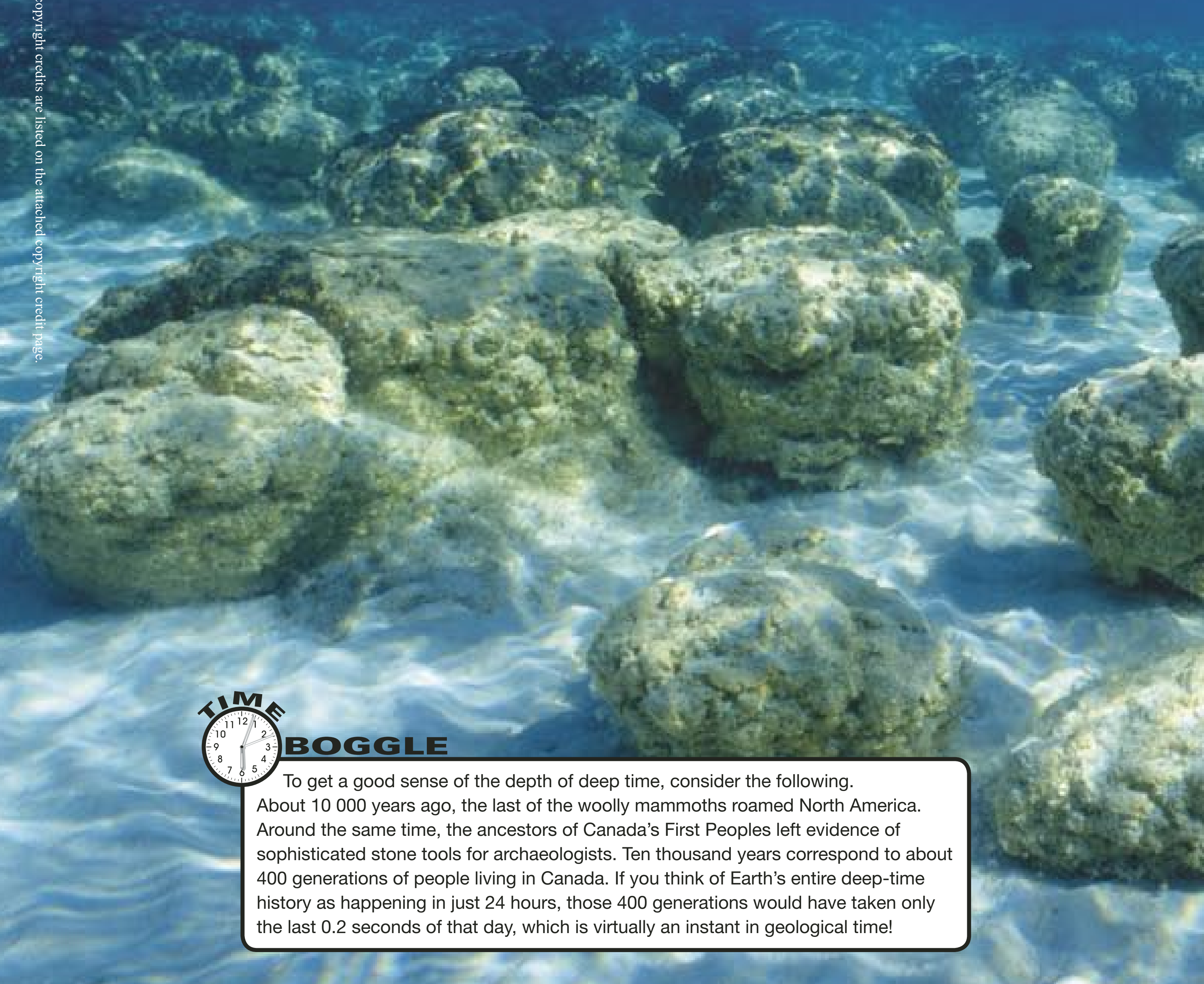
Chapter 1 The Abyss of Time

Your road trip begins at Drywood Creek in southern Alberta, just north of Waterton Lakes National Park. There you can see a large fossilized reef made up of fossils called stromatolites. These fossils might not look like much, but their presence in Drywood Creek—and in many rock formations in the Rocky Mountains—can be used to map out Alberta's coastline over a billion years ago. At that time, British Columbia didn't exist.

Living versions of the bacteria that created Alberta's stromatolites are found at Shark Bay, a popular tourist destination in Western Australia. By studying the modern forms of the bacteria that created the stromatolites, scientists know that these bacteria can survive only in hot, tropical coastal pools like those found by Shark Bay. This suggests that the climate in western Australia today is similar to Alberta's climate of a billion years ago. Although it may seem impossible, this fossil evidence indicates that the Rocky Mountain Range runs along what used to be Alberta's ancient coastline. Alberta is one of the rare places in the world where you can explore the mystery of how a sunny coast can become a snowy inland mountain range.



TIME BOGGLE

To get a good sense of the depth of deep time, consider the following. About 10 000 years ago, the last of the woolly mammoths roamed North America. Around the same time, the ancestors of Canada's First Peoples left evidence of sophisticated stone tools for archaeologists. Ten thousand years correspond to about 400 generations of people living in Canada. If you think of Earth's entire deep-time history as happening in just 24 hours, those 400 generations would have taken only the last 0.2 seconds of that day, which is virtually an instant in geological time!

© Gary Bell/oceanwideimages.com

Try This Activity

Deep Time

Scientists generally agree that Earth is approximately 4.5 billion years old. During this activity you will explore what this means and the concept of **deep time**.

deep time: the theory that Earth has a long history of development and change lasting billions of years

Materials

- handout
- metre-stick
- scissors
- spool of cash-register tape
- glue

Procedure

step 1: Obtain "Significant Events in Earth's History." This list is available on the Science 20 Textbook CD. Use scissors to cut out each event.

step 2: Measure out 5 m of cash-register tape to represent 4.5 billion years of Earth's history. Using the metre-stick, divide the tape into 10-cm sections. Starting from 4500 mya (million years ago), label each 10-cm section as 100 million years of time until you get to zero (the present).

step 3: Label Precambrian Era (4.5 billion years ago to 590 million years ago) on your time line.

step 4: Paste each event on the time line at the appropriate spot.

Science Skills

✓ Performing and Recording

Analysis

1. Describe how the events are distributed along your time line.
2. Determine the percentage of Earth's history taken up by the Precambrian Era.
3. Enumerate the events on your time line that occurred during the Precambrian Era.

Evaluation

4. Why do you think so little seems to have happened in the first 90% of Earth's history?

This unit is divided into three chapters that follow the major eras of geological time. It's a good idea to construct a separate time line for each chapter. First, create a format and scale that will fit onto a sheet of paper you can keep in your binder. Next, every time you see the time line icon, add the event to your time line for that chapter. Once you're done you'll have a very handy study guide.

1.1 The Long Beginning

Figure C1.1: The Slave Granite, home to migrating pelicans and deadly rapids, is among Alberta's oldest exposed rock.

For the last 2500 years, people of the Dene Th'a First Nation have followed the current of the Slave River north as they travel to their hunting grounds. Along the way they've always had to portage—carry their canoes—around a peculiar belt of reddish-coloured granite rock that cut across the river, creating four sections of deadly rapids. Later in Alberta's history, the portage trails established by the Dene Th'a were used by fur traders who ominously named the last of the four rapids "The Rapids of the Drowned."

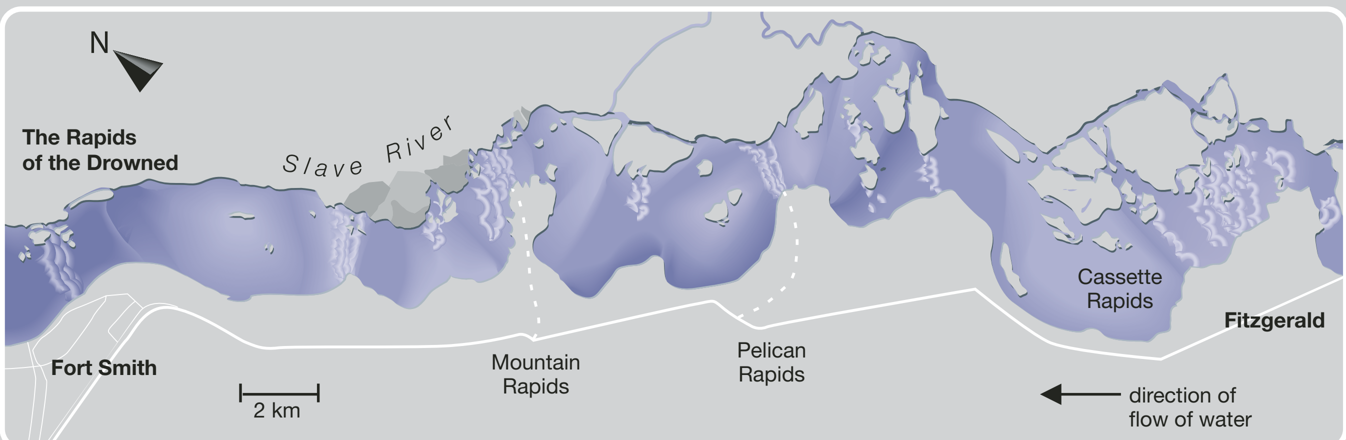


Figure C1.2: People of the Dene Th'a First Nation traditionally had to portage four sections of deadly rapids on the Slave River.

The Precambrian Shield

The strange red belt of granite rock is now called the Slave Granite. At two billion years old, it is among Alberta's oldest rocks. The Slave Granite is part of the Precambrian Shield, often called the Canadian Shield, which was formed in the **Precambrian Era**. The Precambrian Shield is what's left of the original North American continent, which formed four billion years ago. It makes up more than half of Canada's land mass, including most of Ontario and Quebec. In most places in Alberta, you would have to dig several thousand metres below the surface to reach this basement rock. When a rock layer that is normally underground is exposed, like the Slave Granite, it is called an **outcrop**. Other examples of outcrops, such as those noted in Figure C1.4, are mountain rock faces, canyon walls, river valley cliffs, and coastal cliffs.

Precambrian Era: the first major section of geological time, lasting from the origin of Earth 4.5 billion years ago up to 590 million years ago

outcrop: a part of a rock formation that appears above the surface of the surrounding land

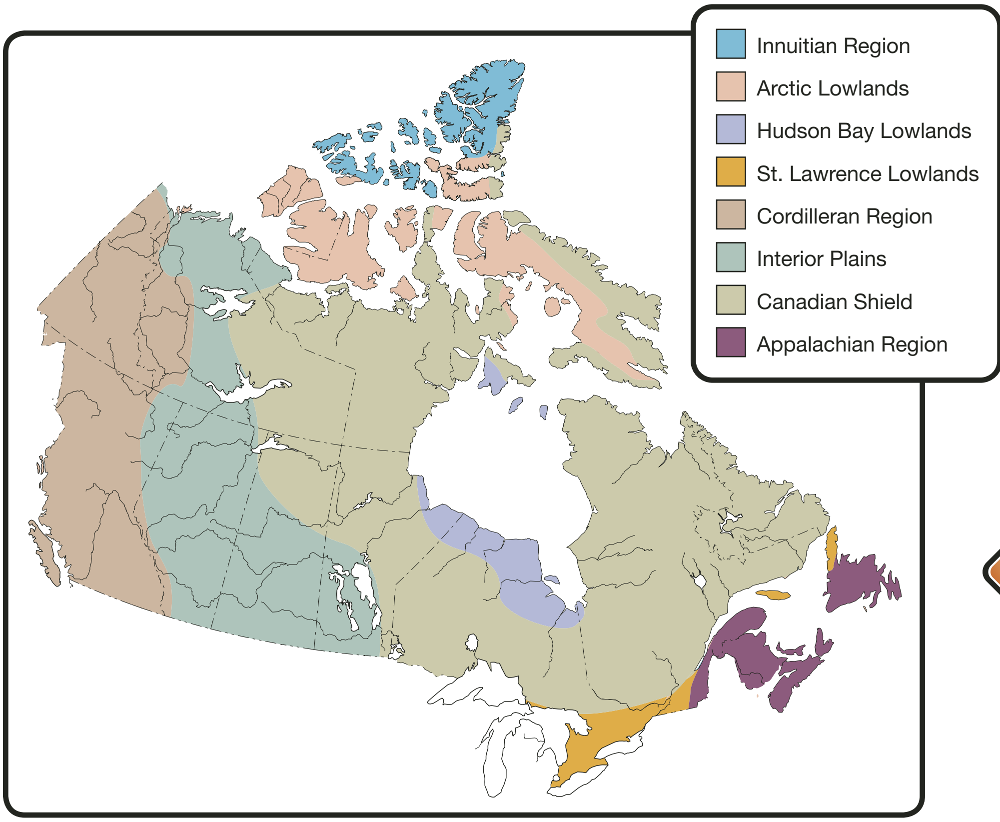


Figure C1.3: The Canadian Shield is one of the eight main physiographic regions of Canada.

Add the following details to your time line for this chapter:

- 4 billion years ago: North American continent formed
- 2 billion years old: age of Alberta's oldest rocks

Figure C1.4: Outcrop examples reveal a remarkable diversity.

Earth Is Like an Egg

If you look closely at a sample of granite, you can see large mineral crystals of various shapes, sizes, and colours peppered throughout the rock. Some of these minerals can be formed only under extremely high temperatures (900°C to 1000°C) and pressures.

If the Slave Granite rock is two billion years old, what were the circumstances that created these high temperatures and pressures to cause this type of rock to form? To answer this question, you have to first consider the composition of Earth's interior.

Earth's internal structure is not something you can observe directly because the deepest mines (4 km) and the deepest wells (13 km) barely scratch the surface—it's over 6000 km to the centre! The following description comes from indirect evidence that will be discussed in Chapter 2.

Earth can be separated into layers arranged according to their densities. The densest material sinks to the centre, while the least dense material floats on the surface. If you were to cut Earth in half, it might resemble a hard-boiled egg. You can think of the **core** as the yolk. The core is the densest layer and is made of nickel and iron.

> **core:** the innermost layer of Earth that consists of a solid inner core and a liquid outer core

The egg analogy isn't perfect, however. Unlike an egg yolk, Earth's core has two parts: a solid inner core and a liquid outer core. The liquid outer core spins compared with the rest of the planet. This induces Earth's magnetic field.

The white of the egg is like the **mantle**. The mantle is a solid layer comprising about 80% of Earth's volume. The extreme heat and pressure within the mantle cause zones of the rock to behave as a **plastic**. Every time you squeeze toothpaste out of a tube, for example, you are causing the flow of a plastic material. Earth's crust floats on the upper part of the mantle called the **asthenosphere**. The asthenosphere is the least rigid and most plastic part of the mantle. This plastic nature can be witnessed when magma from the asthenosphere rises up in the form of volcanoes.

> **mantle:** the layer of Earth between the crust and the core
>
> **plastic:** a substance with the properties of a solid that can flow under pressure
>
> **asthenosphere:** the uppermost layer of the mantle

> **mesosphere:** the part of the mantle beneath the asthenosphere
>
> **lithosphere:** Earth's outermost rigid layer of rock

The rest of the mantle beneath the asthenosphere is more rigid and is called the **mesosphere**. Do not confuse this with the part of the atmosphere that has the same name. The **lithosphere** is like the shell of the egg. The lithosphere includes the solid oceanic crust and continental crust that float on the asthenosphere. Oceanic crust is denser than continental crust and, as a result, is less buoyant.

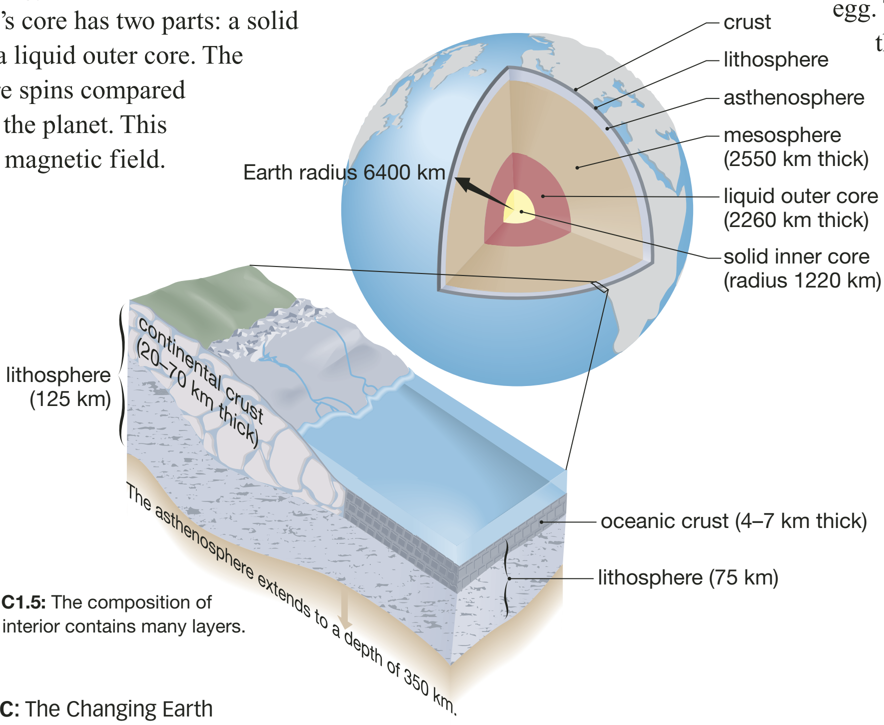


Figure C1.5: The composition of Earth's interior contains many layers.

Practice

1. Earth's internal structure can be compared to an egg. Infer what else Earth's internal structure can be compared to. Think of your own analogy. You could even make a poster or build a 3-D model to teach other people about Earth's interior.

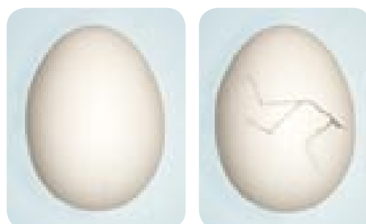
2. Copy and complete the table by inserting the missing information.

Earth's Layers		Density	Description	Thickness
atmosphere		least dense	• gaseous	300 km
			• solid • most rigid layer	
mantle			• least rigid or most plastic layer of mantle	
			• more rigid than uppermost layer of mantle	
core	outer core			
	inner core	most dense		

Motion in the Mantle

Scientists are unable to directly observe the layers below the lithosphere, so they use indirect evidence from events, such as earthquakes, to assist in developing theories about Earth's structure. One such theory is the idea that it is nuclear decay deep within the core that provides much of the heat energy needed to drive the plastic flow of material in the mantle. If this explanation is correct, the movement of matter in the mantle is similar to a hot bowl of French onion soup. Hotter material in the soup rises toward the cheesy crust; then it cools and sinks. This process, called convection, pushes and pulls on the soup's crust. This causes it to crack, tear, and move.

Scientists believe that a similar process is at work in Earth's mantle. Enormous convection cells within the mantle push and pull on Earth's solid crust. The results of convection require a revision to the idea that Earth is like an egg. The lithosphere is like the shell of an egg, but it is not a single rigid cover. Instead, the lithosphere is more like the cracked shell of the egg on the right—a mosaic of rigid pieces called **crustal plates**.



crustal plate: a large piece of continental crust or oceanic crust that floats and slowly moves atop the asthenosphere

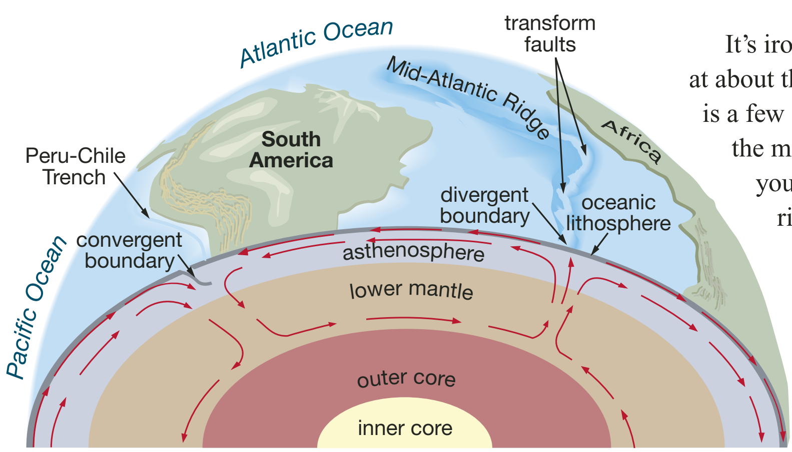


Figure C1.6: Convection cells within Earth's mantle cause the crust to crack, tear, and move.

It's ironic that these monstrous lithospheric plates move at about the same speed that your fingernails grow, which is a few centimetres per year. However, if you could watch the motion of Earth's crust in extreme fast forward, you would see a clumsy dance where crustal plates rift apart to create new oceans, collide to thrust up new mountain ranges, or slide one over the other to force one plate deep into the hot mantle to be melted. Since it isn't possible to see convection occurring within Earth's mantle, you can watch a demonstration of convection on the Science 20 Textbook CD.

Utilizing Technology

Convection

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will watch a demonstration of convection currents occurring within an aquarium. By the end of this activity you should be able to explain the process that causes convection currents to occur. The concepts that you explore here will be extended to explain the movement in Earth's crustal plates.

Procedure

step 1: Read the "Analysis" questions to create a focus for your learning before watching an applet.

step 2: Watch the applet "How Convection Works" on the Science 20 Textbook CD. Then complete the "Analysis" questions.

Analysis

1. Identify the energy source in the demonstration.
2. Identify the energy source for Earth's convection.
3. Sketch a diagram of the demonstration. Beside it, draw a diagram of Earth's convection currents.
4. Summarize the applet's explanation of how convection works.
5. Describe the movement of fluid near the aquarium's surface. How would it affect something floating on the surface?

Dynamic Crust

The same principles that were demonstrated in the applet "How Convection Works" explain how the crustal plates are driven by convection currents of hot material from within the mantle. This explanation is called **plate tectonics**. When the crustal plates separate at mid-oceanic ridges, the process is called sea-floor spreading. This means the youngest rocks on oceanic plates are located closest to the spreading centre; the rocks steadily get older as they move away from the ocean ridges. This has been verified by deep-sea drilling operations. Core samples taken from the ocean floor show a steady increase in age away from the ocean ridges.

Paleomagnetism

Additional evidence for sea-floor spreading and plate tectonics came from **paleomagnetism**. How can the magnetic properties of ancient rocks provide evidence to support plate tectonics? The process is shown in Figures C1.7 and C1.8.

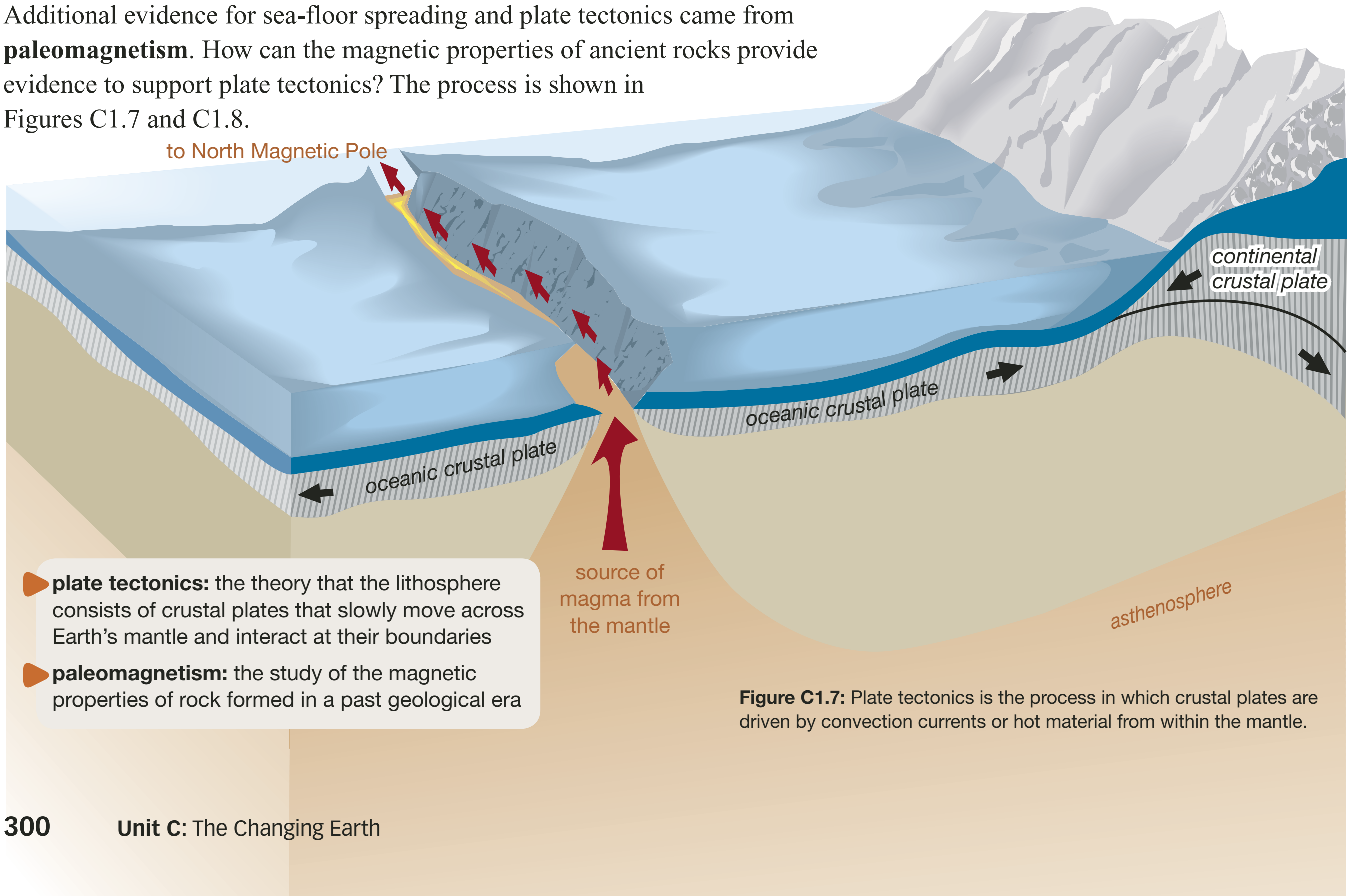


plate tectonics: the theory that the lithosphere consists of crustal plates that slowly move across Earth's mantle and interact at their boundaries

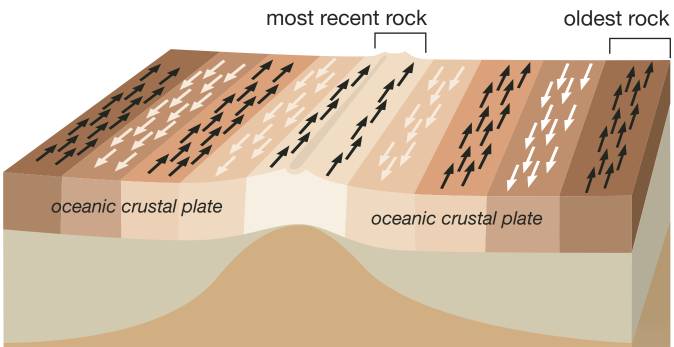
paleomagnetism: the study of the magnetic properties of rock formed in a past geological era

Figure C1.7: Plate tectonics is the process in which crustal plates are driven by convection currents or hot material from within the mantle.

Researchers found that sections of the sea floor have rocks with their magnetic fields pointing in the opposite direction, indicating that the magnetic field of Earth has reversed more than once in the past several million years. Refer to Figure C1.8.

The alternating normal and reversed stripes are parallel to the oceanic ridges. Researchers also discovered that the pattern of normal and reversed magnetic alignments on one side of an ocean ridge is the mirror image of the pattern on the other side. Researchers suggested that as new rock is added to each edge of the spreading plates, it records the current orientation of Earth's magnetic field. Paleomagnetism was one of the strongest pieces of evidence for sea-floor spreading and plate tectonics.

