brachiopod symmetry runs across both shells. Bivalve symmetry runs between the shells.
5. Divide the brachiopods into two groups based on whether you think they lived in a deeper water, low energy environment, or in a shallow water, high-energy environment. Record this in your data table.

Analyze

1. **Interpreting Observations** Explain how symmetry is useful in determining whether a fossil is a brachiopod or a bivalve.
2. **Applying and Interpreting** If you only had one shell, how could you determine if it was the shell of a brachiopod or the shell of a bivalve?
3. **Comparing and Contrasting** Explain the similarities and differences between a streamlined auto and a smooth brachiopod, in terms of their place in wind or water.

Conclude & Apply

1. What principle did you use to determine the environment in which the fossil brachiopods lived? Explain.
2. Hypothesize about the reasons for the different shell types for brachiopods that live in different environments.
3. All living brachiopods pump water through their shells and filter organic particles out of that water to feed. Some brachiopod shells close along a straight line, whereas others close along a zig-zag line. What is the benefit of having a zig-zag opening for a filter feeding brachiopod?

Science & the Environment



Trilobite

Mass Extinctions

Most organisms that have ever lived on Earth are now extinct. For shallow-water, ocean-dwelling species, the average lifetime of a species is about 4 million years. That works out to an average of two or three species becoming extinct every year. The fossil record also indicates that, at certain times, many species became extinct over a short time.

The extinction of the dinosaurs and many other forms of life at the end of the Cretaceous Period has received much attention. For sheer numbers, though, these extinctions can't compare with the extinctions that ended the Paleozoic Era.

The Big Extinction Event

At the end of the Mesozoic, 65 to 75 percent of all species on Earth became extinct. When the Paleozoic ended, as many as 95 percent of all species became extinct. This event is called the Permo-Triassic Extinction Event.

Some marine organisms that became extinct during this Extinction Event were fusulinid foraminifera, rugose corals, and trilobites. On land, therapsids or mammal-like reptiles, became extinct, and insects suffered their only major extinction in their 390 million year history.

Paleontologists once thought that the Permo-Triassic extinctions took place over millions of years. However, recent research indicates that the extinctions were much more rapid. The causes are not well understood, but the extinctions appear to be the result of a fatal combination of changes in sea level, reduced oxygen levels, massive volcanic eruptions and global warming.

Opportunities Lost and Gained

Although the biosphere took millions of years to recover from each mass extinction, such extinctions are not entirely negative. The Permo-

Triassic Extinction Event cleared the way for new kinds of life, including the dinosaurs. The extinction at the end of the Mesozoic cleared the way for mammals to dominate. Without those extinctions, humans might not be here.

Many scientists believe that we are currently in the midst of another mass extinction. Over a thousand species of animals, and probably even more species of plants, are in danger of becoming extinct within our lifetime. This extinction is not caused by a regression or climatic changes, but by the impact of human activities.

Drugs to fight everything from AIDS to cancer have been found in organisms ranging from sponges to trees. Plants might be discovered that can be used to feed the world's hungry people. If a species becomes extinct, we lose the possibility of discovering any potential uses it might have had.

Activity

Go to earthgeu.com to find links to more information about the use of drugs derived from plants or animals to fight disease. Summarize where the drug is found, whether the plant or animal is in danger of becoming extinct, and how it is used to fight disease in humans.

CHAPTER 23 Study Guide

Summary

SECTION 23.1

The Early Paleozoic



Main Ideas

- The ancient North American continent of Laurentia was located near the equator and surrounded by ocean during the Cambrian Period. A shallow sea covered most of Laurentia.
- Laurentia was completely surrounded by passive margins throughout the entire Cambrian Period.
- Many new organisms developed during the Cambrian explosion. Fossils of trilobites and articulate brachiopods are particularly common in Cambrian rocks.
- When environments change position laterally due to changes in sea level, adjacent depositional facies overlie each other in vertical succession.

Vocabulary

Burgess Shale (p. 604)
paleogeography (p. 601)
passive margin (p. 602)
regression (p. 603)
transgression (p. 603)

SECTION 23.2

The Middle Paleozoic



Main Ideas

- High evaporation rates in lagoon settings cause the water to become oversaturated with calcium and sodium. These elements combine with other elements or compounds in the water and precipitate out of solution as the evaporite minerals.
- Clastic wedges provide evidence for orogenic events.
- The seas were dominated by articulate brachiopods, corals, mollusks, bryozoans, crinoids, graptolites and conodonts. Fishes were the top predators of the seas during the Devonian. Ferns, sphenopsids, and lycopods covered the landscape by the Late Devonian.
- Two mass extinctions occurred. A mass extinction occurs when an unusually large number of organisms become extinct over a relatively short period of geologic time.

Vocabulary

Acadian Orogeny (p. 608)
Antler Orogeny (p. 608)
Caledonian Orogeny (p. 608)
mass extinction (p. 611)
Paleozoic fauna (p. 609)
Taconic Orogeny (p. 606)
vascular plant (p. 609)

SECTION 23.3

The Late Paleozoic



Main Ideas

- Pangaea formed as Laurasia (North America + Europe) collided with Gondwana (South America, Africa, India, Australia and Antarctica).
- Cyclothem sequences consist of transgressive and regressive rock sequences stacked one on top of another. They represent cycles of glacial-interglacial periods.
- Seeds evolved and allowed plants to colonize dry land. The amniote egg evolved and allowed reptiles to colonize dry land.
- One possible cause of the Permo-Triassic Extinction Event was regression. Marine habitats around Pangaea shrank. Feedback from this event caused global warming, which affected organisms on land as well as in the sea.