If two oceanic plates are slowly moving apart, a good question to ask is what happens at the end of each oceanic crustal plate that is opposite the fracture? As Figure C1.7 indicates, the edge of the oceanic crustal plate that is opposite the fracture is pushed under the neighbouring continental crustal plate. The oceanic crustal plate melts as it is forced down into the mantle. (You will take a closer look at this process when you study the formation of the Rocky Mountains in Chapter 2.)



step 1: When minerals rich in iron melt, they lose all their magnetic properties.

step 2: When magma cools and begins to solidify, any mineral rich in iron will have its magnetic particles align with Earth's magnetic field. The arrows on the diagram indicate that these magnetic particles are all pointing toward the North Magnetic Pole.

step 3: Rock formed from this magma then preserves a permanent record of the direction of Earth's magnetic field at the time of its solidification.

step 4: If you can use other means to determine the rock's age, you can determine the position of Earth's north and south magnetic poles at the time the magma solidified.

Figure C1.8: Rocks with magnetic fields pointing in opposite directions are found in sections of the sea floor.

Practice

3. Why is the oceanic crust pushed under the continental crustal plate instead of vice versa?

The Slave Granite

Recall the story of the Slave Granite that opened this lesson and the mystery about how the multicoloured crystals in the granite could have been formed under intense heat and pressure. Geologists now think that this rock was formed at the collision site of two continental crustal plates about two billion years ago. Since these plates had equal densities, one plate couldn't slide under the other. In this case, both plates welded together, pushing up huge rock wrinkles to form mountain ranges. At the site of the weld, the granite was formed and then pushed up. The mountain ranges that once stood tall have long since eroded. However, the Slave Granite remains as some of the oldest rock in Alberta.

1.1 Summary

Alberta's oldest rocks are two billion years old. But they are only about half as old as Earth, which was born 4.5 billion years ago. Earth survived violent interplanetary collisions and eventually settled into distinct layers—the core, the mantle, and the crust, depending on their density. Nuclear reactions continue to heat the core and mantle to cause enormous convection currents, which push and pull the plates that make up the crust.

1.1 Questions

Knowledge

1. Identify the first major section of time in Earth's history. Describe when it began and when it ended.
2. Where can you find Alberta's oldest exposed rocks?
3. Define *outcrop*.
4. Define *deep time*.
5. Sketch a simple, labelled diagram showing a cross section of Earth.
6. Infer the main property that determines both the ordering and composition of layers within Earth.

Applying Concepts

7. Like its name suggests, a lava lamp is a good model of Earth's convection currents. The semi-fluid material inside the lamp could represent the mantle. The heat source at the lamp's base could represent heat from Earth's core. A bubble starts at the bottom of the lamp, slowly rises, and then sinks again. Explain, step by step, the forces that affect the movement of fluid bubbles in the lava lamp.

1.2 Early Life

Figure C1.9: An outcrop of ancient sedimentary rock is one of the highlights of Cameron Falls.

Cameron Falls is a popular sightseeing spot in Waterton Lakes National Park, which is located in southwestern Alberta. In Figure C1.9 you can see a stunning outcrop of Alberta's oldest **sedimentary rock**. You can see layer upon layer of sediment compressed into solid rock. The properties of the sediments, and the **fossils** preserved in each **strata**, provide evidence about the type of environment that existed when they were deposited 1.5 billion years ago.

sedimentary rock: rock formed from compressed layers of pre-existing rock or organic matter

fossil: the evidence or remains of ancient life preserved in Earth's crust

strata: the layered bands within sedimentary rock

An Ancient Coast

By studying the processes that form sedimentary rocks in the present, geologists suspect the sediment that formed the layers at Cameron Falls must have been deposited at the mouth of a river flowing into an ancient ocean. Similar Precambrian sedimentary rock formations along the Rocky Mountains indicate that several large rivers deposited sand, clay, and silt into an ancient ocean. A sandwich of sedimentary rock 11 km thick is currently evident.

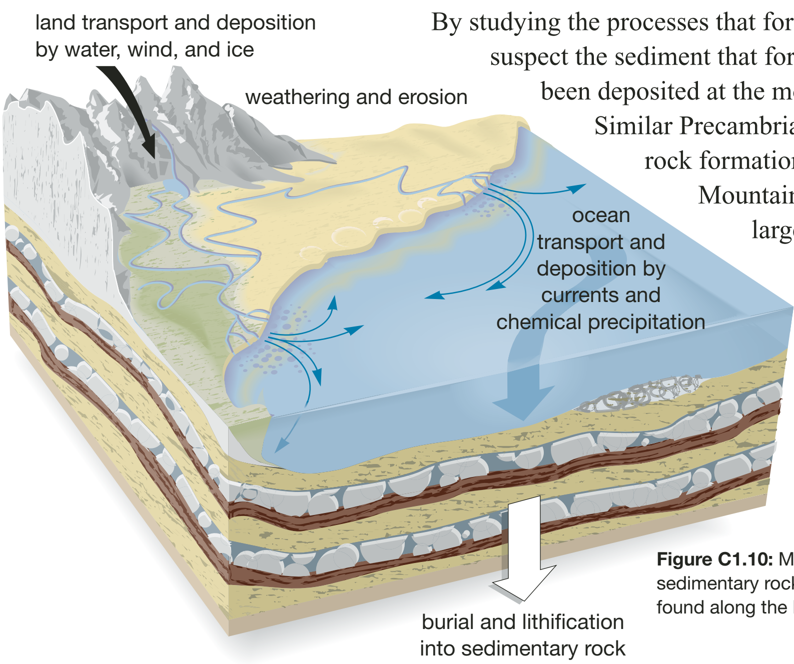


Figure C1.10: Many Precambrian sedimentary rock formations have been found along the Rocky Mountains.

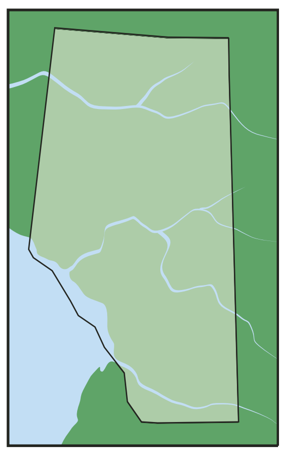


Figure C1.11: Alberta may have looked like this 1.5 billion years ago.

DID YOU KNOW?

Geologists in the nineteenth century attempted to measure the age of Earth by using rates of sedimentation. They theorized the sediment was like sand falling through an hourglass. If you knew the thickness of the sedimentary rock and the rate of sedimentation, you could calculate how long the rock took to form. More than 100 years ago, geologists attempted to determine the age of rocks—and even the age of Earth itself—by using rates of sedimentation. Their calculations did yield numbers in the millions of years, opening the door for the theory of deep time. But these scientists were nowhere near the current value of 4.5 billion years. The assumptions upon which the calculations were based just didn't hold up.

Practice

4. A geologist finds that a present-day river, similar in size to the one thought to have existed at Cameron Falls 1.5 billion years ago, deposits sediment at a rate of 1.0 cm/a. Use this measurement to calculate the time it took to deposit Alberta's 11-km thick sandwich of Precambrian sedimentary rock strata.
5. List assumptions you have to make to perform the calculation in question 4.

Life Gets Its Start

Before looking at the fossil evidence for early life in the rock layers at Cameron Falls, you should consider the evidence from even older fossils found in other places. The world's oldest evidence of life dates back 3.8 billion years. Life may have existed before that, but there is no fossil evidence to support this. Although there is still plenty of debate within the scientific community concerning just how and when life began on Earth, scientists generally agree that the earliest life forms were single-celled bacteria approximately 3.8 billion years ago.

3.8 billion years ago:
first sign of life on Earth

stromatolite: a layered structure built by cyanobacteria

cyanobacteria: microscopic, photosynthetic, single-celled bacteria

Hot Oceans

Early Earth was a hostile place, with frequent volcanic eruptions and poisonous gases, such as methane and hydrogen sulfide. The oceans were extremely hot—more than 100°C—and the atmosphere contained little oxygen. At one time, scientists believed that life under these conditions would have been impossible. But recent studies of current, similar environments have revealed a group of extreme bacteria-like organisms that tolerate the heat and live on poisonous gases.

One of the first discoveries of these creatures, now called *Archaea*, was in the boiling waters of a hot spring in Yellowstone National Park. (See Figure C1.12.) Later, similar creatures were found living in water exceeding 150°C near deep-sea thermal vents.

Figure C1.12: Scientists are sampling a volcanically heated pool for *Archaea*.

Deep-sea thermal vents release intense volcanic heat and hydrogen sulfide gas. Despite these hostile conditions, the *Archaea* organisms living near these vents thrive by feeding on the hydrogen sulfide—a gas deadly to humans. This group of extremist life forms may be the closest living relatives of Earth's earliest life.

Making the Atmosphere Breathable

When the layers of rock at Cameron Falls started to form 1.5 billion years ago, the surrounding area was thought to be a large, shallow mud flat where a large river drained into an ancient ocean. Fossil evidence in the form of **stromatolites** indicates that **cyanobacteria** lived in the tropically warm, shallow waters along the coast of ancient Alberta.

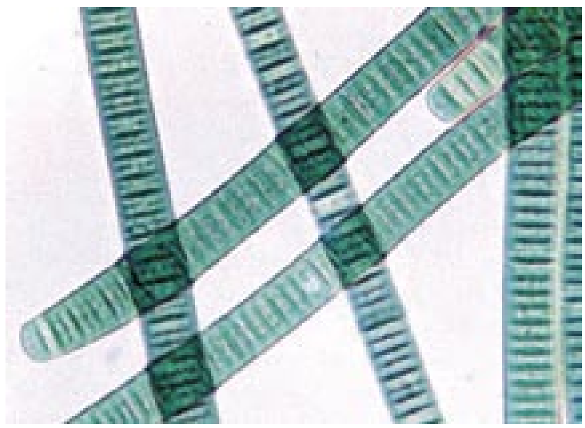


Figure C1.13: Cyanobacteria are single-celled creatures similar to Earth's first photosynthetic organisms.

By growing and dying one layer on top of the other, the cyanobacteria slowly deposited layer after layer of calcium carbonate—the main ingredient of limestone and your bones—leaving large mounds, called stromatolites, that are 10 to 30 cm across and up to 1 m tall. Stromatolites are the remains of the calcium carbonate layers, not the cyanobacteria themselves. This makes stromatolites an example of a **trace fossil**.

trace fossil: indirect fossilized evidence left by ancient organisms rather than the organisms themselves

Figure C1.14: Alberta's oldest fossils are stromatolites.

1.5 billion years old: Alberta's oldest fossils

A Source of Oxygen

Cyanobacteria, such as those that built Alberta's stromatolites, played a key role in making Earth livable for other organisms. Scientists believe that they were one of the only early producers of oxygen. The earliest direct evidence of cyanobacteria—found at Isua Rock in Greenland—dates back 3.7 billion years. Cyanobacteria may have been the first organisms to use a complex molecule, called chlorophyl, to trap the Sun's energy, which is needed to make glucose out of carbon dioxide and water.

Practice

6. Identify the process that uses the Sun's energy to make glucose from carbon dioxide and water.
7. Refer to question 6. Identify the by-product of the process.

Stromatolites and other fossil evidence indicate that cyanobacteria were the dominant form of life on Earth for two billion years. Despite the microscopic size of each individual, these creatures have collectively had a tremendous impact on the whole planet because they are largely responsible for creating Earth's atmospheric oxygen. Some people would argue that the creation of today's oxygen-rich atmosphere is one of the most significant events in geological time.

This is due to the atmosphere's impact on the evolution of future life and because of the spinoff effects on the planet's geology. In the next investigation you will have an opportunity to explore the impact of Earth's oxygen-rich atmosphere on geological phenomena.

Investigation
The Early Atmosphere

Science Skills
✓ Analyzing and Interpreting

Problem

What does banded iron tell you about oxygen in Earth's atmosphere during the Precambrian Era?

Read the following background information.

Banded Iron Formations: Indicators of Oxygen

A type of iron ore, called banded iron, is instantly recognizable for its alternating layers of red and grey. It's of special interest to the mining industry as a source of iron to make steel. Banded iron is a sedimentary rock formed by sediment sinking to the bottom of an ocean. Banded iron formations from around the world range in age from 1.8 billion years to 3.8 billion years. The red layers contain iron (III) oxide, $Fe_2O_3(s)$, commonly called rust. The grey layers contain silica and other minerals.

The iron (III) oxide found in the red layers is produced by dissolved iron ions that have been weathered from continental rocks and carried by a river to the ocean. If oxygen is present, the iron ions react with it to form an oxide of iron.

$$4Fe^{3+}(aq) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

Iron oxide is an insoluble precipitate and sinks to the bottom of the ocean as part of the sediment. Iron oxide forms when oxygen is present. This results in the red layers in the banded iron. Iron oxide does not form when oxygen is not present. This results in the formation of grey layers. Therefore, iron acts as a chemical indicator of oxygen in Earth's early atmosphere.

Figure C1.15: Banded iron is a sedimentary rock.

Analysis

1. Identify the likely source of oxygen required to form the iron (III) oxide found in red layers of banded iron formations.
2. The oldest banded iron formations are 3.8 billion years old. Rock layers below these do not contain iron (III) oxide.
   - **a.** Infer what this suggests about the oxygen level in Earth's atmosphere before the banded iron was deposited.
   - **b.** Banded iron formations of less than 1.8 billion years old are extremely rare. Sedimentary rock layers deposited on top are all rich in iron oxide, but there is no evidence of the striped iron bands. Conclude what this evidence suggests about atmospheric oxygen after the banded iron was deposited.
   - **c.** Describe the atmospheric oxygen levels during the time of banded iron formations.

Snowball Earth

Late in the Precambrian Era, early life barely survived during the most significant ice age ever. Icecaps covered most of the planet for nearly ten million years. This time period is often called "Snowball Earth." The oceans froze solid except for small pockets of water that stayed in liquid form due to heat escaping from Earth's mantle. Evidence of glaciers advancing and retreating is found in late Precambrian rocks all over the world, including Alberta's Rocky Mountains. Some scientists believe that the stresses placed upon organisms as the result of changes in their habitat during this deep freeze, and the thaw that followed, may have resulted in an explosion in species diversity that led to the first complex creatures.

1.2 Summary

By the end of the Precambrian Era, nearly 90% of Earth's history had passed. Earth had been born out of clouds of dust. The first producers, cyanobacteria, transformed the atmosphere. They left behind stromatolite mounds and banded iron deposits as indirect evidence of their existence. Direct evidence, such as fossil imprints found in the Rocky Mountains, reveals that stromatolites now shared their shallow waters with multicellular creatures, like small jellyfish, worm-shaped animals, and early plants. Life had taken a long time to start. Finally, the stage was set for the next major section of time —the Paleozoic Era—initiated by an explosion of new and bizarre creatures that populated Alberta's shoreline.

Figure C1.16: The fossils (from left) are of jellyfish, worm-shaped animals, and ferns.

1.2 Questions

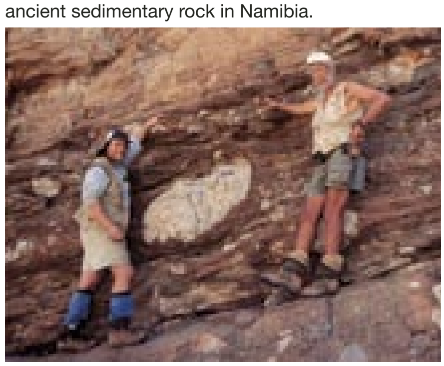
Knowledge

1. Describe how sedimentary rocks form.
2. Outline the significance of Alberta's Precambrian sedimentary rock formations.
3. Summarize the evidence that present-day Alberta was a hot, tropical, coastal area 1.5 billion years ago.
4. Describe Earth's first living creatures.
5. How old are the earliest signs of life?
6. Describe the environment in which Earth's first creatures lived.
7. Describe Alberta's oldest fossils. What did they look like? How were they built?

Applying Concepts

8. Figure C1.17 shows two geologists posing by a 700 million-year-old sedimentary rock in Namibia. These big, embedded rocks are the type that glaciers pick up and carry with them as they flow. These types of glacial deposits are found in many parts of the world in rocks of this time period.
   - **a.** Define the climate theory supported by these global glacial deposits.
   - **b.** Just above the geologists' hands are sedimentary layers of limestone known only to be deposited in warm seas. What do these limestone deposits indicate?

Figure C1.17: These geologists are standing by ancient sedimentary rock in Namibia.



1.3 Strange Rocks

Just south of Lethbridge you can find the Bearspaw Rock Formation. This layer of sedimentary rock contains a rare mineral called ammolite, often called *Alberta's Gemstone*. The raw material for this gemstone is a common fossil found in rocks worldwide. What makes this spot rare is that conditions were ideal to preserve these fossils in a way to give them a quality desired by jewellers.

Figure C1.18: The source for ammolite is a fossil called ammonite.

Try This Activity

Take a Wild Guess!

Identify which modern group of animals the ammonite fossil in Figure C1.18 is most closely related to—bighorn sheep, snakes, snails, or squid.

Science Skills

✓ Analyzing and Interpreting

Look up the answer in the Lesson Answers. Were you surprised at the answer? If you made the wrong choice, determine what led you to the wrong interpretation.

Early Explanations

Rocks that resemble living creatures have always made people curious. For centuries, enthusiasts have travelled the countryside amassing large collections of these little treasures. By the seventeenth century, naturalists had begun to classify fossils but were still unsure of their origins. Figure C1.20 shows beautiful drawings of ammonites published by Robert Plot in his 1677 book *The Natural History of Oxfordshire*.

Figure C1.19: The world's largest ammonites measure up to 1 m in diameter!

Until recent times, the belief that these fossils were the remains of once-living creatures was not widely agreed upon. Few people could imagine the process of fossilization in which organic materials turned into stone.

Figure C1.20: Robert Plot drew ammonites.

DID YOU KNOW?

Shark-tooth fossils are so common because all shark species continually shed their teeth. One tiger shark can shed as many as 24 000 teeth in its lifetime!

Basic Questions

In the latter part of the seventeenth century, Nicolas Steno, a trained physician who travelled all over Europe, finally settled in Florence, Italy. While dissecting a large shark's head in Florence, he noticed that the teeth strongly resembled rocks often called *tonguestones*, which he had seen on his travels. This name was given because they looked like dragon tongues. Steno proposed that tonguestones were actually remnants of once-living shark teeth. Although this was a keen observation, he didn't stop there. Instead, he followed up his observation by asking some very basic questions. How can fossilized shark teeth become imbedded in rock that is on land high above sea level? What process caused these teeth to become fossils embedded in solid rock?

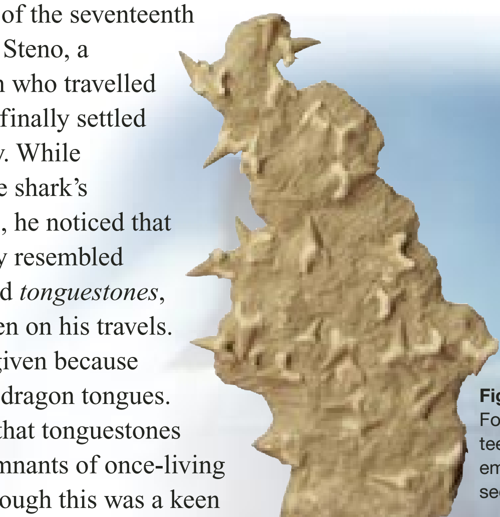


Figure C1.21: Fossilized shark teeth can become embedded in sedimentary rock.

As you answer questions 8 and 9, you can retrace the reasoning Steno used to sort out the mystery of how marine fossils could be found on land.

Practice

8. Look at the fossilized shark teeth in Figure C1.21. How could undamaged solid shark's teeth become embedded in sedimentary rock, which is also solid?
9. Hypothesize about which was deposited first—the shark teeth or the strata below the shark teeth. **Remember:** A good hypothesis includes a reason.

Questions like Practice questions 8 and 9 led Steno to a hypothesis geologists now call the **law of superposition**. It provides a way for geologists to keep track of the order in which rock layers formed. This process is called **relative dating**. Relative dating determines which rock layers are older and which are younger. For instance, you could give a relative date to the clothes in a laundry basket. The clothes at the bottom of the basket must be the oldest because they were deposited first. Clothes on the top must be the youngest because they were deposited last. By using this reasoning, you can determine the relative ages of the clothes (which are older or younger) by examining the basket's strata. In geology, the pattern of rocks in a strata is called the **stratigraphic sequence**.

An exception to the law of superposition can occur when large, underground bodies of magma force hot molten rock to invade cracks found in the sedimentary rock. The invading rock is called an **intrusion**. Since the intrusion was formed by molten rock forcing its way into the cracks of pre-existing rock strata, the intrusion must be younger than the surrounding rock.

law of superposition: a law stating that higher strata in a sequence of rock layers are younger than lower strata

relative dating: the process of placing rocks and geological structures in the correct chronological order

stratigraphic sequence: a sequence of rocks that provides a chronological record of a region's geological history

intrusion: a body of rock that forms from the invasion of magma into a pre-existing rock formation

Practice

During his travels, Steno observed many outcrops of sedimentary rocks with distinct strata.

10. Determine the relative age of each of the minerals in the stratigraphic sequence in Figure C1.22.

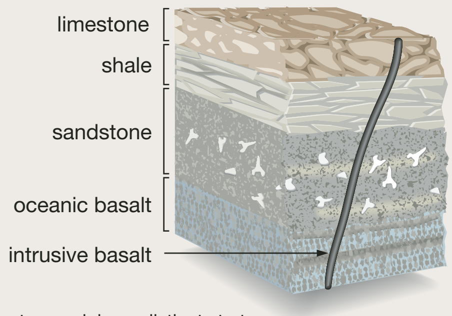
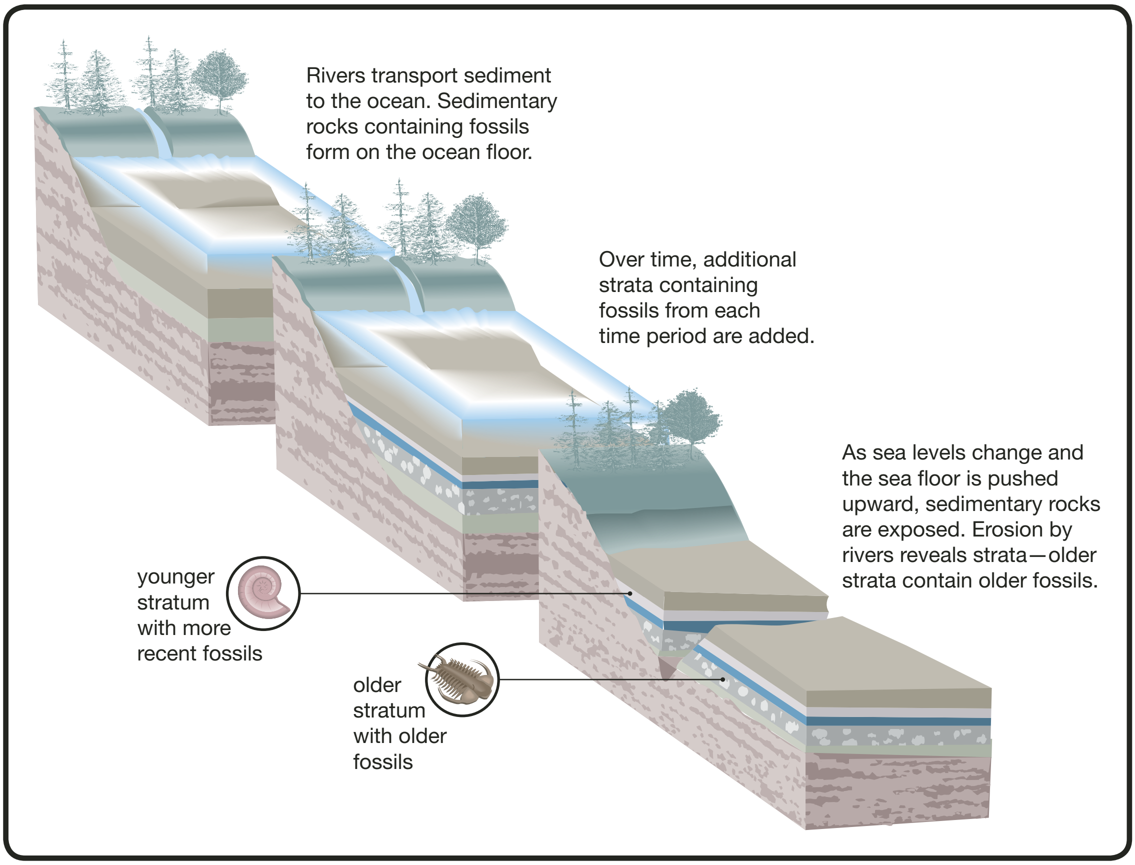


Figure C1.22: Many outcrops of sedimentary rock have distinct strata.

Formation of Sedimentary Rock



Utilizing Technology

Pulling It All Together

Science Skills
✓ Initiating and Planning
✓ Communication and Teamwork

Purpose

Work with other students to develop a concise presentation using either PowerPoint® or a poster to explain the answer to one of Steno's basic questions: "How can fossilized shark teeth become imbedded in rock that is on land high above sea level?"

Procedure

step 1: Plan how many diagrams will be a part of your presentation, what information will be included in each diagram, and what should be communicated in the captions accompanying each diagram.

step 2: Divide the tasks equally among the group members, and complete your first draft of the presentation.

step 3: Locate the handout "Fossilization of Shark Teeth" on the Science 20 Textbook CD. Compare your presentation to the information on this handout. Make any necessary corrections or improvements to your presentation to bring it to second-draft status.

step 4: Share your presentation with at least one other group by asking that group to name three things that you did well, and three things to consider changing for next time.

step 5: View the presentation of at least one other group. Tell that group about three things that they did well, and three things to consider changing for next time.

Evaluation

1. Given the feedback provided by the other group, how would you evaluate your group's presentation?
2. Given the presentation you saw from the other group, what improvements could you add to your own presentation?

Try This Activity

Making a Fossil

Science Skills
✓ Performing and Recording

In "Pulling It All Together" you explored the process of how a shark's tooth could become imbedded in rock that is on land high above sea level. In Chapter 2 you will have an opportunity to participate in the next step of examining fossil evidence to determine the characteristics of the original object. To prepare for the next chapter, you will need to make a fossil that can be used by you and your classmates.

Purpose

It is the purpose of this activity to make an impression of an everyday object using plaster of Paris. Only you and your partner should know the identity of the item—this is because your classmates will try to identify it only from the impression it leaves in the plaster of Paris.

Materials

- plaster of Paris
- water
- foam bowl to hold mould
- cooking oil spray (non-stick coating)
- felt-tipped pen with permanent ink
- newspapers or cardboard to collect dust and debris
- small object to embed in plaster (e.g., a toy soldier, bone, or leaf)
- lab aprons

Procedure

step 1: Label the bowl with the name of you and your partner.

step 2: Mix water with the plaster in the bowl or container so that the bowl is about half full.

step 3: Spray the object with cooking oil and place it on top of the plaster. Make sure there are no air bubbles under the object. Spray a coating of cooking oil on top of the plaster and the object, and then add another plaster layer.

step 4: Set the object aside until you are ready to start Chapter 2.

Rocks Keep a Record of Events

You can use the principle of relative dating to put clothes in a laundry basket in the correct chronological order, but you can't use it to determine how many hours or days ago an individual item was put in the basket. In the same way, by having evidence that younger layers of sediment are deposited on top of older layers, geologists can assign relative dates to fossils and events present in the layers. The main limitation of relative dating is that it does not reveal the **absolute age** of events or fossils.

absolute age: the number of years that have elapsed since an event occurred

Practice

Use Figure C1.23 to answer questions 11 and 12.

Figure C1.23: This road in Hawaii had to be closed because lava from an active volcano spilled over it.

11. Determine the relative age of the lava and the road.

12. Explain why you cannot precisely determine the absolute age of the road or the lava on the road.

Smith's Observations

Using Steno's law of superposition, early geologists had a fundamental tool needed to rank strata—and the fossils and events they contained—in chronological order. What was lacking was a way to construct a unified history of Earth's crust for entire regions or maybe even the entire planet. It took more than 100 years before an English surveyor supplied the key discovery.

William Smith (1769–1839) travelled all over England as a surveyor. One of his biggest jobs was acting as a surveyor for a canal project. Surveyors were important because diggers had to know what types of rocks to expect. Smith carefully examined the rock strata at many dig sites. His careful observations led him to develop a remarkable hypothesis. Smith noticed that certain distinctive fossils kept re-appearing at each surveyed location.

Further, these distinctive fossils always appeared in the same order within the layers of rock at each location.

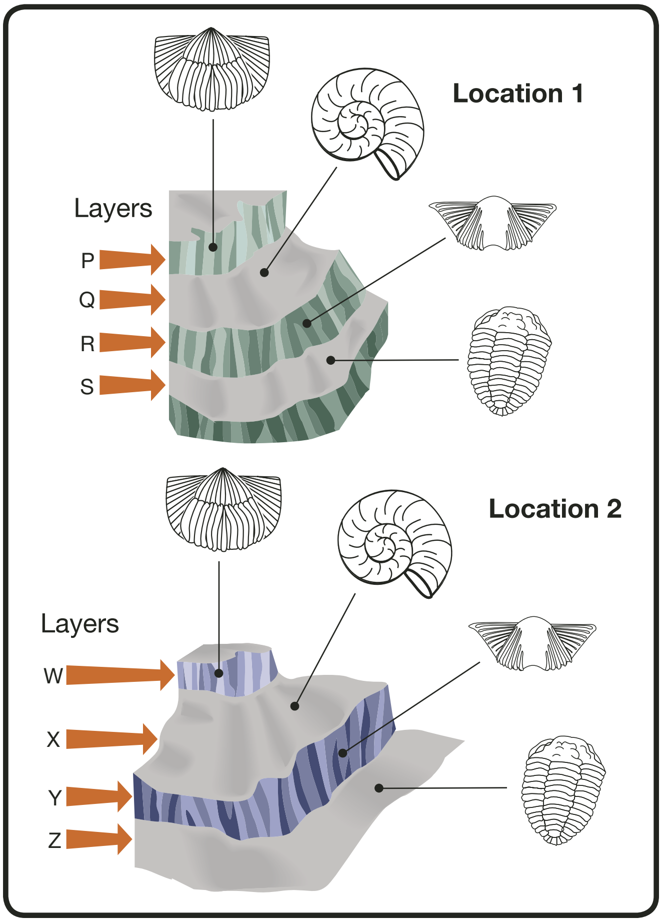


Figure C1.24: The same pattern of fossils is shown in two different locations.

If a distinctive fossil existed only for a limited period of time, then rocks containing that fossil must correspond closely in age with other rocks that contain that same fossil. These distinctive fossils are like an index; they establish a common time of origin for widely dispersed rock layers. That's why these fossils are called **index fossils**.

index fossil: a fossil used to determine the relative age of a layer in a stratigraphic sequence or to match stratigraphic sequences from different locations

Practice

13. Examine Figure C1.24 closely.

a. Determine the oldest layers of rock at Locations 1 and 2.

b. Determine the youngest layers of rock at Locations 1 and 2.

c. Conclude which layer in Location 1 contains rock of roughly the same age as the rock in layer X of Location 2.

A Big Puzzle

Over many years, Smith travelled around England observing and recording stratigraphic sequences and matching them together by using a variety of index fossils. In 1815, Smith published his greatest achievement as a scientist—the first complete geological map of England. Due to his relatively humble beginnings and education, Smith's contribution was largely ignored when it was published. It would take a new generation of geologists to finally recognize his profound impact. Smith finally received a major award for his work at age 62. This was 16 years after the original publication of his geological map.

Investigation

Matching Rock Strata from Different Locations

Problem

Can stratigraphic sequences from different locations be matched by using index fossils to form one larger sequence?

Materials (for each group of students)

- scissors
- handout called "Eight Fossil Cards" from the Science 20 Textbook CD
- handout called "Assembled Stratigraphic Sequence" from the Science 20 Textbook CD

Procedure (for each group of students)

step 1: Use the scissors to cut out the eight fossil cards from the handout.

step 2: Place the fossil card with the letter M in the lower left-hand corner of your workspace. This represents the oldest rock layer, so it is on the bottom.

step 3: Find a rock layer on a fossil card that contains at least one of the fossils you found in the oldest rock layer. This rock layer is younger, as indicated by the presence of a new fossil species. Place this rock layer above the oldest rock layer.

step 4: Repeat the process outlined in step 3 to select a fossil card to be the third rock layer.

step 5: Check your work. If a fossil is present in layer 1, it should not disappear from layer 2 and then re-appear in layer 3. Since extinction is forever, once a fossil disappears from the fossil record it does not return. If necessary, re-adjust the fossil cards you chose for layers 2 and 3.

step 6: Repeat the previous three steps for each of the remaining fossil cards. When you are finished you should have the rock layers assembled into a stratigraphic sequence.

Analysis and Interpretation

1. Use the letters on the cards to list the sequence of cards from youngest to oldest.
2. Conclude if the youngest sequence should be at the top or the bottom. Identify which scientific law you must apply to answer this question.
3. Identify what type of dating is used in this investigation.
4. Evaluate the main limitation of this kind of dating.

Science Skills

✓ Initiating and Planning
✓ Performing and Recording
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Reporting Your Results

5. Use the handout titled "Assembled Stratigraphic Sequence" to summarize your findings. Draw arrows to represent the part of the fossil record in which the organism lived. Remember, it should be one continuous arrow. If there are breaks in the arrow, you have assembled the sequence incorrectly.
6. In paragraph form, write a short report that answers the following questions:
   - How did your group assemble the fossil record?
   - Which species make the best index fossils?
   - Why should these species make good index fossils?
7. Explain how index fossils might be used to estimate the age of newly discovered fossils.

The Grand Record

A useful index fossil appears only briefly in the geological record, has a wide geographical distribution, and is easily recognizable. During the nineteenth century, geologists used index fossils to assemble a generalized relative time scale for all of Earth. The entire sequence is not preserved in any one place, so sequences from all over the world were used to assemble an ideal stratigraphic column that generalizes Earth's entire history. Today, the idealized sequence is called the Geological Time Scale (shown in Figure C1.25). The Geological Time Scale is divided into four major eras: Precambrian, Paleozoic, Mesozoic, and Cenozoic. A massive disappearance of fossils and an unexplained appearance of new fossils mark the boundary between each era. Each era is broken down into smaller divisions called periods. In some cases, periods are broken down into epochs. To this day, geologists continue to debate and refine details of this time scale.

Geological Time Scale

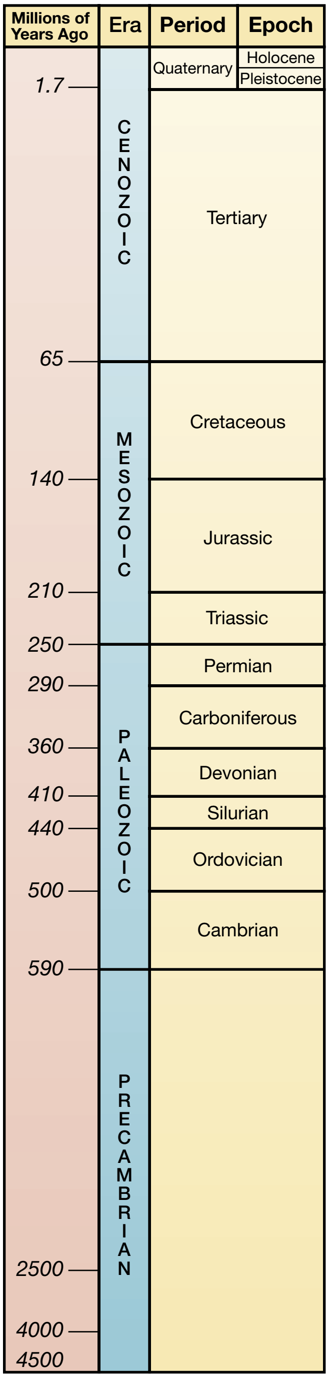


Figure C1.25: You can also find the Geological Time Scale on page 557, and it is also a handout.

An Idealized Rock Column for Alberta

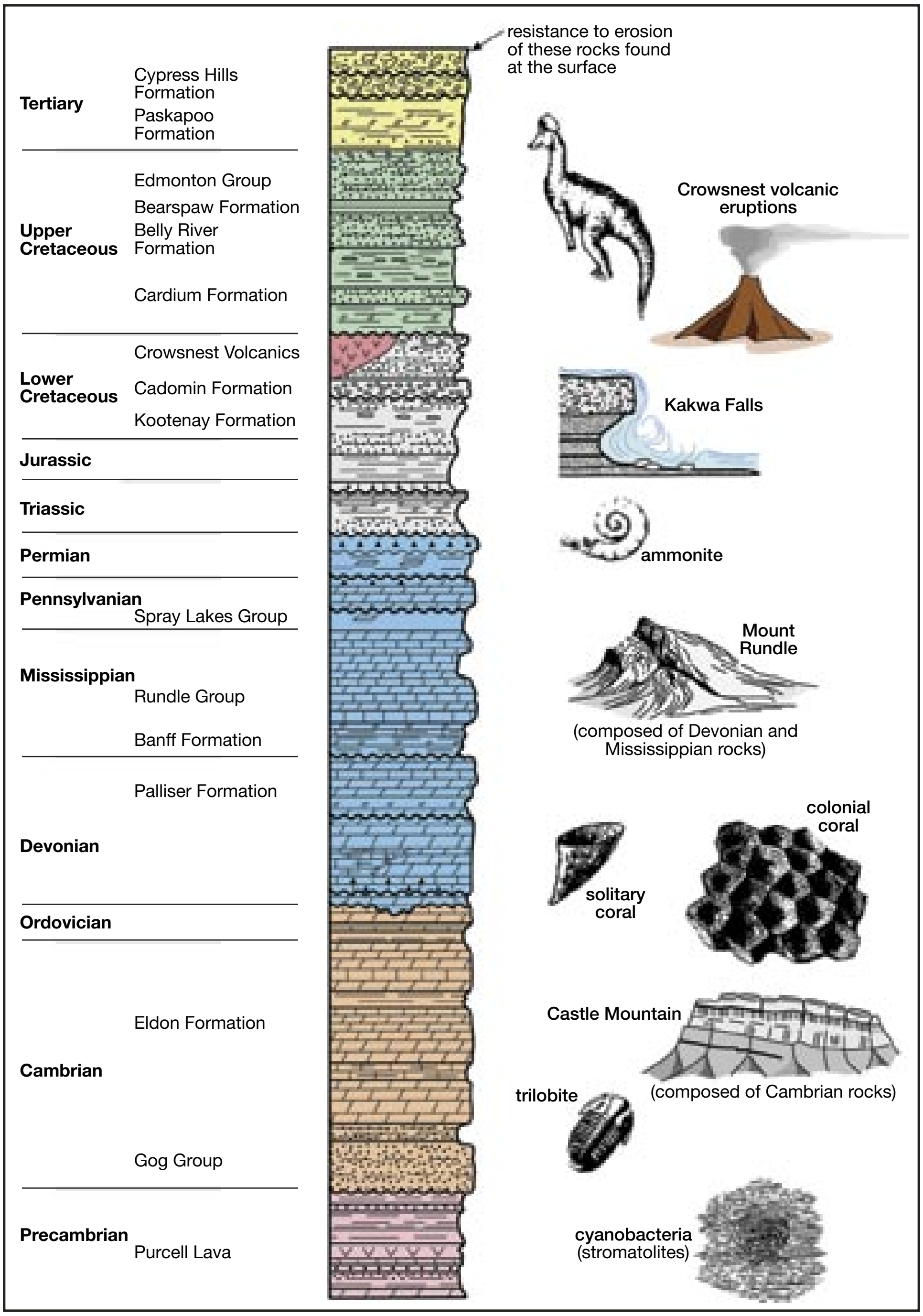


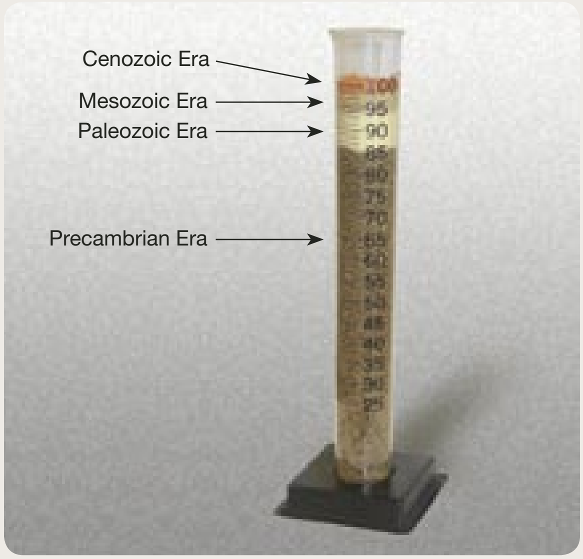
Figure C1.26: This idealized rock column for Alberta does not completely exist in any one place. It is pieced together from outcroppings all over the province.

Try This Activity

Hourglass of Time

The Geological Time Scale is almost never drawn with proper dimensions. This is simply for convenience. Although the Precambrian Era comprises nearly 90% of the time scale, fossil evidence is scarce. Conversely, much more is known about the Cenozoic Era because it is the most recent one. In this activity, each colour of sand represents one of the four eras and the volume of sand approximates the amount of time for that era.

Sketch a diagram of the graduated cylinder filled with sand. Label each era, and include the time it started and the time it ended.



Science Skills
✓ Performing and Recording

1.3 Summary

Throughout history, fossils have made people curious. However, it wasn't until the seventeenth century that a physician named Nicolas Steno was able to figure out that fossils are the remains of once-living species. He also proposed one of the fundamental laws of geology—the law of superposition. This law states that a particular rock layer is younger than the layers below it. This provided geologists with a way to order events. It was still a challenge to compare strata from one location to strata at another place. This problem was solved by William Smith's discovery of index fossils. Work with index fossils eventually led to the creation of a stratigraphic column for all of Earth, called the Geological Time Scale. Geologists use this scale to summarize Earth's history according to fossil evidence. Its largest division is eras, which are broken down into periods.

1.3 Questions

Knowledge

1. Summarize the contributions of Nicolas Steno and William Smith to the field of geology.
2. Identify the qualities of a useful index fossil.
3. List the four eras of the Geological Time Scale.

Applying Concepts

4. a. Calculate the percentage of Earth's history for each era. Round all answers to the nearest percent.
   b. Using the percentages calculated, sketch a pie chart of the four eras.
5. Use your calculations from 4.a. and 4.b. to determine whether the Geological Time Scale shown in Figure C1.25 is drawn to scale.
6. Describe the criteria geologists use to divide the Geological Time Scale into eras.
7. Identify the name for the subdivisions of an era.
8. Identify which period is more recent—the Triassic or the Permian.
9. Which epoch you are living in?
10. The last ice age was called the Pleistocene Ice Age. Identify the period in which it appeared.

1.4 Getting a Handle on Time

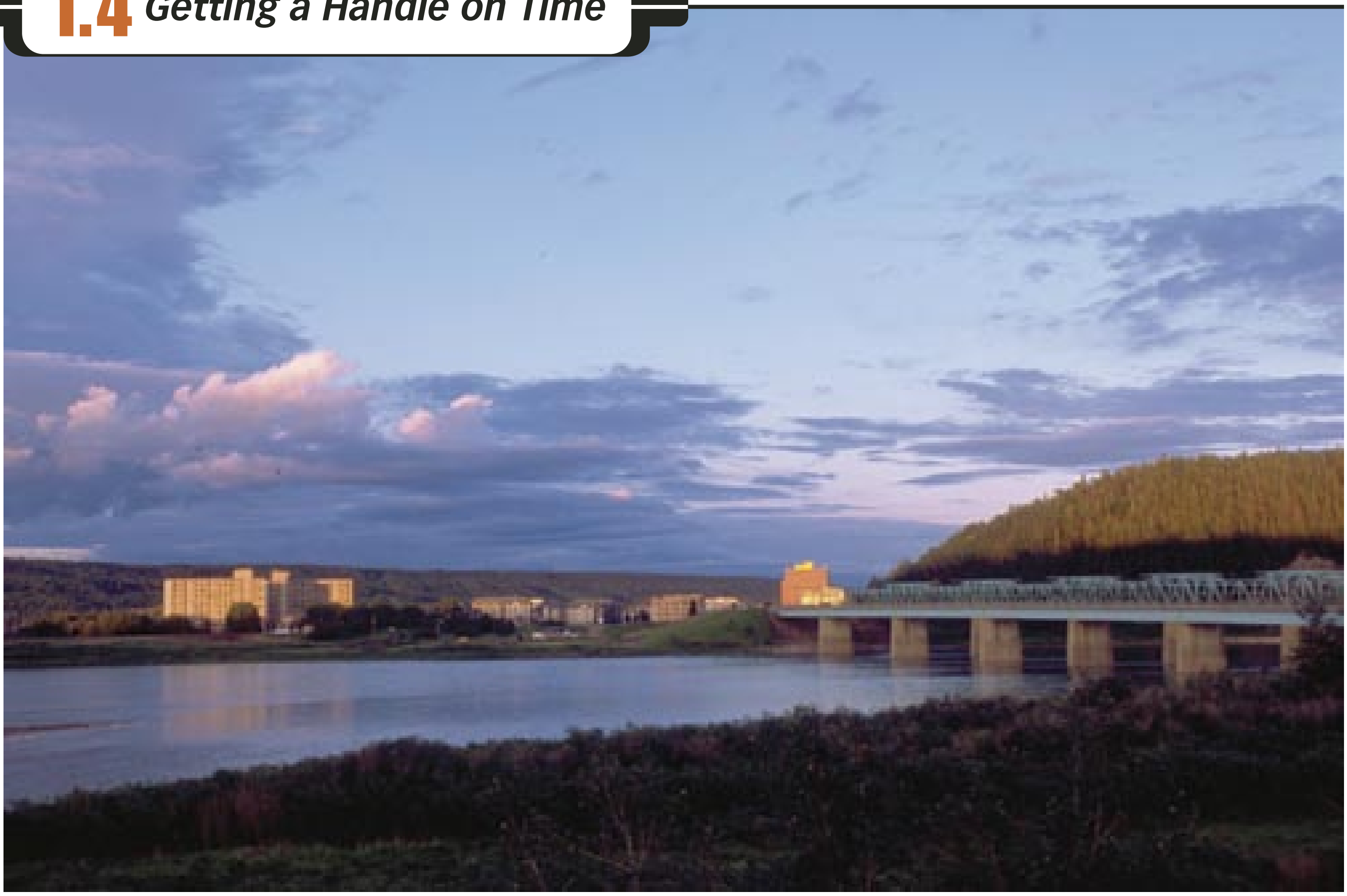


Figure C1.27: Fort McMurray is located at the junction of the Clearwater and Athabasca rivers.

In addition to its proximity to Alberta's oil-sand deposits, which is the world's single largest deposit of oil, Fort McMurray is known for its picturesque setting in northern Alberta's boreal forest. Since it is located at the junction of the Clearwater and Athabasca rivers, local residents can take advantage of these watery highways. If you travel by canoe north along the Athabasca, you can actually see outcrops of oil sand protruding from the river bank. How did such a valuable resource become deposited in the ground under the forests that surround Fort McMurray? Did a catastrope occur that created the oil sands?

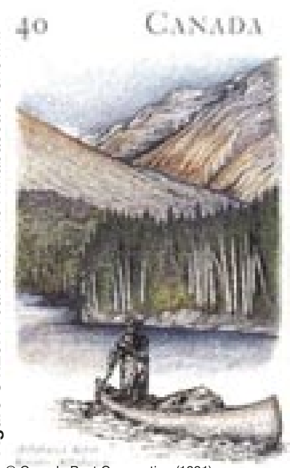


Figure C1.28: A canoe on the Athabasca is shown.

Figure C1.29: The Athabasca River flows through a major portion of Alberta.

Forces of Catastrophe

Figure C1.30: Catastrophism is a theory that cites major, violent disasters as the main forces that shape Earth. In this photo, people run from a tsunami that struck Hawaii in 1946.

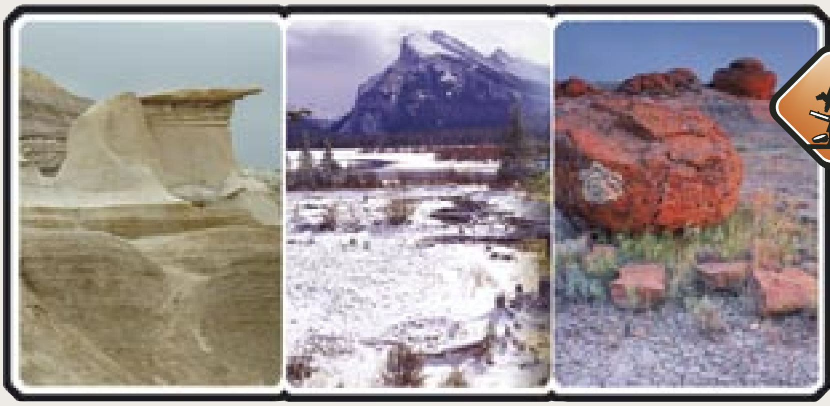
During the time of William Smith (1769–1839), and late into the nineteenth century, many geologists considered violent catastrophes such as earthquakes, volcanic eruptions, enormous floods, meteorite impacts, and upheavals of Earth's crust, to be the main mechanisms of past change. In fact, Smith himself proposed that the sedimentary rock layers he mapped were deposited over England by a series of catastrophic floods. These violent explanations are now called catastrophist theories. A main component of catastrophist theories in the eighteenth and nineteenth centuries is that they involve processes of a different type or intensity than those observed in the present.

Try This Activity

Imagine This: Catastrophic Events

Figures C1.31 shows some of Alberta's most distinctive landmark features. They make you think, how did that get there?

1. Using only catastrophic events, describe plausible explanations for the appearance of these three geological features. You may have to use your imagination to think of events that could be responsible for each of these landmarks.
2. Ask your teacher or use the Internet to find the current scientific explanations of how these features formed. Distinguish the general differences between your catastrophic explanations and current scientific explanations.



Science Skills

✓ Analyzing and Interpreting

Figure C1.31: Note the landmarks from the left. The hoodoos near Drumheller resemble the surface of an alien planet. Majestic Mount Rundle towers over the town of Banff. Strange spherical rocks up to 2.5 m in diameter appear to be strewn about at Red Rock Coulee in southern Alberta.

How Much Time?

Early theories of catastrophism fit in well with human experience. If you ask an 80-year-old woman what changes she has noticed in the landscape during her lifetime, you may hear, "The trees are larger," or "The city sure has grown," or "It seemed to snow a lot more when I was younger."

In the time span of one lifetime, the processes that go on day to day seem too slow to lay down hundreds of metres of sedimentary rock or to lift up mountains. Perhaps catastrophist theories dominated geological discussions for well over 100 years because they fit in well with the common belief that Earth was only several thousand years old.

The processes at work in the present seem too weak and slow to explain evidence of a dramatic change in Earth's past. It's hard to imagine that the slow processes observed in the present could have resulted in the badlands, Mount Rundle, or Red Rock Coulee.

Complex Histories

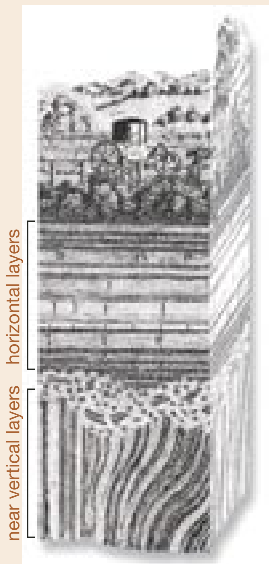


Figure C1.32: James Hutton observed complex geological histories recorded in rock strata.

James Hutton (1726–1797) was a geologist who had opinions contrary to the dominant catastrophist theories of his time. He believed that to unlock the mysteries of the past, you must understand the processes at work in the present. This was the birth of **uniformitarianism**, and Hutton's work is considered by many historians to be the birth of modern geology. Hutton travelled throughout the countryside of Scotland and documented the processes he observed. Because geological change occurs so slowly, he had to rely on rock strata as a record of past events. Hutton was aware of Steno's law of superposition and applied it to rock strata. As an example, he observed nearly vertical layers of rock beneath horizontal layers. This led him to first propose that the bottom layers were originally deposited horizontally but were subsequently tilted. Then, after a long period of erosion, many layers were deposited horizontally on top. The top surface of the lower vertical layers is called an **unconformity**. In this case, the unconformity was likely caused by erosion. If the erosion was caused by a retreating ice sheet, it would also explain the layer peppered with gravel and boulders above the unconformity.

uniformitarianism: the principle that the geological processes in action today have always fundamentally operated in the same way throughout Earth's history

unconformity: a surface in a rock sequence that represents a break in the pattern due to erosion or a lack of deposition

Practice

Figure C1.33 is a geological profile painted by James Hutton on one of his trips through the Scottish countryside.

14. Identify which layer in the painting is the youngest.

15. Identify which layer represents older rock—A or B. Justify your decision.

16. Why do you think the strata in the painting are tilted?

17. Identify the proper name of the surface labelled D.

18. Describe a process that may have created D.

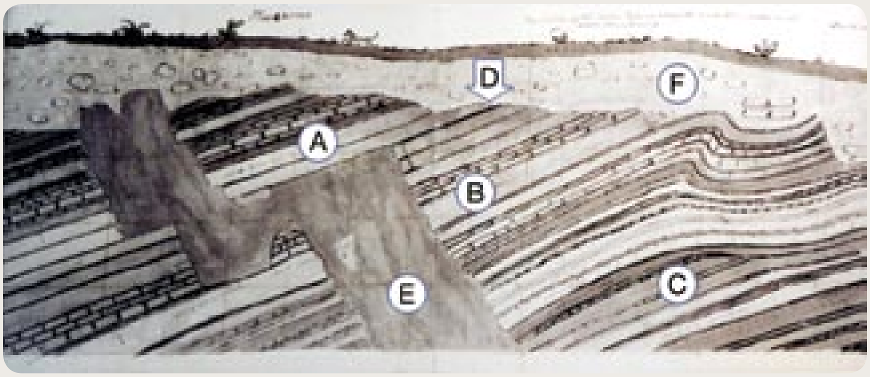


Figure C1.33: James Hutton painted geological profiles.

19. Rock structure E cuts across several sedimentary layers. Describe how structure E may have formed.

20. Is structure E younger or older than the rock in layer A? Justify your decision.

A Self-Sustaining System

Hutton published his theory that the geological process of Earth operates as a self-sustained system. He suggested that a subterranean fire deep within Earth provides a perpetual source of energy that creates and destroys material from the crust—Earth is a system that can remain in balance. Hutton's thinking started the modern understanding of how rocks form.

In the next activity you will see Hutton's theory in action by watching the applet "How Do Rocks Undergo Change?" from the Science 20 Textbook CD. Before you begin the applet, review the characteristics of the three basic types of rock you studied in previous science courses.

Type of Rock	How Formed	Where Formed	Example
Sedimentary	Sedimentary rock consists of eroded fragments of other rock types. The layers of sediment are compressed.	Sedimentary rocks are formed at the surface of Earth under relatively low temperatures.	
Igneous	Igneous rock forms when molten magma from the mantle intrudes into the crust or extrudes onto the surface.	Igneous rocks are formed deep within Earth's crust and mantle under extreme heat. The whole mantle consists of igneous rock.	
Metamorphic	Metamorphic rock forms when sedimentary or igneous rock is transformed at the molecular level by intense pressure and heat.	Metamorphic rocks are often formed at the sites of collisions between crustal plates.	

Utilizing Technology

How Do Rocks Undergo Change?

Purpose

You will observe the path of a rock travelling through the rock cycle and be able to summarize your learning by completing a rock-cycle diagram.

Science Skills

✓ Analyzing and Interpreting

Procedure

step 1: Explore the interactive features of the applet titled "How Do Rocks Undergo Change?" on the Science 20 Textbook CD by watching the main computer animations as well as the detailed visualizations.

step 2: Complete the rock-cycle diagram as directed at the end of the applet.

Analysis

Compare your rock-cycle diagram with other diagrams.