Vocabulary

Alleghenian Orogeny (p. 614)
amniote egg (p. 616)
Ancestral Rockies (p. 614)
cyclothem (p. 613)
Gondwana (p. 612)
Ouachita Orogeny (p. 614)



CHAPTER 23 Assessment

Understanding Main Ideas

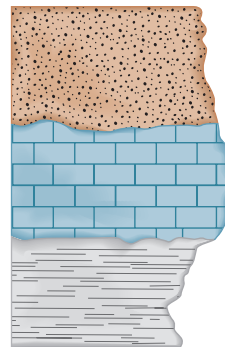
- Where was Laurentia located during the Paleozoic?
 - over the south pole
 - over the north pole
 - over the equator
 - where it is today
- During what period was Laurentia completely surrounded by passive margins?
 - the Cambrian
 - the Ordovician
 - the Devonian
 - the Permian
- What term describes a drop in sea level and the resulting seaward movement of the shoreline?
 - regression
 - excursion
 - explosion
 - transgression
- What are the most common fossils of the Cambrian fauna?
 - sharks
 - trilobites
 - crinoids
 - rugose corals
- What is the calm area behind a reef called?
 - a clastic wedge
 - a passive margin
 - a lagoon
 - a continental shelf
- Which of the following is not an evaporite mineral?
 - anhydrite
 - quartz
 - halite
 - gypsum
- What evaporite mineral is used to make plaster and drywall?
 - gypsum
 - aragonite
 - halite
 - quartz
- What is a triangular-shaped sedimentary rock deposit that was deposited adjacent to an uplifted area called?
 - a passive margin
 - an active margin
 - a clastic wedge
 - an orogeny

- What landmass collided with Laurentia and caused the Acadian Orogeny?
 - Gondwana
 - Avalonia
 - Baltica
 - Siberia
- What group of fishes were able to walk on land?
 - ray-finned fishes
 - sharks
 - lobe-finned fishes
 - Dunkleosteus
- What group of fishes gave rise to the amphibians?
 - acanthodians
 - sharks
 - lobe-finned fishes
 - Dunkleosteus

Applying Main Ideas

- What is special about the fossils of the Burgess Shale?

Use the figure below to answer question 13.



- What change(s) in sea level is/are represented by the sequence of rocks?

Test-Taking Tip

DRAWINGS AND DIAGRAMS WITH TEXT

If a written description is included with a drawing or diagram, read it carefully. Sometimes the written description can clarify or change the meaning of the graphic.

CHAPTER 23 Assessment

- Describe the differences between the Cambrian and Paleozoic fauna.
- What kind of clues do geologists use to determine whether an area was the site of an orogeny in the geologic past?
- How did paleontologists use rugose corals to determine that Earth rotated more rapidly in the geologic past than it does now?
- How did the Pennsylvanian cyclothem form?

Thinking Critically

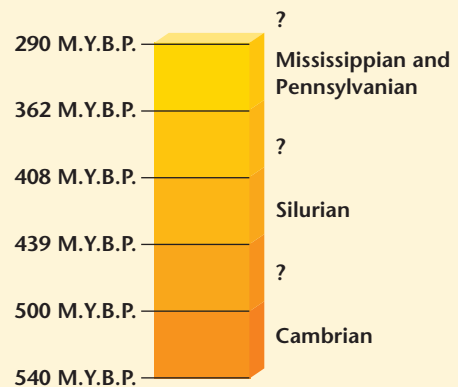
- Explain why many paleontologists consider the development of the seed and the amniote egg to be two of the most important events in Earth's history.
- How do the many coral reef deposits in the Great Lakes area of North America support the hypothesis that Laurentia was positioned across the equator in the Late Paleozoic?
- Explain how identical clastic wedges formed on either side of the mountains that were formed by the Acadian Orogeny.
- Distribution of plants occurs with the help of animals that eat them. Explain how the evolution of the seed ensured the success of this type of plant distribution.

Standardized Test Practice

- What is it called when the sea level rises and shorelines move inland?
 - regression
 - passive Margin
 - transgression
 - laurentia
- Which tectonic event was probably caused by a small microcontinent or island arc that collided with present-day western North America?
 - Taconic Orogeny
 - Caledonian Orogeny
 - Acadian Orogeny
 - Antler Orogeny

INTERPRETING SCIENTIFIC ILLUSTRATIONS

Use the figure to answer question 3.



- During the last period of the Paleozoic Era, much of what is now western North America was covered with dry land. What was this period called?
 - Pennsylvanian
 - Devonian
 - Permian
 - Ordovician
- What was formed in North America when Gondwana and Laurasia collided?
 - Ancestral Rocky Mountains
 - Appalachian Mountains
 - Ouachita Mountains
 - Great Permian Reef