The Rock Cycle

As shown in the applet, rocks undergo change through a process called the **rock cycle**.

rock cycle: a concept that relates the continual change of rocks from one type to another

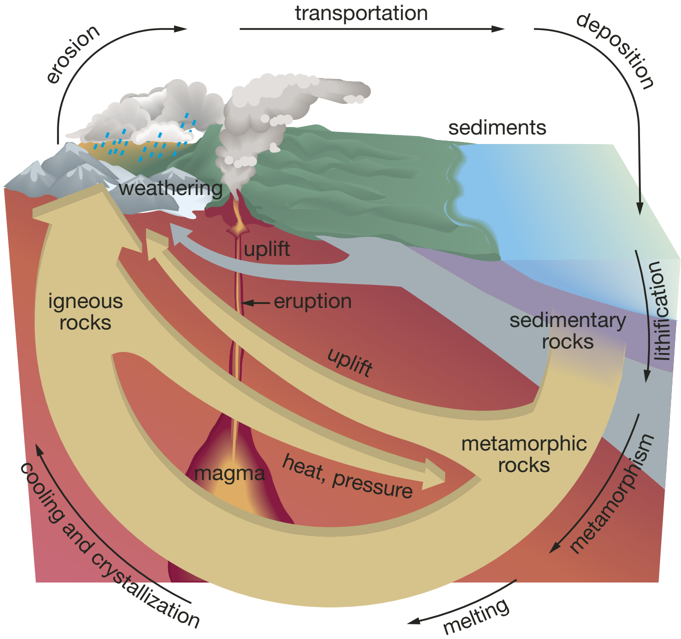


Figure C1.34: Rocks change by a process called the rock cycle.

According to Hutton, all rocks start out as molten magma within Earth's mantle. This magma cools and solidifies on or near the surface to form igneous rock. Rock on the surface is then weathered and eroded by water, wind, and ice to form sediments, which are later deposited to form sedimentary rock. Sedimentary rocks and igneous rocks can be transformed by extreme heat and pressure to become metamorphic rocks. Eventually, all rocks melt and return to the mantle. This is a perpetual, balanced cycle driven by energy released by nuclear reactions in Earth's core.

The Rise of Uniformitarianism

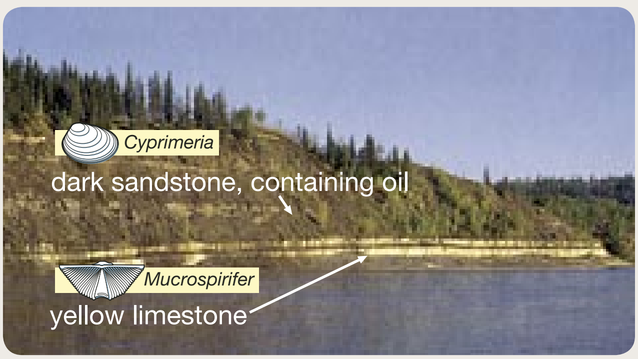
Hutton's theories took a long time to catch on in the scientific community. His theory of uniformitarianism was buried in a 2000-page book filled with difficult language. The geologist who brought Hutton's uniformitarianism to the forefront was Charles Lyell (1797–1875). Lyell added to Hutton's evidence and, using a much more readable style, continued to argue that geological evidence supported the theory of uniformitarianism.

He argued that processes, such as erosion, sediment deposition, volcanic action, and earthquakes have operated in fundamentally the same manner and intensity throughout Earth's history. Lyell helped build the Geological Time Scale by using index fossils. Lyell's methods and writing style greatly influenced young scientists, such as Charles Darwin.

Investigation

The Fort McMurray Unconformity

A striking contrast can be observed within the rock formations revealed along the Athabasca River. In one location, a brown layer of oil sandstone lies above a layer of bright-yellow limestone.



Purpose

You will account for the sudden change in colour between the yellow and dark-brown layers of the river bank.

Background Information

As shown on the previous page, the dark, oily sandstone sits atop bright-yellow limestone, which is only deposited in warm oceans. The yellow limestone contains the Devonian marine fossil *Mucrospirifer* (a brachiopod). The oily sandstone lying atop the limestone contains the Cretaceous Period marine fossil *Cyprimeria*. This fossil lived near coastal river deltas.

Figure C1.35: This is *Mucrospirifer's* environment.

Analysis

1. Use the Geological Time Scale to list the periods missing from Fort McMurray's geological record.
2. Determine the minimum number of years missing from the record.
3. Identify the proper name of the surface between the yellow and dark-brown layers.

Science Skills

✓ Analyzing and Interpreting

Research

4. Analyze which geological processes could account for the sudden change in colour between the yellow and dark-brown layers on the Athabasca River bank near Fort McMurray. Use the Internet to collect information. Your answer should take the form of a brief story about the geological history of the Fort McMurray area. Include the cause of the unconformity. Was the cause catastrophic, or does it fit better with the theory of uniformitarianism? Support your account with evidence.

1.4 Summary

Studying Earth's history is challenging because it occurs on such a large scale—billions of years are recorded in thousands of rock layers. A careful observation of processes that yield barely noticeable changes over an entire lifetime is required. Yet, these processes are relentless. Given enough time, they have completely changed the face of Earth many times.

As you'll see in Chapter 2, geologists suspect that Alberta's resource wealth, whether in oil sands or conventional petroleum reserves, can be traced back to microscopic plants and animals that lived in warm tropical seas more than 300 million years ago. It is speculated that the work of bacteria, followed by millions of years of heat and pressure, transformed the organic matter into Alberta's black gold.

Hutton's and Lyell's theory of uniformitarianism stated that the changes of the past could be explained by geological processes still in operation. Many of these processes are summarized in the rock cycle, which explains how the three major rock types—igneous, sedimentary, and metamorphic—form and change. These two scientists also helped to show that rock strata forms a record that has taken millions of years to develop.

1.4 Questions

Knowledge

1. Define *catastrophism*.
2. Define *uniformitarianism*.
3. Why did James Hutton believe Earth was infinitely old?
4. How does each of the three main rock types form?

Applying Concepts

Use Figure C1.36 to answer questions 5 to 9.

5. Determine which fossil in Diagram 1 is older—the one in A or B. Explain your reasoning.
6. List the layers in Diagram 2 from oldest to youngest.
7. Explain the cause of unconformity in Diagram 2.
8. Determine which layer in Diagram 2 is approximately the same age as layer A in Diagram 1. How can you tell?
9. Based on the rock strata, relate a brief story that explains the geological history of the land area shown in Diagram 3.

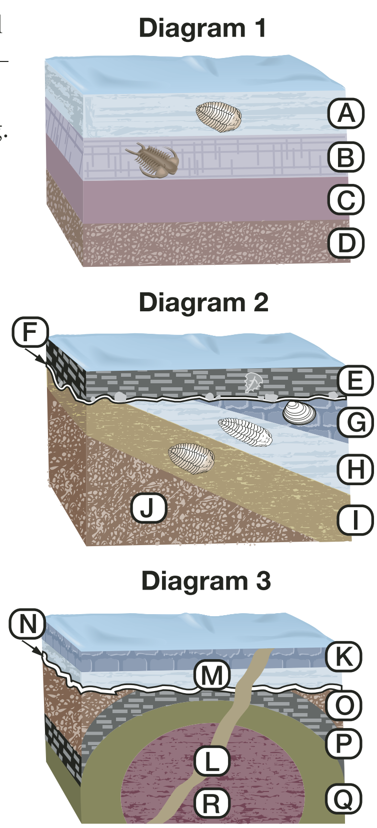


Figure C1.36: Geological history can be told by observing fossils.

1.5 Pinpointing Time

Figure C1.37: Geologists in the late nineteenth century generally agreed that Earth was millions of years old, but there were no accurate methods to measure the absolute age of Earth.

A Question of Time

As the nineteenth century was drawing to a close, the assembled geological record had been built upon accepted principles of relative dating. The increased acceptance of the theory of uniformitarianism had opened peoples' eyes to the concept of deep time. Most geologists accepted that Earth was at least millions of years old. Still, the problem remained: How deep was deep time? There were no reliable methods to measure the absolute age of rocks or Earth itself. Many attempts were made, but different methods gave different results. It would take the development of a new understanding in the area of physics and the invention of new technology to finally understand the extent of time.

Mysterious Rays

radioactivity: the emission of energy from the nuclei of unstable atoms as they change to become more stable atoms

During the late nineteenth century and the early twentieth century, it was discovered that isotopes of certain elements emitted rays invisible to the eye. Marie Curie named this property **radioactivity**. The discovery of radioactivity attracted the interest of a bright young physicist named Ernest Rutherford. While working at Montreal's McGill University, Rutherford discovered that the energy emitted from radioactive materials was in the form of high-speed particles. He was also able to measure the intensity of this radiation by detecting the number of particles emitted per second.

Figure C1.38: Marie Curie used simple technology to study radioactivity.

An Atomic Clock

While measuring the radioactive intensity of a sample of gas containing radon-220, Rutherford discovered a remarkable property of radioactive materials: the intensity decreased (or decayed) over time. Every 55.6 s, the radioactivity of the thorium decreased by half. If its original intensity were 100%, the intensity 55.6 s later was only 50% of the original value. If another 55.6 s passed, the intensity was again cut in half to be only 25% of the original value. Rutherford called the decreasing intensity **radioactive decay**.

No matter what size of gas sample Rutherford started out with, the radioactive intensity was cut in half every 55.6 s. This constant time increment is now called a **half-life**. It occurred to Rutherford that half-lives were like minutes ticking by on a clock. He had discovered the first use of atoms to estimate time.

radioactive decay: the disintegration of an unstable atom, which results in the release of energy in the form of radiation

half-life: the time taken for half of a radioactive sample to decay

A half-life is a constant increment of time that depends on the particular isotope.

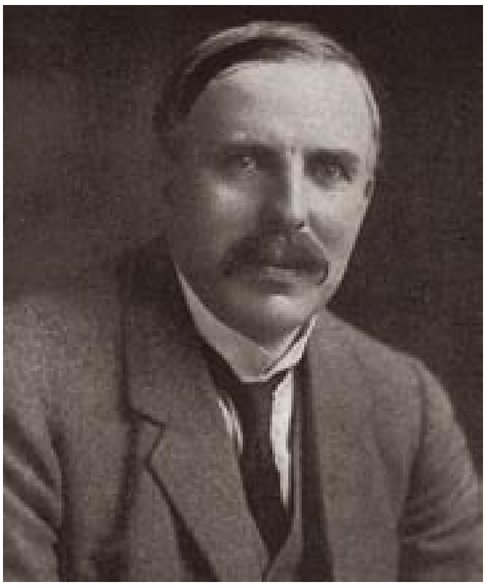


Figure C1.39: Ernest Rutherford discovered that energy was discharged from radioactive materials through high-speed particles.

DID YOU KNOW?

Rutherford measured the speed of alpha particles released by radioactive decay at 24 000 km/s! He showed that this kinetic energy could be transformed into heat. Now scientists believe that radioactive decay in Earth's core is the ongoing source of heat that drives convection currents in the mantle.

Investigation

Constructing a Decay Curve

Problem

What is the shape of a radioactive decay curve?

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Part A: Using Arts and Crafts

You will use paper strips to represent the radioactive sample.

Materials

- coloured paper
- scissors
- glue
- copy of the radioactive decay blank bar graph (available on the Science 20 Textbook CD)

Procedure

step 1: Cut out two strips of coloured paper about 1 cm thick. These strips should be the same height as the vertical axis on the vertical scale provided in the handout.

step 2: Paste one of the strips onto the handout as shown in Figure C1.40.

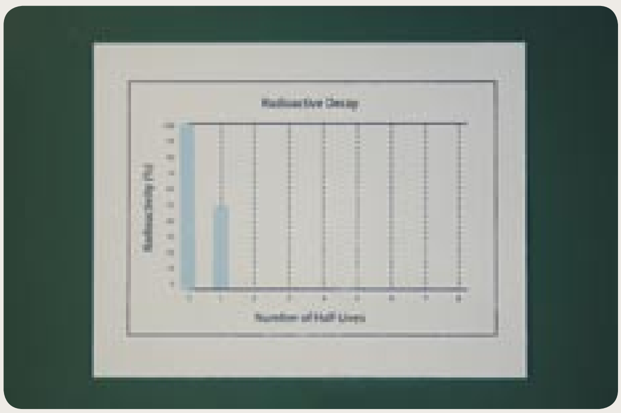


Figure C1.40: You will use paper strips to determine the shape of a radioactive decay curve.

step 3: Fold the second strip so that it is half as long as the first one. Cut the second strip at the crease.

step 4: Paste one of the halves as shown in Figure C1.40.

step 5: Continue this process of cutting and pasting until the paper has gone through eight half-lives.

step 6: Draw a dot at the very top of each strip, and then draw a smooth curve through the dots.

Analysis

1. Describe the curve's shape.

2. Determine if the radioactivity will ever reach 0%. Explain.
3. How many half-lives have passed for a strip that's emitting 60% of its original intensity?

Part B: Using Math

Materials

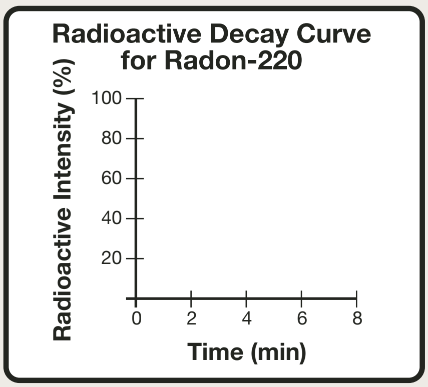
- graph paper or a spreadsheet program

Procedure

step 1: Copy and complete the data table.

Time (min)	Radioactivity (%)
0	100
1	50
2	25
3	
4	
5	
6	
7	
8	

step 2: Use graph paper or a spreadsheet program to construct a radioactive decay curve for radon-22. For simplicity, say the half-life is about one minute (even though it's really 55.6 s). This sample graph shows you how to set it up.



Interpretation Questions

4. Compare the shape of your graph from Part B with your graph from Part A.
5. Define *half-life*.
6. Compare the half-life effect of radioactive decay with the workings of a clock.

The New Alchemy

Why did radon-220 atoms decay? This question led Rutherford to the strangest part of all—he found that the radon-220 was unstable. It spontaneously changed into polonium, a more stable element. As the radon-220 changed, it released energy in the form of radiation. This reminded Rutherford of the alchemists, early chemists who dreamt of changing inexpensive elements like lead into rare, expensive elements like gold.

Rutherford did not discover a way to make gold from other atoms, but he did discover that elements could naturally change their identities. When discussing radioactive decay, two **isotopes** are often referred to: the original unstable atom called the *parent isotope* and the more stable product termed the *daughter isotope*.

isotope: a particular variety of an element as defined by its atomic mass

Radioactive Dating of Rocks and Fossils

Rutherford, Curie, and others found that no matter how much heat, cold, or pressure they applied to radioactive samples, the shape of the decay curve and the length of the half-life were the same. All of the radioactive elements decayed like clockwork; the half-life always elapsed as constant intervals of time. Because the radioactive decay of an element occurs at a fixed rate—a half-life—the decay process can be used to measure the time passed since a rock or fossil has formed.

Counting Atoms Is Hard

After discovering the properties of radioactive decay, Rutherford realized almost immediately that the pattern of radioactive decay could be used to determine the age of rocks and even Earth itself. He attempted to apply this thinking but was never successful because of the limited technology available to him.

Since then, scientists have developed very precise methods of counting the number of each type of atom in a sample to identify the amount of parent isotopes and daughter isotopes present.

The greatest breakthrough occurred with the invention of the mass spectrometer just after World War I. This machine can detect the elements (and their isotopes) present in a sample of rock. It can also be used to determine the percentage of each isotope present in the sample, which is an essential step in radioactive dating.

Using Uranium to Date Canada's Oldest Rocks

Some of the world's oldest rocks are tiny crystals called zircons. These are found embedded in other rocks. Some of the world's oldest zircons are found in Canada's Acasta Gneiss Rock Formation in the Northwest Territories. Zircons contain uranium and are amazingly durable. The rock around the zircons can even be melted and the zircons will remain unchanged. This makes zircons great for radiometric dating. The uranium clock is set at zero when the zircon forms—the uranium begins to decay from that point forward. Uranium can also be used to date volcanic ash layers. By knowing the age of a volcanic ash layer in a stratigraphic sequence, scientists can estimate the age of layers above and below the volcanic ash that can't be dated directly.

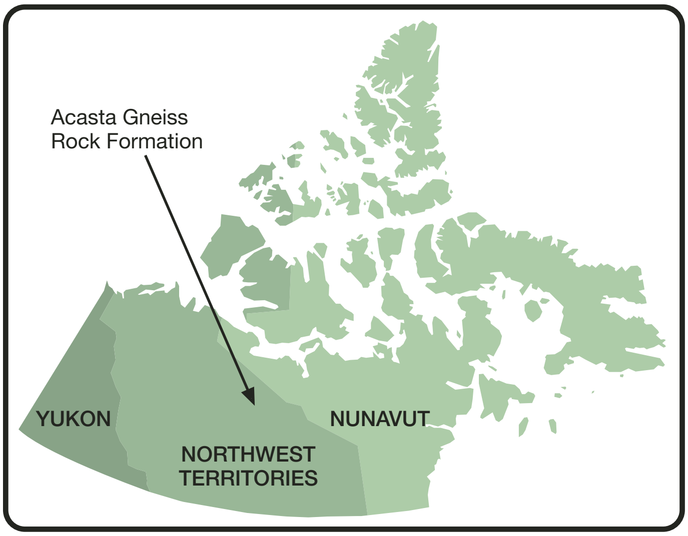


Figure C1.41: The Acasta Gneiss is located in the Northwest Territories.

4 billion years ago:
Canada's oldest rocks form

Figure C1.42: The Acasta Gneiss in the Northwest Territories contains Canada's oldest rocks.

Example Problem

A geologist determines the percentages of uranium-238 and lead-206 found in a zircon. She finds that 30% percent of the sample is lead-206. Determine the age of the zircon.

Solution

step 1: Turn to page 557 and find the table of "Elements for Radioactive Dating" and the "Radioactive Decay Curve." A handout of a large, user-friendly decay curve is available to be printed out from the Science 20 Textbook CD.

step 2: Determine the parent and daughter nuclides by using the "Elements for Radioactive Dating" table.

parent: uranium-238

daughter: lead-206

step 3: If necessary, determine the percentage of parent nuclide remaining in the sample. Use the fact that the percentages of the parent and daughter nuclides must add up to 100%. In this case, it is necessary because the daughter percentage is given, rather than the parent percentage.

$$\textbf{(100\% total)} - \textbf{(30\% daughter)} = \textbf{70\% parent}$$

step 4: Use the decay curve to determine the number of half-lives that have elapsed. About 0.50 half-lives have elapsed.

step 5: Look up the amount of time for each half-life for that element. Multiply it by the number of half-lives.

$$\textbf{(0.5 half-lives) } (4.47 \times 10^9 \textbf{ a/half-lives}) = 2.235 \times 10^9 \textbf{ a.}$$

The abbreviation for annum is *a*, which means year. Use the same number of significant digits in your answer as are used in the "Elements for Radioactive Dating" table. The zircon is 2.24 billion years old.

Practice

21. A sample of orthoclase is dated using potassium-40. A mass spectrometer analysis shows that 20% of the potassium-40 is present in the sample. Use this data to determine the age of the orthoclase sample.

22. It's hard to measure the age of Earth because most of the earliest rocks have since been reworked by the rock cycle. The Moon, on the other hand, doesn't have a rock cycle, so its rocks have remained virtually unchanged. Evidence suggests that the material that makes up the Moon was blasted off before Earth had fully formed. This is why geologists suspect that Earth and the Moon are about the same age. During the 1970s, missions to the Moon collected lunar rocks to bring back to Earth for analysis. One of the experiments completed on the collected lunar rocks was determining their age by using radiometric dating. The oldest Moon rock ever dated contains 6% of the daughter nuclide strontium-87. Using this information, determine the minimum age of Earth.

23. Volcanic ash deposits can be dated using uranium. This helps provide a time benchmark for layers above and below. About 100 million years ago, a series of volcanic eruptions blanketed Alberta with ash, which now forms layers known as the Crowsnest Volcanics in Alberta's geological record. Work your way backward to determine the percentage of uranium-235 present in the Crowsnest Volcanics.

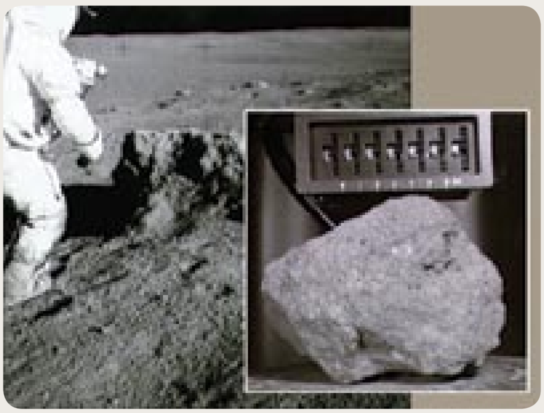


Figure C1.43: Moon rocks are virtually unchanged.

Dating Organic Remains

Carbon-14 is a rare and exotic isotope of carbon that starts out as regular, non-radioactive nitrogen-14. In the atmosphere, carbon-12 combines with two oxygen molecules called carbon-12 dioxide, also known as carbon dioxide. While in the atmosphere, a tiny percentage of the nitrogen-14 atoms are struck by cosmic rays. This turns them into carbon-14. Both types of carbon dioxide are incorporated into plant molecules by photosynthesis. The carbon then makes its way into the food chain.

When an animal dies, the carbon-14 clock is set at zero because dead animals don't ingest carbon. If the animal's organic remains are preserved, the date can be determined by measuring the amount of carbon-14 remaining. Note Figure C1.44. Carbon-14 undergoes radioactive decay to become nitrogen-14, which often escapes from the fossil in gas form. Because the daughter nuclide has escaped, scientists can't directly determine the amount of original carbon-14 in the organism at the time of death. Scientists have to assume that carbon-14 formed in the atmosphere has always been incorporated into organisms at the same rate.

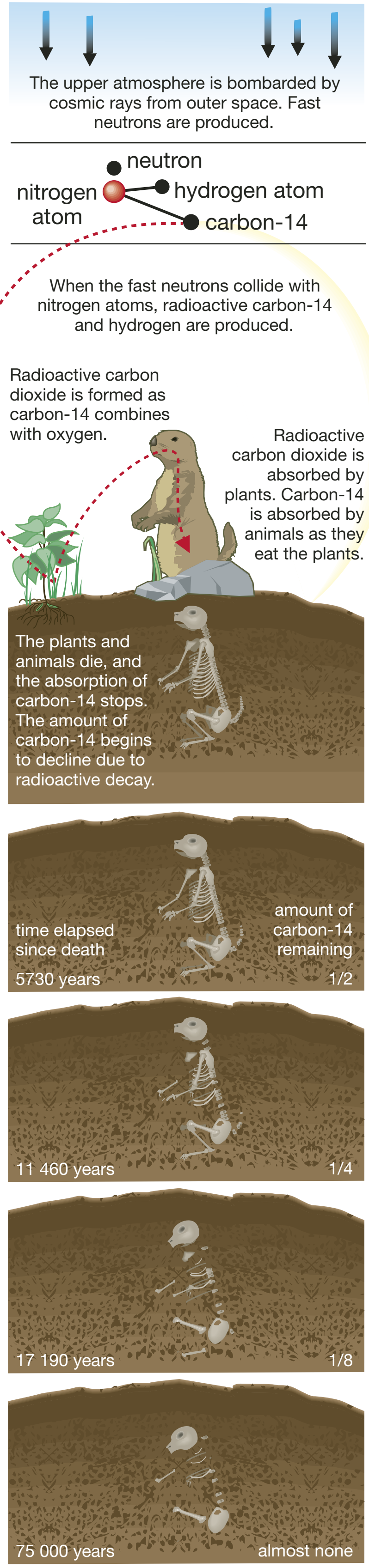


Figure C1.44: Radiocarbon dating determines the age of a fossil.

Science 20 © 2006 Alberta Education (www.education.gov.ab.ca). Third-party copyright credits are listed on the attached copyright credit page.

Practice

24. In the fall of 1991, two hikers discovered a male human body melting in the glacial ice of the Italian Alps. It wasn't until forensic experts were called in that it was discovered the uniqueness of the find. The frozen body of the hunter was much older than anyone guessed. Carbon-14 dating methods found that the body contained 52.5% of the original carbon-14 that would have been in his body at his time of death. Determine the age of the ice mummy.

Figure C1.45: The age of this ice mummy can be determined by carbon-14 dating.

25. Carbon-14 dating cannot be used to date samples more than 45 000 years old. Provide a possible explanation for this.

1.5 Summary

By using radioactive decay, modern geologists now have the ability to determine the absolute age of rocks and the remains of dead organisms. After Curie and Rutherford discovered the fundamental properties of radioactive decay, technology—such as the mass spectrometer—enabled the analysis of isotopes. This led to more accurate predictions of age. With the advent of radioactive dating, numbers were finally added to the Geological Time Scale. Dates can now be assigned to rock layers that contain radioisotopes.

1.5 Questions

Knowledge

1. Identify a major problem facing geologists at the end of the nineteenth century.
2. Describe the oldest rocks in Canada. Where are they?
3. Why does radioactivity make a good clock?
4. Describe what radiometric method is used to date organic remains.

Applying Concepts

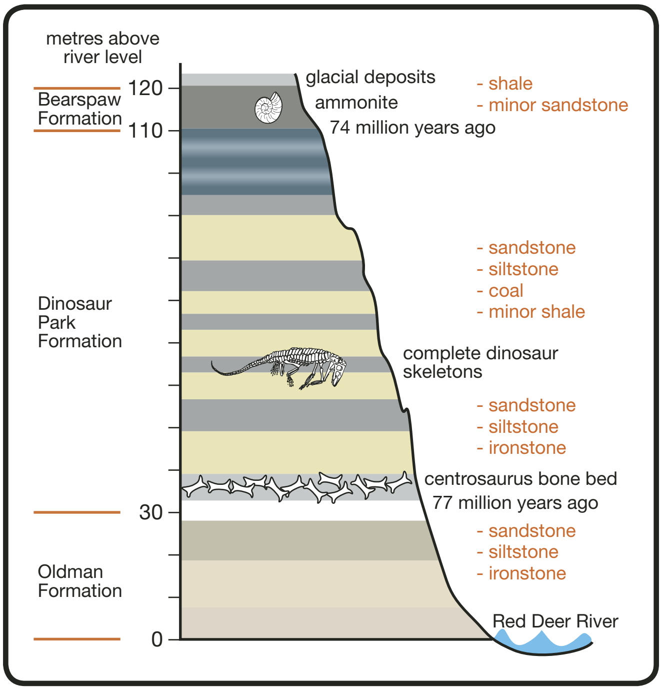


Figure C1.46: An outcropping of the Red Deer River outlines soil composition.

5. Figure C1.46 shows an outcropping of the Red Deer River at Dinosaur Provincial Park near Brooks.
   a. Determine the relative age of the dinosaur skeleton shown in the diagram.
   b. Determine the relative age of the ammonite fossil.
   c. Is the relative age more precise in question 5.a. or question 5.b.? Why?
6. Design a time line showing the development of geological thought and technologies in the study of geology from the time period of Nicolas Steno to the discovery of radiometric dating. Highlight how scientific knowledge is subject to change and how new technologies aid scientific discoveries. Trace a brief description of each item you add to the time line. Be creative. Make a poster or a PowerPoint® presentation, or use an idea of your own.

Chapter 1 Review Questions

Knowledge

1. Explain how the stromatolites, which are Alberta's oldest fossils, had an affect on Earth's early atmosphere.
2. Describe the theory of deep time.
3. List the four eras of geological time.

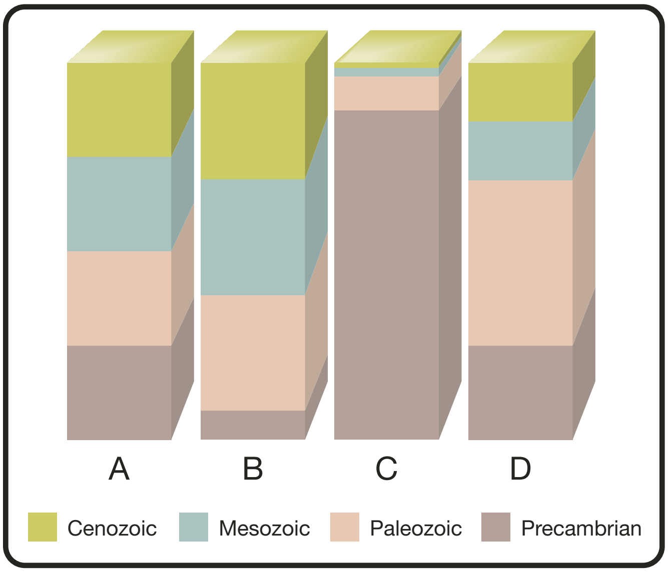


Figure C1.47: These diagrams show different representations of time.

4. Analyze which of the diagrams in Figure C1.47 is the most accurate representation of time for the combined four eras.
5. Describe Alberta's oldest rock outcropping.
6. Zones of rock within Earth's mantle behave as a plastic. Explain this statement.
7. Sketch a diagram showing the layers within Earth. Label each layer.
8. Explain what causes the push and pull on crustal plates.
9. Identify some of the evidence that indicates the Rocky Mountains were once the coastline of Alberta.
10. Describe the hostile environmental conditions that Earth's first organisms had to endure.
11. Scientists suspect that single-celled organisms called cyanobacteria were largely responsible for creating Earth's oxygen-rich atmosphere. Explain how such tiny life forms could produce so much oxygen.
12. Describe evidence suggesting that levels of atmospheric oxygen fluctuated during the Precambrian Era.
13. Describe the organisms living along Alberta's coastal reef at the end of the Precambrian Era.
14. Briefly explain how fossils form and how they can end up high above sea level.
15. State the law of superposition.
16. Explain the difference between relative age and absolute age. Include the major methods used to determine each age.
17. Define the term *index fossil*.
18. Identify three qualities of an ideal index fossil.
19. Describe how the use of index fossils was an integral part of assembling the Geological Time Scale.
20. From general to specific, list the three types of divisions that make up the Geological Time Scale.
21. Describe the theory of uniformitarianism.
22. Identify the three major types of rock.
23. Sketch a simplified version of the rock cycle. Include the processes that create the different rock types.
24. Explain how the existence of a rock cycle provides support for the theory of deep time.
25. Explain why a body of intrusive, igneous rock must be younger than the surrounding rock.
26. Define the term *unconformity*.
27. Describe the process of radioactive decay.
28. Sketch a radioactive decay curve. Include the percentage of parent material remaining and the half-lives.
29. Explain how radioactive decay makes a good clock for measuring the absolute age of ancient objects.
30. Explain how radioactive decay is believed to be the driving force for the rock cycle.
31. Describe how the absolute ages of Canada's oldest rocks were determined.
32. How are the absolute ages of organic remains determined?

Applying Concepts

Use Figure C1.48 to answer question 33.

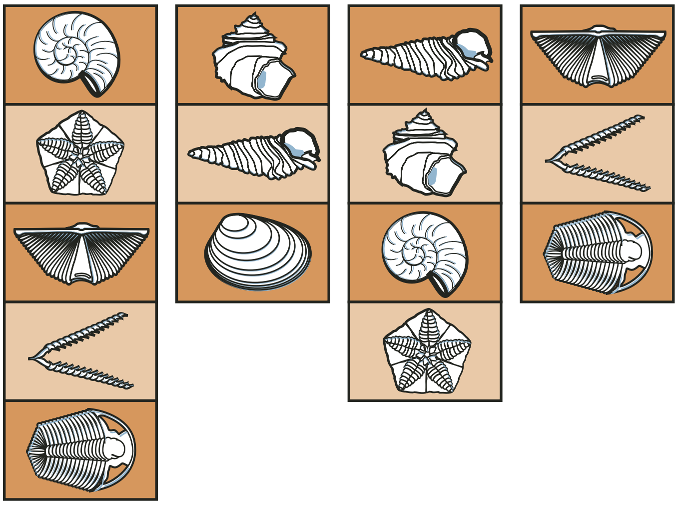


Figure C1.48: Stratigraphic sequences are represented.

33. Figure C1.48 shows four stratigraphic sequences of fossils found at four different locations.

- **a.** Explain how these sequences can be combined to build a larger stratigraphic sequence.
- **b.** Sketch the combined stratigraphic sequence.
- **c.** Label the oldest layer and the youngest layer.

Use Figure C1.49 to answer question 34.

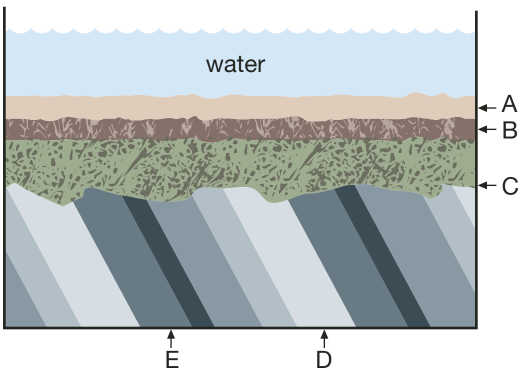


Figure C1.49: A rock cross section is highlighted.

34. Figure C1.49 shows a rock cross section.

- **a.** List rock layers A, B, D, and E in order of age from oldest to youngest.
- **b.** Explain how the identified layers became tilted.
- **c.** Explain what event has occurred at C. Define what this is called.

Use Figure C1.50 to answer question 35.

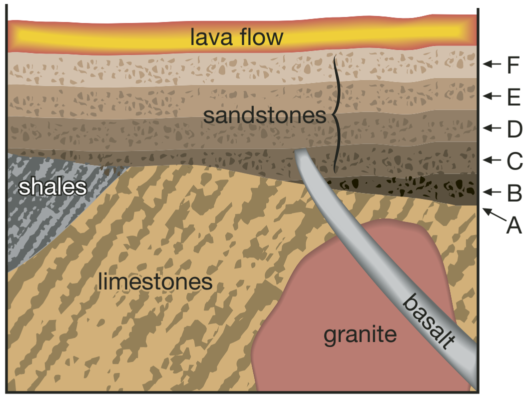


Figure C1.50: This cross section has granite and basalt intrusions.

35. Figure C1.50 shows the cross section of a rock.

- **a.** What types of rock are the granite, basalt, and lava flow?
- **b.** Identify which is older—the granite or the basalt.
- **c.** Identify which is older—the shales or the limestones.
- **d.** Relate what has occurred at A.
- **e.** Identify which group is older—the sandstones or the lava flow.
- **f.** Which layers of sandstone are older than the basalt?

Use Figure C1.51 to answer question 36.

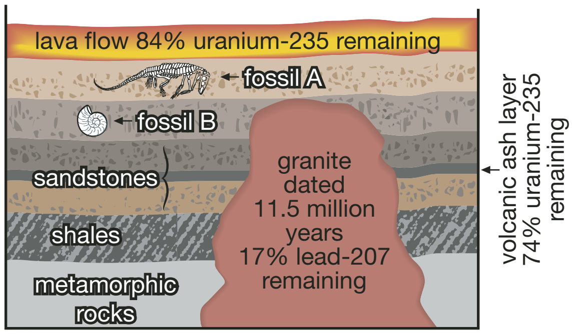


Figure C1.51: Fossils are included in this cross section.

36. Figure C1.51 shows a rock cross section. Determine the ages of

- **a.** the lava flow (Use radiometric dating and the half-life of U-235.)
- **b.** the granite intrusion (Use radiometric dating and the half-life of U-235.)
- **c.** the volcanic ash layer (Use radiometric dating and the half-life of U-235.)
- **d.** fossil A (An exact age cannot be determined. Give a range of ages.)
- **e.** fossil B (An exact age cannot be determined. Give a range of ages.)

Chapter 2 A Tropical Alberta

One of the more popular activities in the Rocky Mountains is hiking. Imagine you are on a guided hike on Mount Wapta in Yoho National Park. Just before you get to the steep cliffs by one of the remaining snow banks on the mountain's right side, you notice a camp of university researchers digging and splitting shale. In the flat pieces of rock are impressions and remains of strange creatures that you have never seen before. Some of them are obviously swimming organisms.

You might start to wonder why these creatures are now found in rock on the side of a mountain. In an environment where the most common organisms around you now are lichens growing on rocks, how can these complex creatures be here? How old are they? Some of them are mysterious—are they plant or animal?

In this chapter you will learn about the geology of Alberta in both the Paleozoic and Mesozoic eras. You will be able to explain how the remains of animals can last for millions of years, and you will also determine what information they can tell people about the ancient environment.

Try This Activity

Interpreting Fossil Evidence

Introduction

In Chapter 1 you made a fossil by embedding an object in plaster of Paris so that it would leave a permanent impression. This impression has become an artificial fossil. Since your classmates don't know what object you used to make the impression, and you don't know the objects they used, this activity turns into a simulation of the detective work scientists do when they're attempting to interpret fossil evidence.

Purpose

You will make careful observations of the fossil impressions made by your classmates. In each case you will use your observations in an attempt to determine the identity of the original object that made the impression.

Materials

- object embedded in the plaster of Paris mould
- felt-tipped pen with permanent ink
- safety glasses
- newspapers or cardboard to catch any crumbling pieces of material
- hammer, flat-bladed screwdriver, or some other tool to help pry open your mould if it's stuck

CAUTION!

Direct the prying tool away from yourself and others.

Procedure

step 1: Put on your safety glasses and spread the newspapers or cardboard on your work area. Gently work the plaster out of the container. A line should be visible between the first and second layers. Carefully tap the line with a hammer, and the layers should split. If they don't, you must carefully pry the layers apart with a screwdriver or some other prying tool.

step 2: Without disturbing the impression, remove the object that created the impression in the plaster of Paris. Keep this object hidden from your classmates. Decide which half of the impression to put on display. Write your name just below the impression that your classmates will analyze.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

step 3: Clean up the work area and prepare the impression of your fossil for display.

step 4: Set up a table with the following columns, and complete the first three columns by carefully examining each fossil created by your classmates. You may need to add more rows.

Name of Person Who Built Impression	Observations of Impression Left by Embedded Object	Suspected Identity of Embedded Object	Actual Identity of Embedded Object

step 5: Once everyone has examined all of the fossil impressions, each person should place the other half of the impression—as well as the embedded object—beside the half examined by the class.

step 6: Return to the fossil table. Complete the last column of the table.

Analysis

1. Compare your results with the findings of the other students.
   - **a.** List the fossil impressions where students had the greatest success identifying the embedded object.
   - **b.** List the fossil impressions where students had the most difficulty identifying the embedded object.
   - **c.** How do you account for differences in the last two columns?
   - **d.** Would your answers to 1.a. and 1.b. change if the class had access to both parts of the impression? Explain.
2. You embedded a single object. How would your fossil impression be different if you used an object composed of many parts held together with water-soluble glue?

2.1 The Cambrian Explosion

Figure C2.1: Trilobite fossils are from the Cambrian Period.

The photograph in Figure C2.1 shows the remains of an organism called a trilobite. Trilobites are excellent index fossils from the Cambrian Period, which took place in the first part of the Paleozoic Era. About 50% of all Cambrian fossils are trilobites. The evidence suggests that more than 500 million years ago, the animal in this photograph swam near the bottom of a tropical sea, feeding on nutrients in the sediment.

How could anyone possibly know these things if they occurred such a long time ago? What kind of evidence could allow someone to come to that kind of conclusion? The answers to these questions are in the trilobite photograph.

Fossilization

In "Interpreting Fossil Evidence," you created a fossil impression of an everyday object by simply pouring plaster of Paris into a mould. The actual process of **fossilization** is much more complex and can be summarized as follows:

fossilization: the process by which any trace of the existence of ancient life is preserved within rock

life → death → burial → preservation → discovery → recovery

Just as you may have found it challenging to identify an embedded object when working with only half of the impression, working with actual fossils often means trying to solve a puzzle that has many missing pieces.

The first step in the process of fossilization is the burying of the organism before that organism's complete decomposition. Hard parts—such as shells and teeth—can be found in the rock as unaltered remains. If the original material is replaced by a mineral, such as silica, the resulting fossil would be petrified. In the right conditions, and given enough time, even the hardest shells and teeth may dissolve. When the material dissolves, the space left behind is called a mould. The outside of a shell is called an external mould. The impression of the inside of a shell results in an internal mould. These are sometimes so detailed that the places where the muscles are attached to the shell can be preserved.

Soft tissue—such as leaves and skin—can be fossilized by the complete replacement of the organic material, with an impression of the organic material left behind. Soft parts can sometimes be preserved as a thin film of carbon.

Fossils are most often found in sedimentary rock because the remains were usually buried in layers of sediment. But there are cases where tree trunks have been found in volcanic lava because lava flows so quickly that it creates an impression of the tree. If a mould is filled in by a mineral, such as calcite or silica, a cast is formed.

Practice

1. Explain why the last four steps in the process of fossilization produce an incomplete record of life forms that have existed on Earth.
2. Explain why coal, oil, and natural gas are not considered fossils even though they originate from the remains of ancient plants and animals.

Trace Fossils

Just as you discovered in "Try This Activity: Interpreting Fossil Evidence," two parts often result when a geologist splits a rock to find a fossil. The actual fossil is on one part of the rock, and the impression is on the other piece. This is much like a finger and its fingerprint.

There are sometimes no remains of actual organisms, but there is evidence of their presence in the form of trace fossils. Trace fossils are very important when determining the ecology of ancient plants and animals. The stromatolites that you studied in Chapter 1 illustrate the importance of information that can be derived from trace fossils.

Comparing Fossils and Modern Organisms

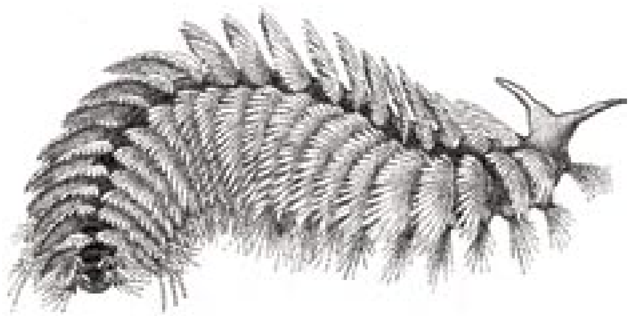


Figure C2.2: This is an artist's drawing of *Canadia*, a marine worm.

Canadia belongs to a group of worms that are the marine equivalent of common earthworms. Note the feather-like structures along the body and the small tentacles or stalks on the head.

Figure C2.3: A modern bristle worm lives on the ocean bottom.

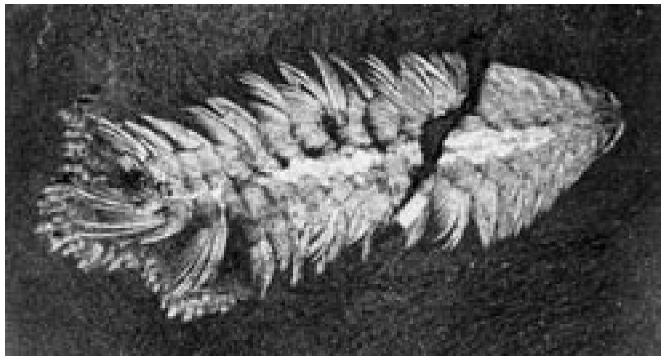


Figure C2.4: Note the small stalks on the right-hand end of this *Canadia* fossil.

Geologists and paleontologists often need to compare fossils to living organisms because some information is not preserved in the fossil record. *Canadia*, shown in both Figure C2.2 and Figure C2.4, is a member of the group of marine worms known as bristle worms. These animals first appeared in the fossil record more than 500 million years ago; and no hard parts, such as jaws or teeth, have ever been found. Specimens of *Canadia* are found in a shale formation on Mount Wapta.

Modern species, such as the one in Figure C2.3, form a diverse group found in areas ranging from shallow water to deep water and from the tropics to the polar regions. Some organisms crawl along the bottom; some are free-swimming; and others live in burrows made in soft sediment. The feathery structures in modern bristle worms work as gills, as well as for locomotion.

Bristle worms range in size from a few centimetres long to almost three metres in length. With jaws consisting of nine separate parts, some modern species are predators that drill holes in clam shells. Other species are filter feeders.

Practice

3. Compare the features of the modern bristle worm with the *Canadia* specimen. What purpose would the stalks or small tentacles serve on *Canadia*?
4. Given that the modern bristle worm shown in Figure C2.3 is found on the ocean bottom, what inferences can you make about the lifestyle (free swimming, fixed to the bottom, bottom crawling) of the fossil organism named *Canadia*?
5. What inferences can you make about *Canadia's* food source? Was *Canadia* a predator, a herbivore that ate algae, or a scavenger that filtered organic material from mud and water near the sea bottom?
6. Which geological principle are paleontologists applying when they compare fossils with modern creatures?

Investigation

Hypothetical Interpretations of Fossil Evidence

Purpose

You will look at fossil evidence and then apply it to create a hypothetical interpretation about the possible lifestyle of a fossilized organism.

Science Skills

✓ Analyzing and Interpreting

Fossil Evidence from 1977

One of the weirdest fossils ever recovered from the shale at Mount Wapta was named *Hallucigenia* because it looked like something you might see in a hallucination.

Figure C2.5: This is a photo of a *Hallucigenia* fossil.

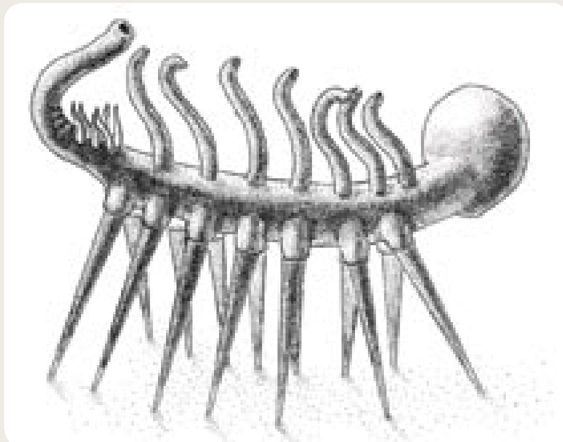


Figure C2.6: This drawing is a representation of *Hallucigenia*.

A close examination of the fossil in Figure C2.5 revealed that *Hallucigenia* had a cylindrical body with seven pairs of slender spikes on one side and a row of seven tentacles along the other side. Since a single row of tentacles is not a normal leg arrangement, *Hallucigenia* was thought to walk on its rigid spikes, with its tentacles rising from its back. Each tentacle appeared to end with a tiny opening. This fossil, only about 25 mm long, was found in a bed of fossils of aquatic organisms that appear to have lived near the bottom in shallow, tropical ocean water.

Hypothetical Interpretation of Evidence from 1977

1. Carefully examine the fossil evidence from 1977. Based upon this evidence, describe a possible ecosystem, feeding habits, and some description of a day in the life of this creature. This is called a hypothetical interpretation because it requires a creative and speculative response given that the fossil evidence is so limited.

Fossil Evidence from 1992

In the late 1980s, Swedish paleontologist Lars Ramskold was studying similar fossils from China. He proposed that the spikes of *Hallucigenia* served a protective function and were actually placed along the back of the animal. If Ramskold's hypothesis was true, this meant that the seven tentacles were legs. If they were legs, then they should be paired. To test his idea, Ramskold asked permission to remove a few chips of shale that encased one of the few samples of rare *Hallucigenia* fossils. Ramskold was given permission and, as soon as he removed a few chips of shale, he discovered a second row of seven tentacles lay under the first row.

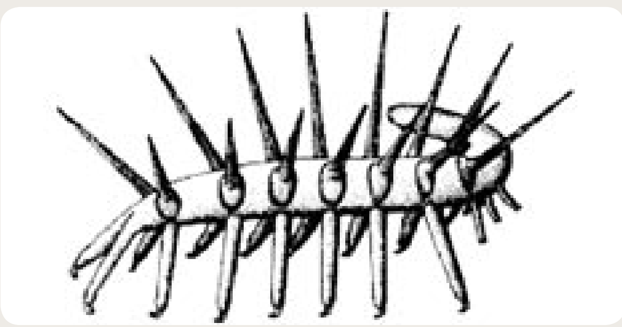


Figure C2.7: *Hallucigenia* resembles *Onychophora*.

Figure C2.8: An *Onychophora* resembles a caterpillar.

This confirmed Ramskold's hypothesis. *Hallucigenia*—note Figure C2.7—is now thought to be an animal that walked on seven pairs of flexible legs protected by seven pairs of spikes on its back. Although it is still a strange-looking organism, *Hallucigenia* now shows some resemblance to caterpillar-like animals called *Onychophora*. Unlike its ancient, aquatic ancestor, *Onychophora* can be found in tropical rain forests in the Southern Hemisphere.

Hypothetical Interpretation of Evidence from 1992

2. Carefully examine the fossil evidence from 1992. Based upon this evidence, describe a possible ecosystem, feeding habits, and some description of a day in the life of *Hallucigenia*. Again, the speculative nature of this question makes your response a hypothetical interpretation.

Analysis

3. Why must the hypothetical interpretations generated by interpreting fossil evidence always be considered to be tentative best attempts at explanations rather than facts that people state with 100% confidence?
4. If some hiker visiting a bed of rare fossils had taken the *Hallucigenia* fossil containing the hidden row of legs discovered by Lars Ramskold, where would people's understanding of the structure of *Hallucigenia* be? Why is it essential for rare fossil evidence to be treated with great care?
5. You will have noticed that the science skills icon appears throughout this textbook to describe the process of scientific investigation. Skills listed on the icon are Initiating and Planning, Performing and Recording, Analyzing and Interpreting, and Communication and Teamwork. Describe how the parts of the experiment carried out by Ramskold with the *Hallucigenia* fossil could each be categorized with the skills noted on the icon.

As you saw in "Hypothetical Interpretations of Fossil Evidence," the fossil evidence left by the *Hallucigenia* fossils is so scant that it's very difficult to attempt to interpret this evidence by suggesting the organism's lifestyle. However, this is not always the case. As you'll soon see, there are some places where the number and variety of fossils provide a wealth of data. The interpretation of the fossil evidence from these places can provide glimpses into ancient ecosystems.

The Burgess Shale

In Chapter 2 you have been introduced to three fossils: a trilobite, *Canadia*, and *Hallucigenia*. Samples of all three fossils have been found in the shale on the side of Mount Wapta, about 80 km west of Banff. This location is known as the **Burgess Shale**, and it's considered by many scientists to be the most important source of Cambrian fossils on Earth.

Geologists have evidence that more than 500 million years ago, the organisms now fossilized in the Burgess Shale were inhabiting a shallow area close to the shore of a tropical sea. An artist's representation of what this might have been like is shown in Figure C2.9.

Burgess Shale: a Cambrian-age rock unit found on the side of Mount Wapta in the Canadian Rockies known for its well-preserved fossils

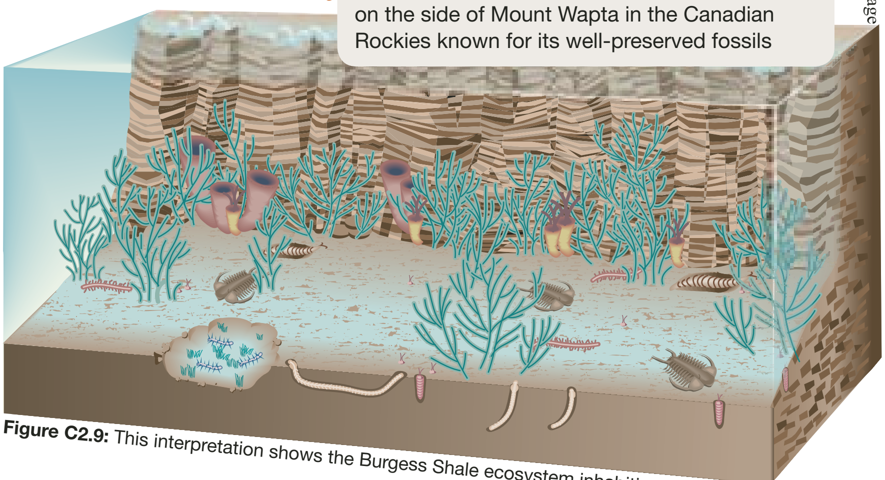


Figure C2.9: This interpretation shows the Burgess Shale ecosystem inhabiting a shallow area.

Practice

7. In "Hypothetical Interpretations of Fossil Evidence" you were asked to use fossil evidence to speculate about and create a hypothetical interpretation by suggesting a possible habitat for *Hallucigenia*. Concisely explain why the artist's illustration of the Burgess Shale in Figure C2.9 is also considered to be a hypothetical interpretation.
8. Identify a trilobite, a *Canadia*, and a *Hallucigenia* in Figure C2.9. Describe the location of each of these organisms in the illustration.

Alberta's Tropical Coastline

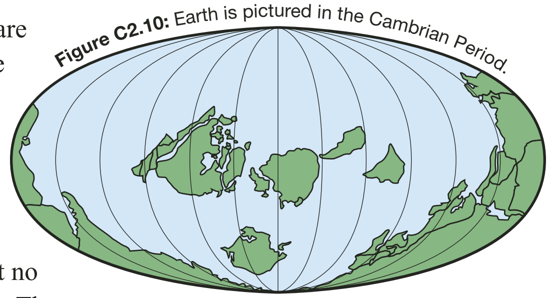


Figure C2.10: Earth is pictured in the Cambrian Period.

The idea of Alberta having a tropical climate is hard to imagine when you are outdoors between November and March. However, this was indeed the case for millions of years. For much of the time following the Precambrian Era, evidence suggests that Alberta was positioned close to the equator and was repeatedly submerged and then lifted above the ocean's surface. After the Paleozoic Era, most of Alberta was above the ocean's surface for millions of years.

During the Cambrian Period of the Paleozoic Era, scientists suspect that no plants or animals were living on land—life was confined to bodies of water. The previously formed Precambrian rock was being eroded by rivers. Particles of sand, silt, and clay were carried by these rivers to the ocean on Alberta's shoreline. The fine particles of silt and clay that collected along Alberta's Cambrian coastline were eventually transformed by geological processes into the sandstones and shales that form part of the Rocky Mountains, which are found along the current border with British Columbia.

A Muddy Grave

The animals found in the Burgess Shale form a collection of both warm shallow-water creatures and deep-water organisms. They represent a complete ecosystem. These animals are all found in what used to be soft mud on the seaward side of a **reef**. Evidence suggests that a series of underwater mud avalanches carried the organisms over the cliff edge, where they were then buried within layers of mud. The hard body parts of these organisms were fossilized in much the same way as other Cambrian fossils.

reef: a submerged ridge of rock, sand, or coral that rises to the water's surface

However, what makes the Burgess Shale unique is that the soft body parts of these animals were also preserved. This good fortune was due to the fact that the mud was comprised of such tiny particles that the organisms caught in the mud avalanche were immediately encased in mud and swept down into deep water, which likely had low concentrations of oxygen. The result was that decay was limited and the effects of scavengers were eliminated.

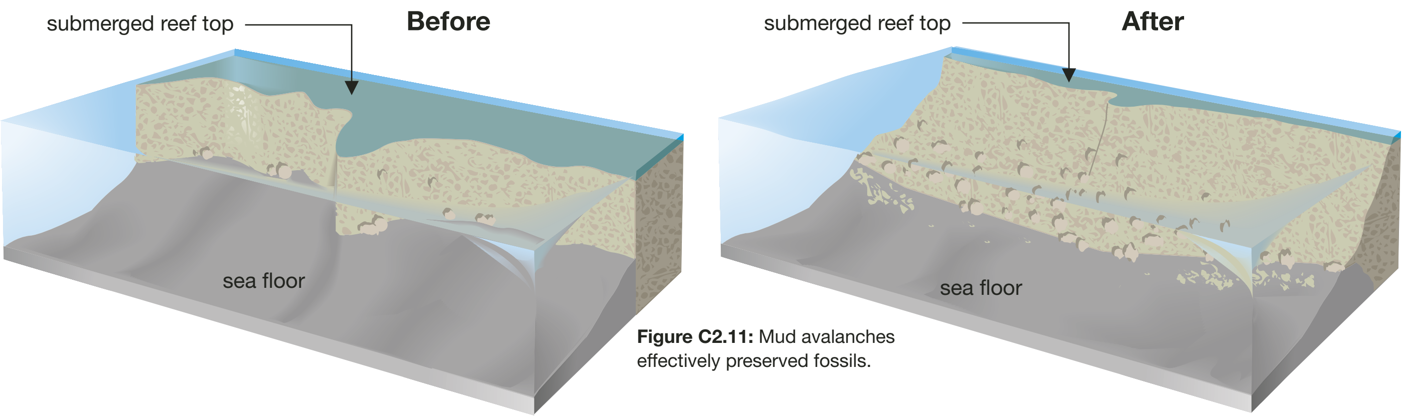


Figure C2.11: Mud avalanches effectively preserved fossils.

The effect of later mud avalanches, noted in Figure C2.11, meant that additional mud layers were added on top of the buried organisms. The pressure from the layers above would have further sealed the carcasses, allowing the mud to be undisturbed as it began to chemically react with the organism's body tissues. Eventually, even delicate structures—such as the smallest sections of gills—became preserved as thin carbon films interspersed with particles of fine mud. The extent of preservation is so fine that one fossil of a predator had its last meal preserved in its digestive system.

Practice

9. Layers of microscopic silt and clay particles are often deposited as sediment at the mouths of rivers. If these sediments are acted upon by geological processes for millions of years, the result is shale. Shale is the most common type of sedimentary rock.

  a. Identify the source of the fine silt and clay particles that formed the Burgess Shale.

  b. Describe the significance of these microscopic particles in the preservation of the Burgess Shale fossils.

10. Particles in the Burgess Shale fossils are found in a variety of positions: some upside down, some vertical. Hypothesize why the fossils of the Burgess Shale are not arranged in an orderly way, such as lying on their sides.

The Cambrian Explosion

The earliest examples for all the basic designs or body plans for animals that have lived on Earth can be found in Cambrian rocks dating from 545 to 525 million years ago. Prior to this time, the fossil record suggests that the variety of organisms was limited to soft-bodied organisms, such as worms. The Cambrian Period that marks the beginning of the Paleozoic Era signals the first appearance of a wide variety of animals with hard body parts like shells. On the Geological Time Scale, this 20-million-year time interval is a relatively short time to see such a burst of animal origins, so some evolutionary biologists refer to this rapid diversification as an explosion. Nearly all modern groups of animals can trace their origins to the beginning of the Cambrian Period.

Why did so much biological diversification occur at this time? Some researchers have suggested that the atmospheric oxygen levels finally reached a concentration high enough to support the more active metabolism of these mobile animals. While scientists continue to investigate possible answers to this question, it is remarkable that life on Earth for the past half-billion years seems to involve variations on the basic designs that first emerged from the Cambrian Explosion.

545 to 525 million years ago: Cambrian Explosion

A World Heritage Site

The Burgess Shale provides a wonderful snapshot of what was happening during this significant event in Earth's history. For this reason, the United Nations has declared the Burgess Shale to be a World Heritage Site. These fossils are of great scientific importance, but the site is also in a national park, which is accessible to all Canadians.

Parks Canada is responsible for the protection of such a rare, fragile, and scientifically important site. But this is balanced by the need for Canadians and visitors from other countries to have opportunities to learn about their heritage. Because of these priorities, you can take guided tours of the various fossil sites. Strict laws protect natural artifacts in all of Canada's national parks.

2.1 Summary

In this lesson you reviewed the process of fossilization. "Interpreting Fossil Evidence" and the investigation with the *Hallucigenia* fossils indicate that the interpretation of fossil evidence is challenging. The explanations that follow from scant evidence should always be treated as tentative. In the case of the Burgess Shale, the wealth of data from the fossil beds provides insights into an underwater ecosystem from more than 500 million years ago.

Geologists suspect that organisms of the Burgess Shale were caught in an underwater mud avalanche that helped to create what are considered to be the most extensive and best-preserved Cambrian fossils on Earth. In the rapid diversification of life known as the Cambrian Explosion, the seeds were sown for the origin of nearly all modern groups of animals.

2.1 Questions

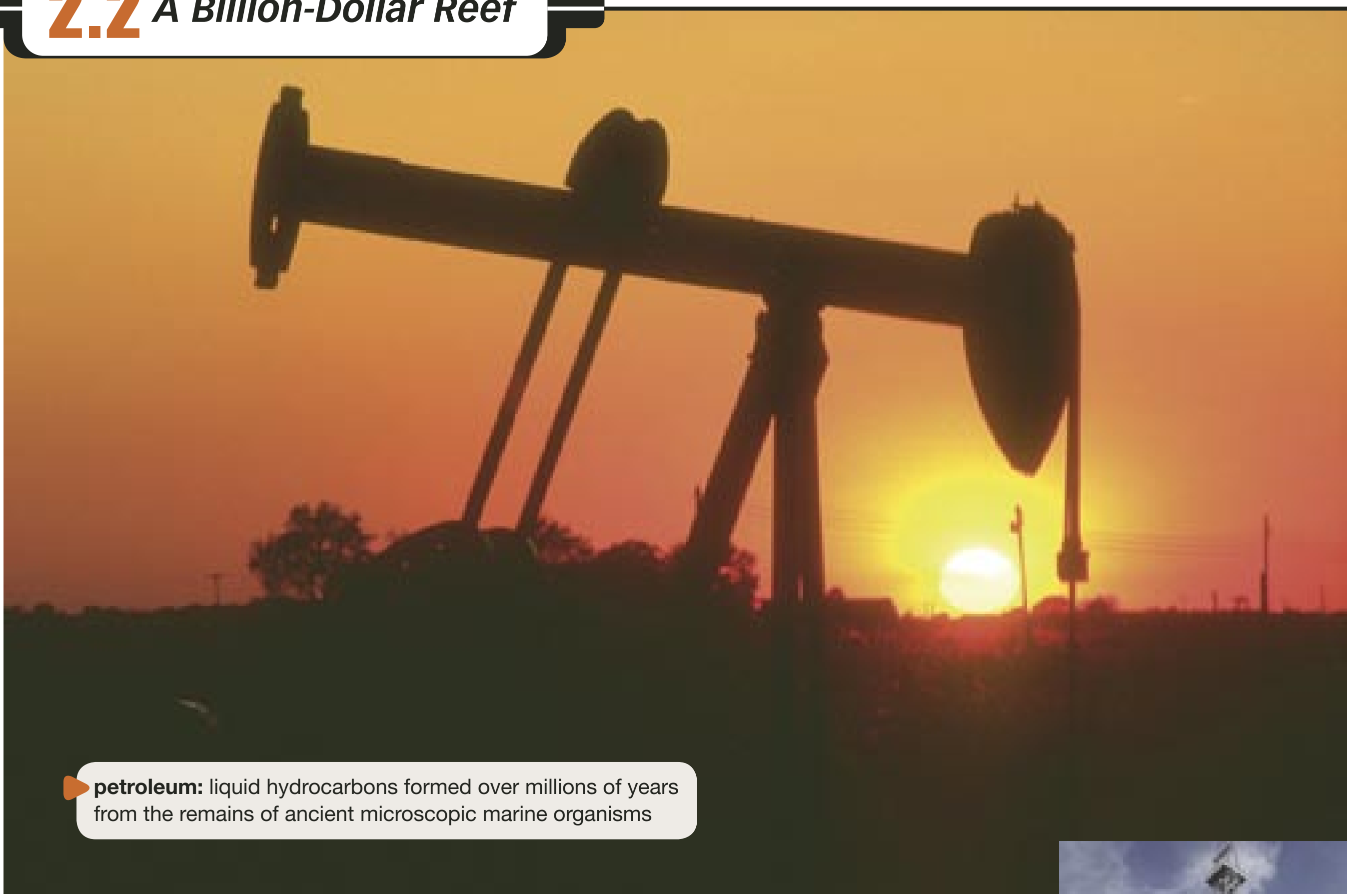
Knowledge

1. Define the following key terms.
   - **a.** shale
   - **b.** trace fossil
   - **c.** preservation
   - **d.** Cambrian Period
   - **e.** Paleozoic Era

Applying Concepts

2. The Burgess Shale is a site of exceptional fossil preservation. The key to this degree of preservation lies in the way the fossilization process occurred.
   - **a.** List the steps in the fossilization process.
   - **b.** The process of fossilization occurred in a unique way for the organisms found in the Burgess Shale. Describe the steps involving unique features that led to the exceptional fossil preservation at this site.
3. Explain why trace fossils, such as burrows, are not found in the Burgess Shale.
4. The Cambrian Explosion is thought to have lasted about 20 million years. Although this sounds like a long time, on the Geological Time Scale this is a relatively short time span. Determine the percentage of Earth's history that corresponds to this time interval.
5. What triggered the burst of animal origins called the Cambrian Explosion? One explanation has to do with atmospheric oxygen levels finally reaching concentrations adequate enough to support the metabolisms of active mobile organisms.
   - **a.** Recall your work from Chapter 1 where a process was described to account for the origins of Earth's oxygen-rich atmosphere. Concisely describe this process and the fossil evidence that supports it.
   - **b.** Based upon your answer to 5.a., explain why it is reasonable to assume that shallow-water ecosystems would also have more oxygen available to them during the early part of the Cambrian Period.
   - **c.** Deep-water ecosystems have lower concentrations of dissolved oxygen. Explain why this would be the case. How did this fact aid in the excellent preservation of the Burgess Shale fossils?

2.2 A Billion-Dollar Reef



petroleum: liquid hydrocarbons formed over millions of years from the remains of ancient microscopic marine organisms

Figure C2.12: Pump jacks can often be spotted when you travel through Alberta's oil fields.

As you drive around Alberta you can't help noticing the landscape of mountains, trees, grasslands, and oil wells. You may pass, or be passed by, a number of trucks owned by various oilfield service companies. Just south of Devon, you will find the Leduc #1 Provincial Historic Site.

The Leduc oil field has produced more than 400 million barrels of **petroleum** since its discovery in 1947. This discovery came after more than 130 dry holes were drilled. Dry holes are wells that don't produce profitable amounts of petroleum or gas. Clearly, this is an example of persistence paying off because the discovery of petroleum associated with Leduc #1 radically changed Alberta from a farm-based economy to one based upon petroleum. Alberta's prosperity and its status as Canada's top energy-producing province are due to its rich reserves of petroleum.

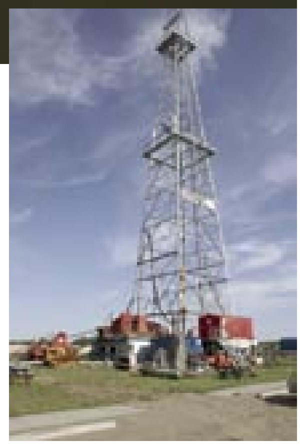


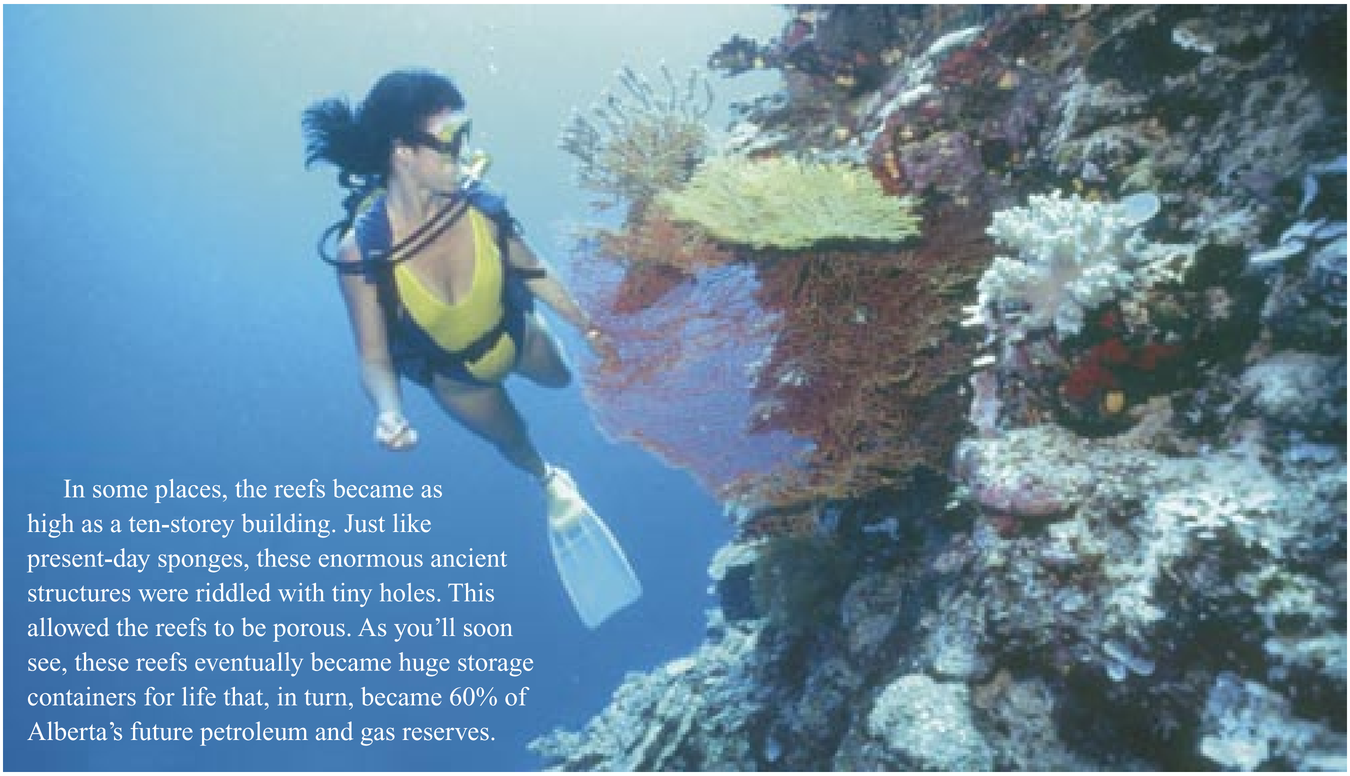
Figure C2.13: The Leduc #1 oil well was built in 1947.

Wealth from Ancient Seas

It's natural to wonder about the source of Alberta's good fortune. How was the petroleum formed? Why are these vast reserves found under Alberta and not beneath other provinces? The answers to these questions can be found in the clues about Alberta's ancient past left in the fossil record.

Earlier in this chapter you saw how the Burgess Shale preserved a fantastic record of life in the Cambrian Period of the Paleozoic Era. During this period, life on Earth was aquatic. The Cambrian Period was followed by the Ordovician Period, which was marked by life moving from water to the land. The earliest fossils of terrestrial plants date back 470 million years. The Ordovician Period also saw the emergence of jawless fishes thought to be the first animals with backbones. Geologists suspect most of Alberta became submerged at the bottom of a tropical sea by the end of the Ordovician Period. Over the next 200 million years, sea levels rose and fell in a complicated pattern that is a challenge to reconstruct. When it was submerged, Alberta became the home to a now extinct group of sponges. These sponges secreted a brittle calcium carbonate skeleton that, together with coral, became the main component of huge reefs that eventually occupied hundreds of square kilometres of the underwater environment.

470 million years ago: first terrestrial plants



In some places, the reefs became as high as a ten-storey building. Just like present-day sponges, these enormous ancient structures were riddled with tiny holes. This allowed the reefs to be porous. As you'll soon see, these reefs eventually became huge storage containers for life that, in turn, became 60% of Alberta's future petroleum and gas reserves.

Figure C2.14: Alberta was once the home of many reefs.

Practice

11. Refer to the "Geological Time Scale" on page 312. Determine the length of the time interval represented by the Ordovician Period.

12. During the Ordovician Period, it is thought that land plants began to contribute to the levels of atmospheric oxygen. You will need to recall key ideas from previous science courses to answer the parts of this question.

- **a.** Describe the process by which plants produce oxygen as a by-product. Include a chemical equation to aid your description.
- **b.** Some geologists believe it is not accidental that evidence from the fossil record suggests the first amphibians appeared on land 40 million years after the appearance of the first land plants. It has been suggested that this time period was necessary to provide enough oxygen to help produce an atmospheric ozone layer. Explain why an atmospheric ozone layer would be important to early amphibians.

Making Petroleum

The Ordovician Period was followed by the Silurian Period. During this time, sponges continued to expand their hold on Alberta's watery landscape and reefs continued to grow. For the parts of Earth not underwater, the colonization of the land by primitive plants was nearly complete. The first land-dwelling animals—scorpions and millipedes—began to leave their traces in the fossil record.

500 to 300 million years ago:
accumulation of organic matter
to be transformed into petroleum

Then came the Devonian Period, when reef building reached its apex. Since the Ordovician Period, microscopic marine organisms—mostly plankton—had been living and dying in the warm tropical seas that often covered most of Alberta for tens of millions of years. Many geologists suspect that the dead plankton remains created thick blankets of organic ooze that fell to the bottom of the sea to become a food source for bacteria. The bacteria were thought to have removed most of the oxygen and nitrogen from this organic matter to leave mostly carbon and hydrogen, which are the main ingredients of petroleum.

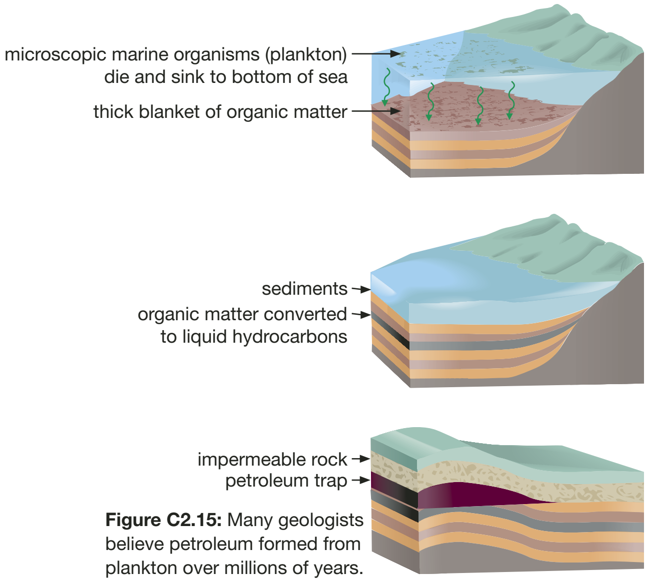


Figure C2.15: Many geologists believe petroleum formed from plankton over millions of years.

During the next 380 million years, this layer of organic material was subjected to heat and pressure that encouraged chemical reactions to occur as thousands of metres of sediment were piled on top. The accumulated top layer of sediment eventually changed into rock. Once the hydrocarbons had been converted into liquids, the pressure from above pushed these materials into more porous rock—the fossilized remnants of the ancient reefs. Since the type of rock formed above and below the reservoir of petroleum was impermeable shale, the petroleum had no place to go. As with the Burgess Shale, when fine particles of mud and sediment are subjected to geological processes, the result is impermeable rock. This is why a large concentration of petroleum in subsurface rock is called a **petroleum trap**.

petroleum trap: a large quantity of petroleum confined between layers of impermeable rock

Practice

13. During the 140 million years from the beginning of the Ordovician Period to the end of the Devonian Period, Alberta was mostly submerged below a warm tropical sea. Explain the significance of this time period to the creation of Alberta's petroleum reserves.
14. Characteristics of ocean waters off the coast of the Bahamas are thought to be similar in many ways to tropical waters that once covered Alberta. Explain why petroleum cannot be extracted from the bottom of the shallow waters that surround the Bahamas.

When geologists first began to look for petroleum, they looked for evidence at Earth's surface. This usually meant finding places where petroleum had seeped to the surface. Finding this kind of evidence wasn't easy in Alberta because, other than in the foothills and mountains, there are very few outcrops of rock that would indicate petroleum reserves.

As you can see in Figure C2.16, the Devonian rock containing the petroleum traps was located 1 km below the surface.

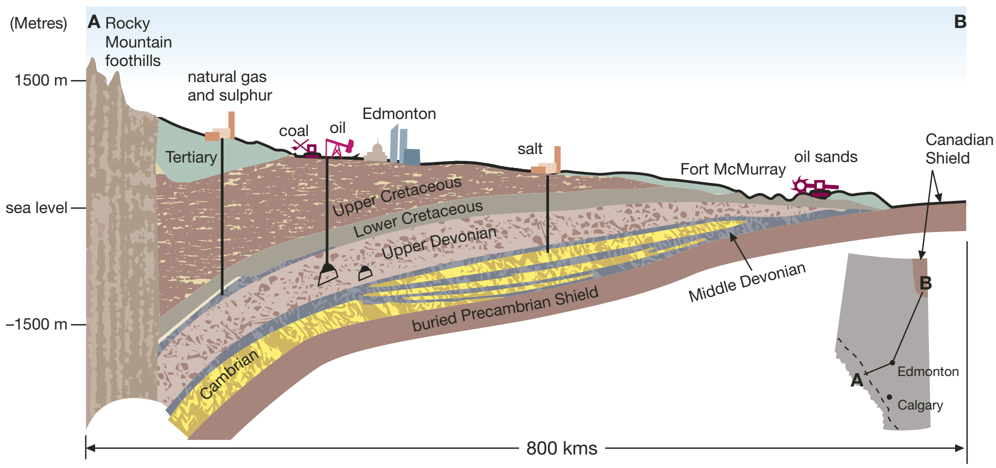


Figure C2.16: A cross section of Alberta shows major rock layers and some of the mineral resources they contain.

You can see the location of the Leduc oil field in Figure C2.16. It's located near Edmonton. How did geologists locate the petroleum trap that made Leduc #1 so famous in 1947? One method used was to drill a well and carefully examine the **drill-core** samples taken.

drill core: a cylindrical sample of subsurface rock taken during drilling operations and returned to the surface for analysis

The analysis of a drill-core sample allows geologists to identify the type of rock below the surface. Fossils may be present in the core sample. These fossils not only provide information about the age of the rocks, but they also reveal the environmental conditions. This information tells geologists if they are drilling into a reef or into rocks that formed in the deep water away from a reef.

After many years of drilling and studying thousands of drill-core samples, there is now a detailed picture of the subsurface rock under Alberta, as summarized in Figure C2.16.


Figure C2.17: This section of a core sample is from a sandstone formation. The black material is crude oil.


Figure C2.18: This top view of a limestone core sample shows fossil corals.

Investigation

Charting Patterns in Drill-Core Samples

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Introduction

Imagine you are the newest geologist with Big Moose Petroleum. One of your jobs is to look at records from drill-core samples and draw cross sections of the rocks (similar to the one in Figure C2.16).

Purpose

You will use drill-core data to chart patterns in subsurface rock formations.

Materials

- blank piece of paper
- ruler
- pencil

Procedure

step 1: Prepare your piece of paper by recording a scale of 1 cm = 1000 m and a sign convention of left being west and right being east. Draw a horizontal line 14 cm long in the middle of your paper to represent the 14 km east/west line separating the first drill site from the last site.

step 2: Add the following information to the horizontal line on your diagram. Well 1 is located at the western (far left) end of the line, while well 2 is 5400 m east of well 1. Well 3 is 1400 m east of well 2. Well 4 is 2400 m east of well 3, and well 5 is the farthest east at 4800 m east of well 4. Add a label for the location of each well.

step 3: Refer to the "Drill-Core Data" table on the next page. In this step you will begin to plot the drill-core data under each well. Use a ruler to mark a tick at the boundaries between the rock layers under each well.

step 4: When all the boundaries (or *contacts* in geological terms) have been plotted, connect the tick marks with a smooth line or curve.

step 5: Transfer the labels from the "Drill-Core Data" table to your diagram of the rock layers under the wells.

DRILL-CORE DATA

Rock Type	Well 1 Depth (m) Comments	Well 2 Depth (m) Comments	Well 3 Depth (m) Comments	Well 4 Depth (m) Comments	Well 5 Depth (m) Comments
sandstone, shale, and thin coal	0 to 1000	0 to 1000	0 to 1100	0 to 1000	0 to 950
sandstone	1000 to 1550 shallow-water fossils	1000 to 1600 shallow-water fossils	1100 to 1600 shallow-water fossils	1000 to 1600 shallow-water fossils	950 to 1450 shallow-water fossils
shale	1550 to 2900 deep-water fossils	1600 to 2700 deep-water fossils—same age as fossils in well #1	1600 to 2000 deep-water fossils—same age as fossils in wells #1 and #2	1600 to 2800 deep-water fossils—same age as fossils in wells #1, #2, and #3	1450 to 2950 deep-water fossils—same age as fossils in wells #1 through #4
reef	not found	2700 to 3000 fossilized remains of sponges	2000 to 3000 fossilized remains of sponges—very old fossils at bottom of section	2800 to 3000 fossilized remains of sponges	not found
limestone	2900 to ? no fossils	3000 to ? no fossils	3000 to ? very few fossils	3000 to ? no fossils	2900 to ? no fossils

Analysis

The rock layers in your diagram have all been formed by geological processes that lasted millions of years. Sandstone is made from layers of sand particles compressed together. Shale is formed from compacting smaller particles of fine mud and silt. Limestone results from the compaction of carbonate minerals, usually precipitated out of seawater or formed of calcium carbonate from the shells of ancient sea life. Coal is formed from the compressed remains of land plants.

1. **a.** Identify each of the rock layers as sedimentary, igneous, or metamorphic.
   b. Label the oldest and the youngest layers of rock on your diagram. What principle are you using?
   c. Concisely describe how the region's environment between these wells changed over geological time.
2. Identify the most likely location of a petroleum trap on your diagram.
3. Even though the petroleum might be confined to a fairly large trap, it's not necessary to drill hundreds of wells into the same trap to extract most of the recoverable petroleum. Explain why it may take only one well to begin the process of extracting the petroleum from a large trap.

Seismic Waves

Figure C2.19: Leduc #1 was discovered in 1947.

The location for Leduc #1 was chosen on the basis of seismic information. Seismology is the study of how waves of energy—called **seismic waves**—move through Earth. Geologists have known for some time that natural events, like earthquakes, create seismic waves. But waiting for an earthquake to send seismic waves through the rock you want to study is inconvenient when searching for oil.

seismic waves: waves that travel through Earth as a result of explosions or earthquakes

Instead, geologists and geophysicists use two methods to generate the waves. One method is to use explosives placed in a hole. Another uses a system to vibrate a massive plate attached to a truck. The vibrating plate can strike the ground with a force of more than 3.1×10^5 N. The seismic waves travel through the ground, and some of the energy in the waves reflects off each boundary between the rock layers.

Recording the Data

Geophones on the surface detect seismic waves and convert them into electronic signals to be recorded. This is done in the same way microphones convert sound into signals. The data is then processed by a **seismograph**. Once the seismograph has analyzed the data, it can provide a summary of the results in the form of a **seismogram**. In Figure C2.20 you can see that the horizontal lines correspond to the horizontal layers of rock and the tilted lines correspond to the tilted layers of rock. Some boundaries reflect more energy than others, so they appear to be darker on the seismogram. Seismic exploration data can suggest where traps might be located, but only by drilling a well can you be sure if there is oil or gas present within the traps. In "Seismograph Simulation" you will have an opportunity to see the basic operation of a seismograph.

seismograph: an instrument that records seismic waves

seismogram: a record of seismic waves provided by a seismograph

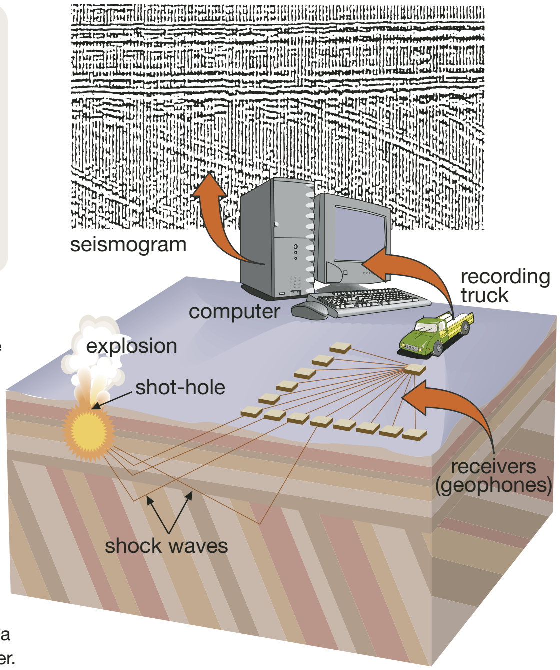


Figure C2.20: Explosives generate waves that travel through the rock. The waves reflect off the boundaries with other rock layers and return to the surface. Geophones convert the seismic waves into electrical signals to be processed by a specialized computer.

Utilizing Technology

Seismograph Simulation

Science Skills

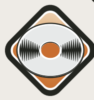
✓ Performing and Recording

Purpose

You will observe a simulation of a seismograph in operation.

Procedure

Follow the instructions provided in the applet titled "Seismograph" on the Science 20 Textbook CD. Then answer the following questions.



Analysis

1. Would geophones first detect reflections in layers close to the surface or in deeper layers? Explain your answer.
2. Seismic exploration on land requires that geophones be arranged in lines, as in Figure C2.20. In forested areas, this requires that small roads and tracks be made in the forests, often for many kilometres. Briefly describe the environmental impact of these seismic lines. You will examine the environmental impact of seismic exploration in greater detail in Unit D.

2.2 *Summary*

Alberta remained near the equator following the end of the Cambrian Period and throughout most of the Paleozoic Era. During most of the Ordovician, Silurian, and Devonian Periods, Alberta was submerged under the shallow waters of warm tropical seas. The fossil evidence suggests that huge reefs flourished in these waters. Geologists think that microscopic marine life had been living in these tropical seas for tens of millions of years. The dead remains of these organisms created a thick blanket of ooze on the bottom of these seas that was eventually to become Alberta's reserves of petroleum. Most of Alberta's petroleum is found in the remains of ancient reefs.

Locating sources of petroleum in subsurface rock can be done by analyzing drill-core samples and by using seismograms. This information can help predict the location of petroleum traps.

2.2 Questions

Knowledge

1. Define the following key terms.

a. petroleum
b. reef
c. petroleum trap
d. seismic waves

2. Construct a portion of the Geological Time Scale similar to this one.

Devonian
Silurian
Ordovician
Cambrian
Precambrian

Using the "Geological Time Scale" on page 312, place the following events in their approximate places.

a. Burgess Shale
b. Cambrian Explosion
c. first appearance of land plants in fossil record
d. first appearance of animals with backbones in fossil record
e. first appearance of land-dwelling animals
f. microscopic marine organisms thrive—source of Alberta's future petroleum

Applying Concepts

3. The speed of a seismic wave depends mostly upon the density of material the wave is travelling through. In general, the denser the material, the faster the wave travels. The following table represents typical densities for crude oil—a common form of petroleum—and a few types of rock.

Material	crude oil	limestone	sandstone	shale
Density (g/cm^3)	0.9	2.5	2.3	2.2

When the seismic wave encounters a boundary between two layers of rock with different densities, the sudden change in speed can cause a reflection to occur. It is usually the case that the larger the speed difference between materials at the boundary, the stronger the reflection. The reflected part of the seismic wave is redirected toward the surface.

a. If the seismic wave is capable of travelling through all of these materials, rank the materials from slowest to fastest.
b. Which combination of materials would produce the strongest reflection?
c. Which combination of materials would produce the weakest reflection?

2.3 Earthquakes

Figure C2.21: The Four Seasons Apartments in Alaska collapsed during the earthquake of March 27, 1964. The building was under construction and unoccupied.

Geologists think intense earthquakes and volcanoes frequently occurred in Alberta hundreds of millions of years ago. No one was around to observe these ancient events, so if you really want to know what earthquakes are like, you need to observe the effects of earthquakes in modern times.

Around supper hour on the evening of March 27, 1964, most people in Alaska were already home from work or on their way home. Since this day was also Good Friday, the start of the Easter holiday, many businesses had closed early. College students had already left to go home for the holiday, and most highrise office buildings were empty. All these factors proved to be lifesavers because, at 5:36 p.m., the second-largest earthquake ever recorded by a seismograph occurred.

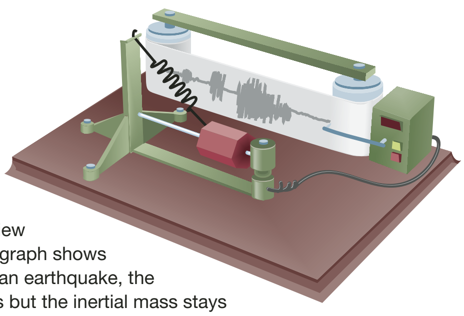


Figure C2.22: This simplified view of a seismograph shows that during an earthquake, the base moves but the inertial mass stays still and a recording of the motion is made on the paper. The paper is fed at a constant speed.

Earlier in this chapter, you learned that when searching for petroleum in subsurface rock formations, man-made explosions can create seismic waves that can be recorded by a seismograph. In the case of The Alaska Earthquake of 1964, the seismic waves were so intense that a seismograph in Alaska that was attempting to record the event literally went off the chart.

The energy released by this earthquake was so intense that Earth vibrated like a gigantic planetary bell. The ringing triggered effects that were felt around the world. The next day, farmers in both Alberta and Saskatchewan noticed changes in the height of their well water. Similar effects were later reported from places as far away as South Africa.

Most property damage occurred in the coastal areas of Alaska closest to the actual location where Earth's tectonic plates suddenly moved. The city of Anchorage suffered the greatest amount of property damage—about 30 blocks of office buildings and apartment buildings were destroyed. Most schools were severely damaged. For example, the Government Hill Grade School was completely destroyed by one of the many landslides that resulted from the three minutes of violent ground shaking.

As you will learn later in this lesson, underwater landslides proved to be particularly devastating due to the huge water waves they generated in both bays and fjords.

What caused this earthquake? How did seismic waves carry this energy to other parts of the planet? The 1964 earthquake measured 9.2 on the Richter scale. What does this number mean? How is it determined? In this lesson you will answer these questions. The answers will form important background information for the next parts of Chapter 2, as you return to events within Alberta and study the processes responsible for the formation of the Rocky Mountains.

Practice

15. Use the information from this lesson and Lesson 1.1 to define the following terms.

- **a.** crustal plate
- **b.** plate tectonics
- **c.** seismic wave

16. Why do urban areas usually suffer the greatest loss of life as a result of earthquakes?

fault: a crack in Earth's crust due to the motion of one tectonic plate relative to another

subduction: the downturning of oceanic crust under another crustal plate

Causes of The Alaska Earthquake of 1964

The Alaska Earthquake of 1964 was caused by the motion of the Pacific Plate relative to the North American Plate. The boundary between these two crustal plates is called a **fault**. The Pacific Plate is made of dense oceanic crust, so it tends to be pushed under the less dense continental crust of the North American Plate.

This process is called **subduction**. As a result of this subduction, the continental crust that made up most of southern Alaska was compressed and warped by the huge pressures between these two plates. The stress caused the rock to deform or change shape by bending. Energy was stored in the deformed areas in the form of elastic potential energy, much like when a spring is compressed. When the stress became greater than the breaking strength of the rock, a break occurred in the fault. The stored energy within the misshapen plate was suddenly released.

The stress between the two plates was relieved on March 27, 1964, when portions of southern coastal Alaska could no longer withstand the strain and suddenly moved to the southeast over the Pacific Plate. On average, the total distance moved was about 9 m. This sudden motion of the lithosphere caused seismic waves to be sent out. This transferred energy from the lurching crust to other points on Earth's surface.

During The Alaska Earthquake of 1964, the seismic waves originated from the initial breaking point along the fault (called the **focus**), which was a region 25 km below Earth's surface. Prince William Sound, located approximately 120 km east of Anchorage, was the place on Earth's surface directly above the earthquake's focus, so it was called the **epicentre**.

focus: the region that first breaks along a fault during an earthquake

epicentre: the point on Earth's surface directly above the focus of an earthquake

In "Utilizing Technology: Subduction," you can view an applet on the Science 20 Textbook CD to see how the process of subduction can lead to earthquakes.

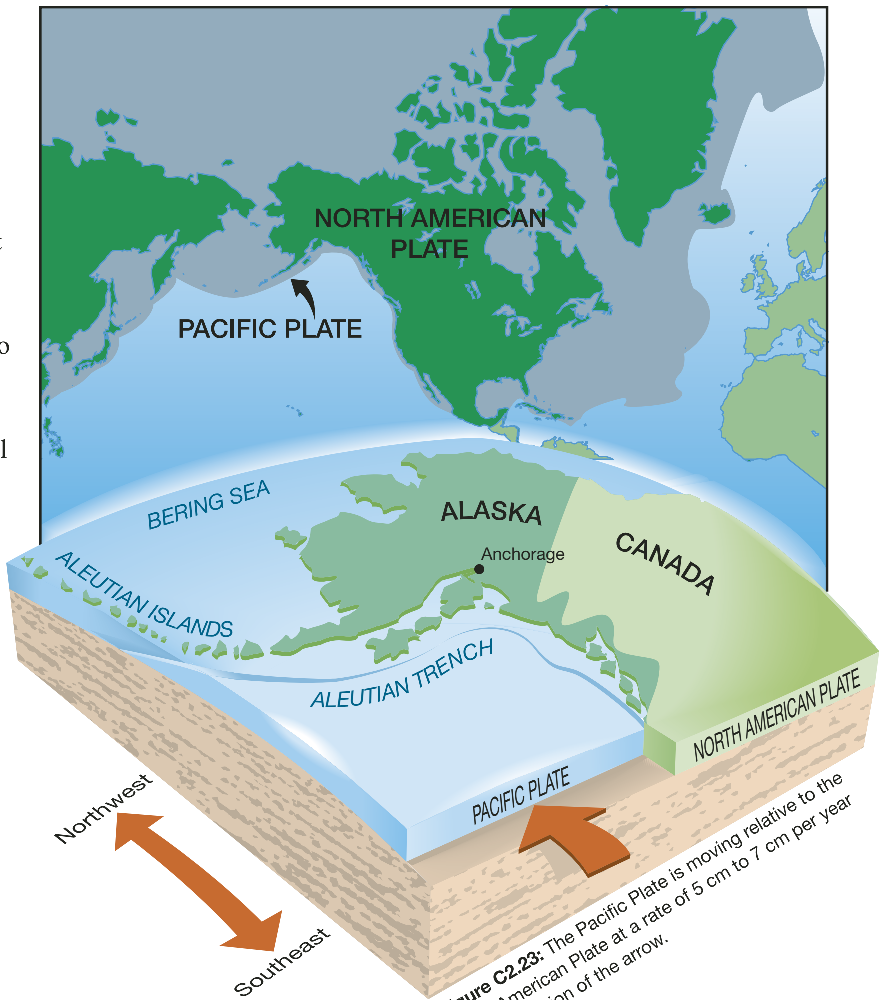


Figure C2.23: The Pacific Plate is moving relative to the North American Plate at a rate of 5 cm to 7 cm per year in the direction of the arrow.

Utilizing Technology

Subduction

Purpose

You will watch the applet "Subduction" that animates a similar process to the subduction of the Pacific Plate under the North American Plate, which caused the famous 1964 earthquake. The analysis questions will allow you to apply the information presented in this lesson to the process shown in the applet on the Science 20 Textbook CD.

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Analysis

Use Figure C2.24 to answer the next two questions.

The following labels have been omitted from the diagram: fault, focus, epicentre, lithosphere, asthenosphere, seismic waves, oceanic crust, and continental crust.

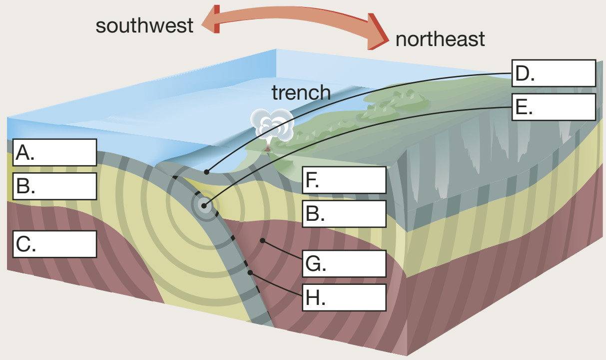


Figure C2.24: This diagram outlines an earthquake's focus and epicentre.

1. Correctly match each label on the diagram with its correct box in Figure C2.24.
2. Recall your work with the rock cycle in Chapter 1.
   - **a.** Identify the type of rock (sedimentary, igneous, or metamorphic) you would expect to find at the point labelled E.
   - **b.** Concisely explain what happens to the oceanic crust as it descends into the mantle.
   - **c.** Use your answer from question 2.b. to concisely explain why it is quite likely that the mountains shown in Figure C2.24 are volcanically active.

Types of Seismic Waves

So that energy released at the focus can reach the surface, seismic waves have to transfer the energy through the subsurface rock. One way for seismic waves to transfer energy is through **primary waves**, which are often called **P-waves** for short.

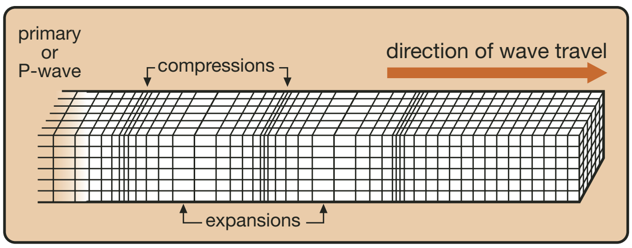


Figure C2.25: P-waves are also known as primary waves.

As the name suggests, the primary or P-waves are the first to arrive because they travel the fastest. As these waves travel through the rock, the matter is alternately compressed and then expanded. Since P-waves are like an extremely low-frequency sound wave, they are able to travel through solids, liquids, and gases.

Another way that seismic waves can transfer energy is through **secondary waves or S-waves**.

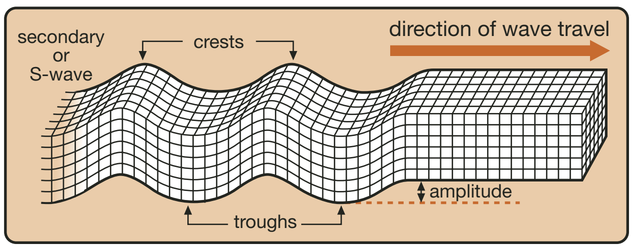


Figure C2.26: S-waves are also termed secondary waves.

S-waves move slower than P-waves and can only move through solid rock. In an S-wave the rock vibrates up and down—or left and right—as the wave moves forward. As a result, S-waves cause the rock to change shape without changing volume. Since liquids and gases do not resist a change in shape (liquids and gases flow instead), S-waves cannot pass through liquids and gases. S-waves have a larger **amplitude** and, therefore, transfer more energy than P-waves.

primary wave or P-wave: a seismic wave that travels through rock as a series of compressions and expansions of particles

A P-wave is able to pass through solids, liquids, and gases.

secondary wave or S-wave: a seismic wave that travels through rock as a series of crests and troughs

An S-wave can pass through solids but not liquids or gases.

amplitude: the maximum displacement of a wave from the rest position

Investigation

Modelling Seismic Waves with a Spring

Purpose

You and your partners will use a large-diameter spring (a Slinky) to generate waves that model P-waves and S-waves. You will also have an opportunity to observe the connection between spring properties and the speed of the wave that travels through the spring.

Science Skills

✓ Initiating and Planning
✓ Performing and Recording
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Materials

- metre-stick
- stopwatch
- large-diameter spring (for example, a Slinky)

CAUTION!

Don't overstretch the spring. Overstretching may cause the spring to become permanently deformed. Don't suddenly release one end of the spring when it's stretched. The recoiling spring may strike and injure your partners.

Procedure

step 1: Model a P-wave. Generate a P-wave by thrusting your hand—which is holding the spring—back and forth toward the other end of the spring. You can tell if this is being done correctly because the spring will remain in a straight line. There will be little sideways motion. The main motion should be the compression travelling down the spring.

step 2: Repeat the previous step until all members of your group have a chance to generate the model of the P-wave.

step 3: Record a sketch of your model of a P-wave. Be sure to include labels for compressions and expansions.

step 4: Model an S-wave. Have two members of your team stretch the spring out several metres across a hard-surfaced floor. Have one partner hold his or her end of the spring still while the other partner moves the end of the spring to the left and to the right at a steady rate. Adjust the rate of hand motion so the wave clearly shows crests and troughs.

step 5: Repeat step 4 until all members of your group have an opportunity to generate the model of an S-wave.

step 6: Record a sketch of your model of an S-wave. Be sure to include labels for crests and troughs.

step 7: Design a simple procedure to measure the speed of a model S-wave when the spring is stretched to its safest maximum length. Concisely record your method.

step 8: Record your measurements and calculations in an appropriate format.

step 9: Repeat steps 7 and 8 when the spring is only stretched to half of its maximum length. Record your results.

Observations

1. Record your labelled sketch of a model P-wave.
2. Record your labelled sketch of a model S-wave.
3. Record the procedure used to determine the speed of a wave.

Calculations

4. Record the data and calculations for the speed of the S-wave when the spring is at its safest maximum stretch.
5. Record the data and calculations for the speed of the S-wave when the spring is at one-half the length of its safest maximum stretch.

Evaluation

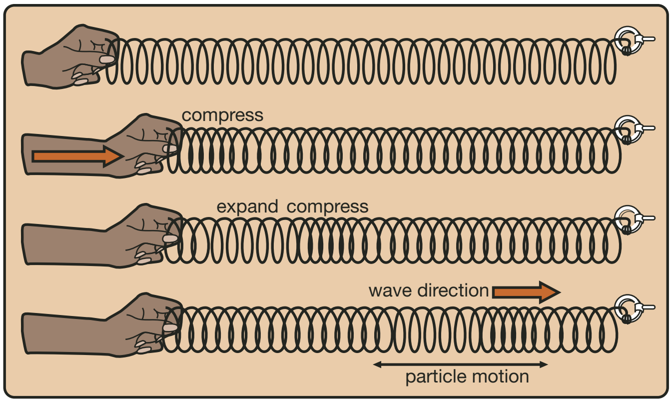
6. Share the results of your calculations with other student teams.
   a. Compare your speed values with those of other groups. How do you account for any differences?
   b. Compare your procedure for determining velocity with the methods devised by other groups. If you had to repeat this activity, what improvements would you incorporate?

In "Modelling Seismic Waves with a Spring," you created a model of P-waves by moving your hand in a direction parallel to the direction the wave was moving. This is why a P-wave is classified as a **longitudinal wave**. When you created a model of S-waves, your hand moved in a direction perpendicular to the direction the wave was moving. It is for this reason that an S-wave is classified as a **transverse wave**.

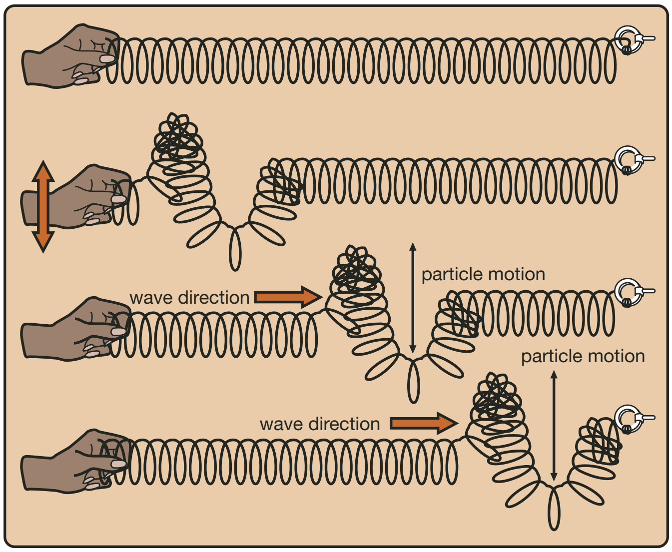
longitudinal wave: a wave in which the vibration of the particles is parallel to the direction the wave is travelling

transverse wave: a wave in which the vibration of the particles is perpendicular to the direction the wave is travelling

P-Wave Model



S-Wave Model



P- Waves, S-Waves, and Earth's Interior

In "Modelling Seismic Waves with a Spring," you observed that changing a property—like the tension in a spring—influences the speed of a wave that travels through that spring. In Chapter 1 you learned that Earth is comprised of a number of layers. These layers have different properties, such as density, temperature, and pressure, that all increase as you move from Earth's crust to its inner core. If you combine the results of the investigation with this idea, it is reasonable to suppose that seismic waves should travel at different speeds as they pass through different layers of Earth's interior. Geologists have found evidence to support this.

As depth increases, the speed of both P-waves and S-waves increase. Sudden changes in rock properties cause the waves to quickly change direction. This is similar to light waves bending as they enter a lens. This sudden change in direction causes a region where P-waves from an earthquake cannot be detected; this region is called a P-wave shadow zone. Researchers concluded that the P-wave shadow zone could be explained if Earth's centre were composed of different material than the mantle.

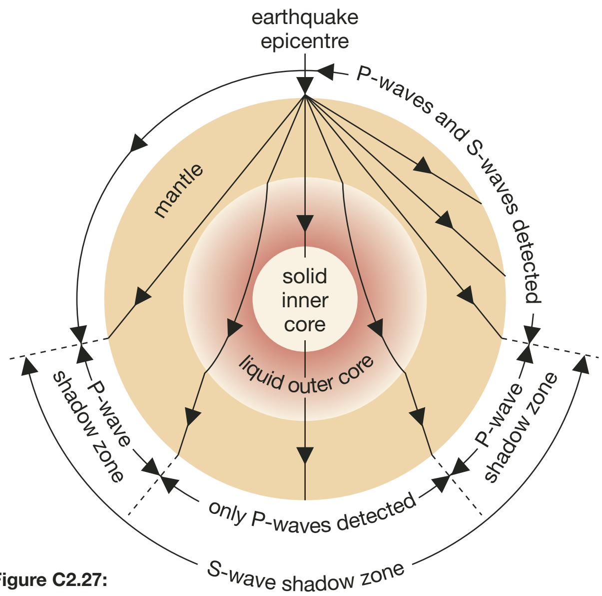


Figure C2.27: Shown are the changes in direction of seismic waves as they pass through Earth. The sudden change of properties at the mantle/core boundary causes the P-waves to bend.

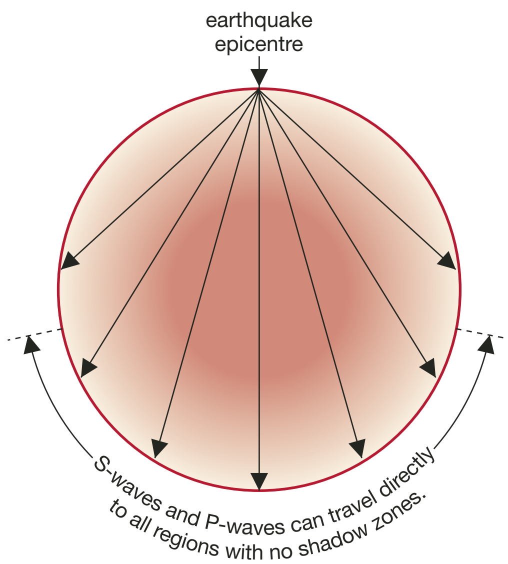


Figure C2.28: An imaginary Earth with a completely solid interior of uniform composition would have no shadow zones.

If you look carefully at Figure C2.27, you will see a region on the side of Earth opposite the earthquake epicentre where only P-waves are detected. There is a much larger region called the S-wave shadow zone where no direct S-waves are received. What could prevent S-waves from travelling directly from the earthquake through the planet's centre? The simplest explanation is that the outer portion of the core must be liquid, since S-waves do not move through liquids. If Earth had a uniformly solid composition from its crust to its centre, both P-waves and S-waves would move in straight lines at a constant speed, as in Figure C2.28. Therefore, there would be no bending and no shadow zones.

Surface Wave Examples

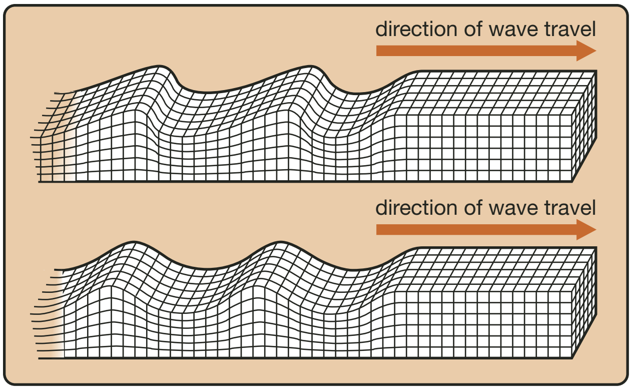


Figure C2.29: Surface waves move along the surface of Earth's crust.

Surface waves do not travel through the interior of Earth, but they do move along the surface of Earth's crust. The motion of surface waves is more complex than P-waves or S-waves.

As a surface wave moves along the ground, it causes the ground to move, much like a water wave will move a boat up and down. Surface waves will also move the ground from side to side, similar to an S-wave. Surface waves do not travel far from the epicentre, and they travel slower than S-waves.

The "Properties of Seismic Waves" table summarizes the properties of types of seismic waves.

PROPERTIES OF SEISMIC WAVES

Property	Primary Waves	Secondary Waves	Surface Waves
range of speeds (km/s)	6 to 14	3 to 8	1 to 6
mode of vibration	longitudinal: particles vibrate parallel to wave velocity by creating compressions and expansions	transverse: particles vibrate perpendicular to wave velocity by creating crests and troughs	complicated combination of transverse and longitudinal vibrations
transmitting materials	solids, liquids, and gases	solids only	mainly through solids
part of Earth transmitting type of wave	all parts of Earth—atmosphere, lithosphere, mantle, and core	the lithosphere and mantle only	top layer of Earth's crust in upper lithosphere
effects during an earthquake	• first wave to arrive • perceived as abrupt thud	• second wave to arrive • causes first period of ground rolling • more damaging than P-waves	• last waves to arrive • responsible for most of ground shaking • cause most damage because buildings can only withstand minimal shaking

Practice

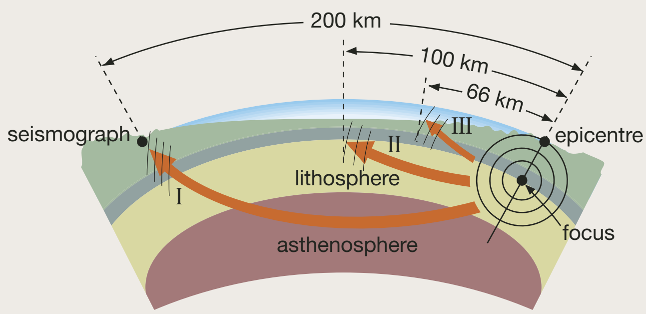


Figure C2.30: Three seismic waves are illustrated.

Refer to Figure C2.30 to answer questions 17 and 18. It shows three seismic waves—labelled I, II, and III. It also shows the distance travelled by these waves from the focus of an earthquake after 20 s. These waves are all eventually detected and recorded by the seismograph located 200 km away from the epicentre.

17. Assume that all three waves travel 200 km from the focus to the seismograph.

  a. Calculate the speed of waves I, II, and III.

  b. Use your answer from 17.a. to determine the type of wave that corresponds to each wave.

  c. The energy of a seismic wave is indicated by the amplitude of the signal recorded by the seismograph. The maximum amplitude of wave III is indicated as A_3 on Figure C2.31. Relate two reasons why wave III is more likely than waves I and II to damage buildings at the seismograph's location.

18. Refer to your answers for question 17. Determine which of the waves could travel directly to a seismograph on the completely opposite side of the planet from the epicentre.

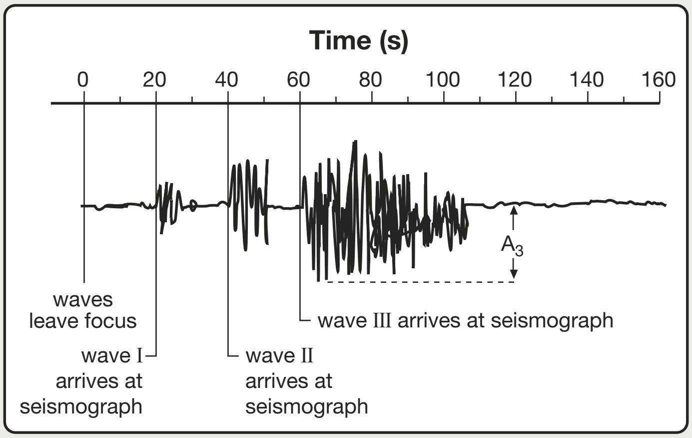


Figure C2.31: A seismogram is an earthquake record obtained by a seismograph.

Studying Earthquakes Using Seismic Waves

Although surface waves produce the most damage in an earthquake, most geologists are more interested in P-waves and S-waves—these waves can travel through Earth and provide a lot of information about its internal structure. Although they were generically referred to as seismic waves earlier in Chapter 2, the waves that geologists generate to look for petroleum in subsurface rock are, in fact, P-waves.

One of the most common applications of P-waves and S-waves is locating an earthquake's epicentre. In questions 17 and 18, you saw how the S-waves lag behind the P-waves. This is due to the lower speed of the S-waves.

The time difference between the arrival of S-waves, as compared to P-waves, provides a method of locating the distance between the seismograph and the epicentre. The farther away from the epicentre, the greater the time difference between the arrival of the P-waves and S-waves. This principle is similar to two runners, where the faster runner will always reach the finish line first. But the longer the race, the greater the time difference between the arrival of the two runners.

Figure C2.32: This United States Coast Guard dock was drastically altered after The Alaska Earthquake of 1964. It was raised more than two metres above the high-tide mark.

The time interval between the two waves can also be used with other values to determine the **Richter magnitude** of an earthquake. The Richter magnitude is useful for both categorizing and comparing earthquakes. An earthquake with a Richter magnitude of 3.0 is barely detectable by people. The Alaska Earthquake of 1964 had a Richter magnitude of 9.2, second only to the 9.5 magnitude of the Chilean earthquake of 1960. Earthquakes with larger magnitudes may have occurred prior to the development of the Richter scale.

Richter magnitude: a number assigned to an earthquake based upon the amount of vertical ground motion at its epicentre

"Earthquake Analysis" on page 350 uses an applet that illustrates the key points in both finding the epicentre and determining the Richter magnitude of an earthquake.

Utilizing Technology

Earthquake Analysis

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will locate the epicentre of an interactive earthquake by using the applet titled "Earthquake Analysis" on the Science 20 Textbook CD. You will also have an opportunity to calculate the Richter magnitude of the virtual earthquake by using your data.

Preparation

This application is completely self-contained and is quite user-friendly. It would be very helpful to have access to a printer. You will want to print key documents to not only record your progress but also provide study materials to prepare for tests.

Work through the application according to the instructions. To create a record of your progress, print the following key documents:

- the seismograms that allow the measurement of the S-wave and P-wave intervals
- the tables for calculating distance to the epicentre
- a map that shows the triangulation to find the epicentre
- the seismograms that allow the measurement of the S-wave amplitudes
- a table (nomogram) for determining the earthquake's Richter magnitude

Check for Understanding

1. Outline the basic steps to determine an earthquake's epicentre by using data from three different seismographs. Answer in the form of a flowchart.
2. Concisely explain why the amplitude for the S-wave measured by a seismograph is a smaller value at a seismic station located farther away from an earthquake's epicentre.

Tsunamis

Although it was a victim of The Alaska Earthquake of 1964, the fishing boat in Figure C2.33 was not carried to the centre of the town of Kodiak by earth movement. This damage was done by a **tsunami**, which is sometimes incorrectly called a tidal wave. The sudden movement of the sea floor that occurred as the Pacific Plate moved under the North American Plate caused a series of enormous seismic sea waves.

tsunami: a seismic sea wave set off by an earthquake in or near an ocean basin

Most of the damage and loss of life from this earthquake was due to the resulting tsunami that moved down the Pacific coast of North America and across the Pacific Ocean.

Figure C2.33: This boat was damaged by a tsunami in 1964.

On December 26, 2004, the strongest earthquake since The Alaska Earthquake of 1964 occurred 255 km off Sumatra's coast in the Indian Ocean. Like the Alaska earthquake, this was a large earthquake—with a Richter magnitude of 9.0—caused by one tectonic plate being subducted under another. This generated a powerful tsunami.

However, in this case, the tsunami hit densely populated areas in South Asia and East Africa. Hardest hit were parts of Sumatra, Indonesia, and India's Nicobar Islands. In total, approximately 300 000 people lost their lives in this tragedy.

Tsunamis and First Nations People

The oral traditions of the Pachena people from northern Vancouver Island suggest that an earthquake and the large tsunami that followed destroyed a village. This was described by Chief Louis Clamhouse in 1964.

> They had practically no way or time to try to save themselves. I think it was at nighttime that the land shook . . . . I think a big wave smashed into the beach. The Pachena Bay people were lost . . . .

The oral traditions of other First Nations people recall a time when Earth shook for days, whales were found in the forest, and landslides buried entire villages. Many geologists regard these stories as accurate oral accounts of an earthquake that occurred on the west coast of Vancouver Island on January 26, 1700, at about 9:00 p.m. How could scientists deduce the time of this event? The arrival of the resulting tsunami ten hours later was accurately recorded in the historical records of fishing villages all along the east coast of Japan.

Using this data and other evidence, geologists suspect that the quake probably originated off the coast of Vancouver Island. You can learn more about the Cascadia Megathrust Earthquake of 1700 in the Chapter 2 Review Questions.

2.3 Summary

Earthquakes occur due to the sudden release of stored energy. This energy builds up over time due to the motion of crustal plates. When the energy is released, one plate suddenly moves relative to another—this causes seismic waves to travel through the surrounding rock. Primary waves, or P-waves, travel the fastest, so they are the first to arrive at some other point on Earth's crust. Secondary waves, or S-waves, arrive next and these tend to cause more damage than P-waves. Although they do not travel as far as primary waves and move at relatively low speeds, surface waves tend to do the greatest damage during an earthquake. The difference in the arrival times of P-waves and S-waves can be used to determine the location of the epicentre of the earthquake if data from at least three seismographs is available. This information can also be combined with the maximum amplitude of the S-wave to determine the Richter magnitude number of the earthquake.

2.3 Questions

Knowledge

1. Sketch two diagrams to illustrate the differences between S-waves and P-waves.
2. Identify which type of seismic wave produces the most damage in an earthquake.
3. Explain why it is incorrect to say that the seismic waves produced by an earthquake start at its epicentre.

Applying Concepts

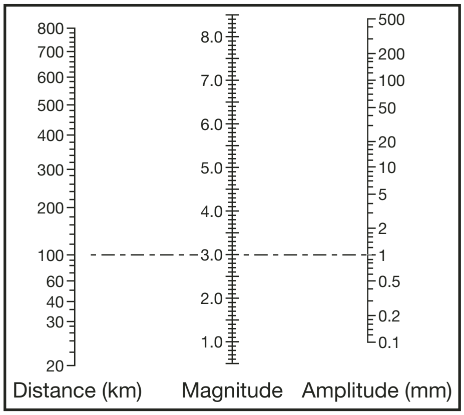
Figure C2.34: This map of British Columbia shows estimated distances to an earthquake's epicentre.

4. Figure C2.34 shows the estimated distances to the epicentre of an earthquake for three seismographs. Use the map to determine the epicentre of this earthquake.
5. Refer to Figure C2.34. The three seismograph stations shown on the map recorded the following data.

Seismograph Station	S-P Interval (s)	Distance to Epicentre (km)	Maximum Amplitude of S-wave (mm)
Vancouver	77	760	9
Bella Coola	40	390	140
Prince George	63	620	20

Use this data and the "Richter Magnitude Chart" to determine the Richter magnitude for this earthquake.

Richter Magnitude Chart



6. Concisely explain why the maximum amplitude of the S-wave is larger in Bella Coola than it is in Vancouver, even though the seismographs are measuring the same earthquake.
7. Internet Search: The largest earthquake recorded by seismographs in Canada had its epicentre in the same location as the fictional earthquake described in questions 4 to 6. Use the Internet to research answers to the following questions.
   a. Identify when Canada's largest earthquake recorded by a seismograph occurred.
   b. What was the Richter magnitude number for this earthquake?
   c. Concisely describe the cause of this earthquake in terms of the motion of tectonic plates.
   d. Explain how you located information to answer the other parts of question 7. Identify the search strategies used and how much time you needed. Compare your strategies and results with other students. How could you have improved your approach to more efficiently find the information?

2.4 Raising the Rockies

Figure C2.35: Mount Michener has complex folds within its beds of shale and limestone.

The Rocky Mountains are truly spectacular. Your eyes may at first be drawn to the peaks and the overall beauty of the surrounding landscape. As you take in the view, your eyes may start to notice some of the finer details. For example, you may begin to appreciate the beauty of the patterns within the rock layers. Note the complex folds within the beds of shale and limestone in the photo of Mount Michener in Figure C2.35.

You earlier discovered that shale is a sedimentary rock originally laid down in nearly horizontal layers of fine sediment at the bottom of tropical seas. The fossil evidence from sites such as the Burgess Shale supports this idea. So, how does the floor of a tropical sea get raised up to become a mountain? How can such massive layers of rock become folded into such intricate designs? What forces could produce these incredible effects? The answers have a lot to do with plate tectonics. In this lesson you'll see that there is much in common with the mechanisms that caused both The Alaska Earthquake of 1964 and the raising of the Rocky Mountains about 170 million years ago.

Locating Plate Boundaries

Before returning to the Alberta of ancient times, it is important to develop a better understanding of plate tectonics and the mechanisms capable of building mountains. Finding the current boundaries of Earth's tectonic plates is a good place to begin.

It was the years of built-up stress between the Pacific Plate and the North American Plate that gradually accumulated a huge amount of stored energy along the southern coast of Alaska in the early 1960s. The sudden release of this energy caused The Alaska Earthquake of 1964 in March of that year. Since earthquakes usually occur at the boundaries of crustal plates, it makes sense to plot the locations of major earthquakes on a world map to locate the edges of the major plates.

A case can also be made for plotting volcanoes on a world map. In Chapter 1, it was stated that Earth's crust is comprised of a series of rigid crustal plates that move over the asthenosphere—a zone of partially molten rock. The asthenosphere is the source of magma for volcanoes. Volcanoes usually occur at a boundary where two plates move apart, or at a boundary where one plate is pushed under another plate. Even though volcanoes sometimes occur at places not close to plate boundaries, plotting the locations of the world's active volcanoes can still provide valuable insights for mapping out the edges of crustal plates. In "Mapping the Edges of Crustal Plates," you will have an opportunity to use the Internet to collect information about the locations of active volcanoes and earthquakes.

Utilizing Technology

Mapping the Edges of Crustal Plates

Purpose

You will use the Internet to determine the locations of active volcanoes and earthquakes. You will record your results on a world map and label the plates from a provided list of names.

Materials

You will need access to a computer. You will also need a copy of the "World Map" on the Science 20 Textbook CD to record the locations of volcanoes and earthquakes.

You may decide to print this map and record your findings on the print copy with different pens—one colour for earthquakes, another for volcanoes. Alternatively, you could electronically paste a copy of the map into another software application that would allow you to electronically add your colour-coded findings to the map before printing your finished map.

Figure C2.36: A copy of this map can be found on the Science 20 Textbook CD.

Science Skills

✓ Initiating and Planning
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Procedure

step 1: As with any Internet search, your success will largely depend upon your ability to choose appropriate combinations of key words to enter into the search engine. You should also consider the time frame you used to limit the scope of your search. For example, do you search for earthquakes that occurred in the last year, the last five years, or the last 100 years?

step 2: Transfer the results of your Internet search to your map by using one colour to represent an earthquake and another for the location of a volcano.

step 3: You should start to notice that the dots will form a pattern of lines that corresponds to the edges of the crustal plates. If the dots are too far apart and too random to form a clear pattern, return to step 1 and modify your search techniques either by changing the key words or by modifying the time line in your search. On the map you created in step 2, record the modifications that improved your results.

step 4: Repeat steps 1 to 3 until you have a clear pattern of plate boundaries.

Analysis

1. Your map now needs labels to be added for the larger plates. Select your labels from the following list:

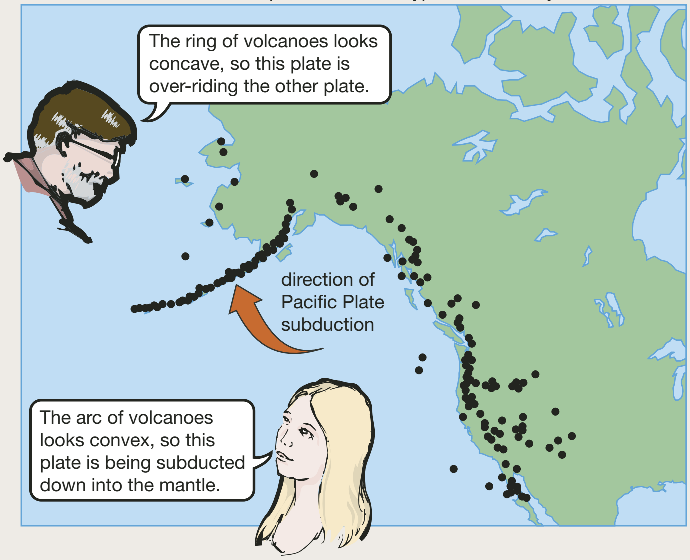
   - North American Plate
   - South American Plate
   - Pacific Plate
   - African Plate
   - Antarctic Plate
   - Indo-Australian Plate
   - Eurasian Plate
   - Arabian Plate

   There are many smaller plates, but many do not have recognizable names. For example, the Nazca Plate lies to the west of the South American Plate, and the Cocos Plate is west of Central America. Add these names to your map.

2. Lines of volcanoes are generally found in places where one plate is being pushed under another plate. The volcanoes are located on the over-riding plate. As shown in Figure C2.37 of Alaska's Aleutian Islands, an arrow can be added to show the direction of the down-going Pacific Plate relative to the over-riding North American Plate. A pattern has been noticed by geologists concerning the type of curve in the arc of volcanoes. If an observer looks at the arc and it appears convex—the middle of the curve is the closest part to the person—then that observer is on the down-riding plate being subducted. If an observer looks at the arc and it appears concave—the middle of the curve is the farthest part from the person—then that observer is on the over-riding plate.

Use this information to add arrows that show where the northern section of the Pacific Plate is being subducted.

Figure C2.37: Depending on where they're viewing an arc of volcanoes from, observers will have different opinions on what type of curve they see.



3. Refer to your answer to question 2. Infer a reason why the perimeter of the North Pacific is called *the ring of fire*. Does the direction of the arrows imply the Pacific Ocean is growing or shrinking?

Evaluation

4. It is helpful to share your findings with other students. Compare your map with the work of other students. Are there major differences in the labelled maps produced? If you had to do a similar exercise again, what would you have done differently?

DID YOU KNOW?

The Global Positioning System (GPS) can be used to very accurately determine your position on Earth's surface. The United States Geological Survey uses GPS in Southern California and other places to measure movement along the many fault lines that mark the edge of the tectonic plates. GPS is also used near volcanoes to record the uplifting of surface rock due to the motion of magma deep beneath the surface.

Further Evidence for Plate Tectonics

In Chapter 1 you saw how paleomagnetism from the bottom of the Atlantic Ocean provided evidence for the theory of plate tectonics. In "Mapping the Edges of Crustal Plates," you saw how the location of earthquakes and volcanoes can produce a world map showing crustal plate boundaries.

Pangaea: a single supercontinent that formed in the late Paleozoic Era

Some of the strongest evidence for the theory of plate tectonics emerges from the end of the Paleozoic Era. Geologists think Earth's land masses formed a single gigantic continent called **Pangaea** at that time. The name *Pangaea* was coined by Alfred Wegener in 1915 when he first proposed his theory of continental drift, which is a forerunner to the theory of plate tectonics.

In "Plate Tectonics" on page 355, you will consolidate your understanding of plate tectonics by watching an applet on the Science 20 Textbook CD.

Utilizing Technology

Plate Tectonics

Purpose

You will have an opportunity to collect further evidence that supports the theory of plate tectonics by watching "Plate Tectonics" on the Science 20 Textbook CD.

Science Skills

✓ Performing and Recording

Procedure

Preview the questions in "Analysis" before watching the applet. When information presented addresses a particular question, pause the applet and concisely record your answer.

Analysis

1. Sketch a diagram of two continents that illustrates the jigsaw-fit argument for plate tectonics.
2. Identify one example of places on Earth that are now widely separated by ocean waters but were once part of a common geological formation.
3. A mesosaurus was a small freshwater reptile that lived in the late Paleozoic Era. The illustration in Figure C2.38 is an artist's conception of what a mesosaurus might have looked like, based upon the current fossil evidence. Concisely explain how the distribution of mesosaurus fossils supports the existence of both Pangaea and the theory of plate tectonics.

Figure C2.38: A mesosaurus might have looked similar to this.

Alberta Becomes Part of Pangaea

It was during the Devonian Period that beds of organic matter were being laid down to form part of Alberta's future economic wealth in the form of petroleum. In terms of crustal plate movement, the Devonian Period saw Greenland and eastern Canada colliding with northern Europe to begin the process of forming a single northern land mass. Geologists believe the result of this collision was the mountain chain referred to in the "Plate Tectonics" applet. Africa, India, Australia, and South America were already joined as a huge southern land mass. The spaces between the pieces of this ancient continental jigsaw puzzle were closing.

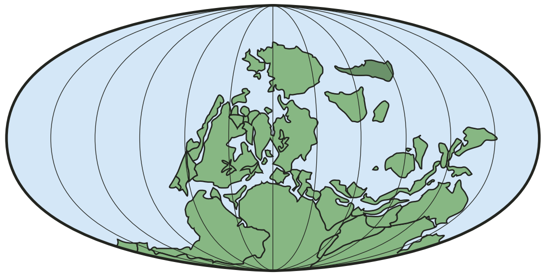


Figure C2.39: Earth may have looked like this 350 million years ago at the beginning of the Carboniferous Period.

As the continents continued to creep toward their eventual merger, the fossil evidence shows that life was continuing to diversify. In the Carboniferous Period, swamps covered much of eastern North America. The lush vegetation that flourished at this time would eventually become the raw material for current coal beds. This vegetation also played a key role in creating an environment to allow insects and the first vertebrates to live on land. The fossil record shows evidence of early amphibians and the first reptiles in the Carboniferous Period—they were small lizard-like creatures. Fossil evidence suggests these early reptiles were the ancestors of future dinosaurs, birds, and mammals.

Figure C2.40: Dimetrodons were fierce carnivores.

During the Permian Period, reptiles began to diversify into a wide variety of forms. Fierce carnivores, such as Dimetrodons, were thought to have roamed the equatorial landscape in search of prey. The fossil record shows that life during this time reached a rich level of diversity on both land and sea. By the end of the Permian Period, the huge northern and southern continents had begun to form Pangaea and life was flourishing.

250 million years ago: supercontinent (Pangaea) starts forming

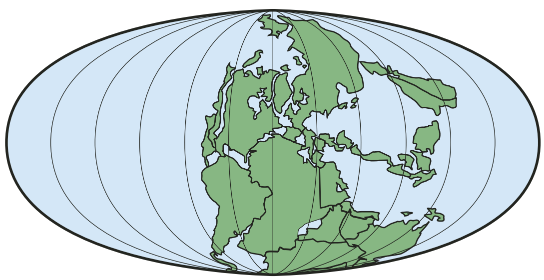


Figure C2.41: Continents may have appeared like this 250 million years ago at the end of the Permian Period.

The Empty Sea

The fossil record contains evidence of six mass extinctions—or large-scale extinctions—in a short time period. The end of the Permian Period 250 million years ago is marked by the greatest extinction of life in the fossil record. It occurred at the end of the Paleozoic Era. At this time, about 90% of ocean species and approximately 70% of land animal species became extinct.

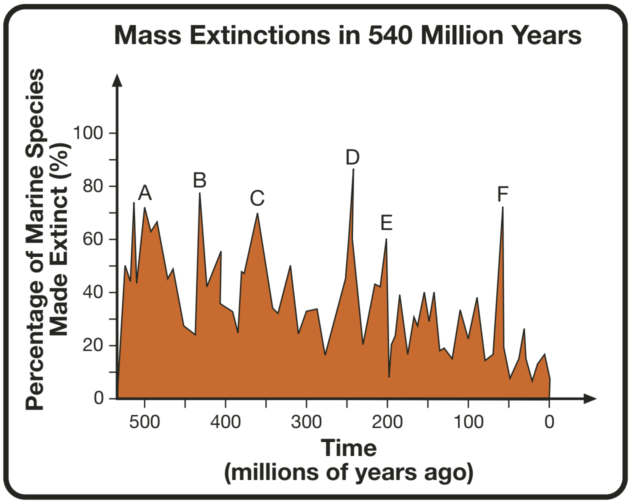


Figure C2.42: The six largest extinction events recorded in the fossil record are identified with the letters A through F.

At the end of the Paleozoic Era, species of animals that had existed since the Cambrian Explosion died or had their numbers greatly reduced. The marine invertebrates were the hardest hit. The simple colonial corals and all trilobite species became extinct. Through the fossil record, scientists have known about the Permian Extinction since the eighteenth century.

Practice

19. Recall your work with the Geological Time Scale in Chapter 1. Is it a coincidence that the largest extinction event occurred at exactly the same time as the end of the Paleozoic Era and the beginning of the Mesozoic Era?

20. Why are trilobites an excellent index fossil for the Paleozoic Era?

21. Use the Geological Time Scale on page 312 to determine the boundaries between eras and periods that correspond to each of the extinction events labelled A through F in Figure C2.42.

Causes of the Permian Extinction

Just what could have caused such a massive extinction event 250 million years ago? There is evidence that widespread glaciation occurred—there are glacial deposits dating back to the Permian Period in some areas of what was Pangaea. If there was a major glaciation at the end of the Permian Period, the sea level would have dropped. Also, shallow water surrounding the land would disappear. There would also be a lower average global temperature.

Another possible cause could be the formation of Pangaea. When the continents collided, the shallow seas between them would be greatly reduced and the coastline area would decrease. This would cause an increasing competition among the organisms in that environment. However, the formation of Pangaea occurred in the middle of the Permian Period. The mass extinctions took place at the end of the Permian Period.

Figure C2.43: This is an artist's representation of an asteroid colliding with Earth.

A deep impact caused by a comet or a very large asteroid colliding with Earth is another possibility for the extinctions. Scientists speculate that this kind of an event would have worldwide implications similar to the aftermath of a nuclear war, such as massive firestorms and enough dust blasted into the atmosphere to block out sunlight for months. The evidence is growing that the mass extinction event that marked the end of the Cretaceous Period—labelled as mass extinction F on Figure C2.42—was primarily caused by such a collision. Researchers are currently looking for evidence that a similar event caused the Permian Extinction.

Geologists have also suggested that the Permian Extinction was due to massive volcanic activity. In what is now Siberia, massive volcanic eruptions and lava flows covered thousands of square kilometres to a depth of more than 3000 m in some locations. Radioactive dating indicates that the eruptions happened about 250 million years ago, which is the same time that the Permian Extinction occurred.

The Effects of Volcanoes

Figure C2.44: Mount Pinatubo, a subduction-related volcano, erupted in the Philippines in 1991.

The twentieth century's largest volcanic eruption took place on Mount Pinatubo in the Philippines, but it was a small disruption compared to the eruptions at the end of the Permian Period. Mount Pinatubo caused a 0.5°C reduction in the average global temperature a year after the eruption because of the more than 20 million tonnes of ash ejected into the atmosphere. The eruptions in ancient Siberia consisted of lava flows and a large amount of ash deposits. Geological evidence indicates that lava erupting from the Siberian volcanoes was very explosive and that these eruptions lasted for hundreds of thousands of years. Given that the ash was believed to be explosive it was likely to have been blasted high into the upper levels of the atmosphere. Sunlight was blocked from reaching the surface, and this caused a global drop in temperatures.

Ash from modern volcanoes has been known to circle Earth for years before settling out. Perhaps the most recent notable climate change caused by a volcano took place in 1815 when Mount Tambora erupted in Indonesia. The next year, 1816, was known as the year without a summer due to a cool spring and summer and the early arrival of fall. The growing season for crops in both Europe and North America was shortened, and some regions suffered a famine.

Practice

22. Identify four of the possible causes of the Permian Extinction.

23. Some geologists suggest that glaciation may, in fact, be a spinoff effect of either the deep impact of a very large meteor or massive Siberian volcanic activity. Explain how each of these causes of the Permian Extinction could also trigger a period of glaciation.

24. Reconsider Figure C2.42. Carefully examine the event labelled D that corresponds to the Permian Extinction and the event labelled F that corresponds to the Cretaceous/Tertiary Mass Extinction.

- **a.** How does the shape of the graph that describes these mass extinctions suggest that the event was more sudden than gradual in these cases?
- **b.** Given your answer to question 24.a., which of the possible causes of the Permian Extinction seems most likely?

The Mesozoic Era

210 million years ago: dinosaurs begin to flourish

Figure C2.45: The dinosaurs were ready to take over.

The Triassic Period was the first part of the Mesozoic Era. During this time, the North American Plate continued its movement to the north and west. As Alberta moved, portions of the plate were alternately above and below sea level. When the Pacific Ocean retreated from Alberta, swampy areas and forests grew in the low-lying coastal areas. Fossil evidence indicates that the first mammals inhabited these forests. Over geological time, vegetation from these forests and swamps became coal deposits.

By the time the Triassic Period ended, Pangaea was coming apart. Geologists believed that this caused sea levels to rise once again and that much of the North American continent was again submerged. Geological evidence suggests that this event, combined with possible collisions by meteorites, triggered another mass extinction that marked the end of the Triassic Period. This corresponds to the mass extinction labelled E on Figure C2.42. A group of creatures took advantage of the vacancies left in the food chain—the age of the dinosaurs was about to begin.

Dinosaurs developed rapidly during the Jurassic Period. Their fossils show the relationship between the land masses during the Mesozoic Era. Fossils of similar, early Jurassic dinosaurs are found all over the world.

Building the Rocky Mountains

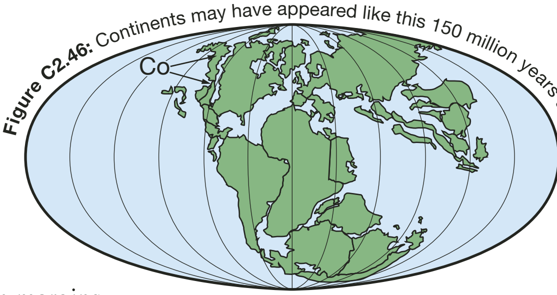
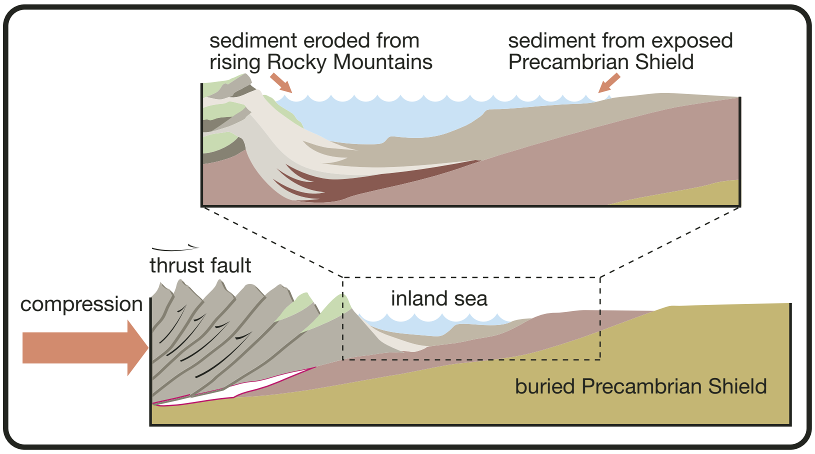


Figure C2.46: Continents may have appeared like this 150 million years ago.

In the middle of the Jurassic Period the break-up of Pangaea continued. North America continued to drift to the west, away from Africa. Arcs of volcanic islands began colliding with the western shore of the North American Plate. These fragments were about to become the western **cordillera** of the North American continent, so they are labelled Co on Figure C2.46.

The tectonic plate carrying these islands was subducted under the westward advances of the North American Plate. This caused the western margins of the North American Plate to be lifted, folded, and thrusted to the east. You should be able to see the similarities between the geological processes at work in present-day southern Alaska and in late Mesozoic Alberta. Geologists suspect that the margins of western Alberta must have been a land of earthquakes and volcanoes at that time.

The slivers of continental crust making up these islands had no place to go, so they became welded to the western coast of North America. Alberta was losing its Pacific coast line, and the continental crust that was to become present-day British Columbia was being added to the North American continent. The volcanic activity that is characteristic of subduction took place as rivers of magma poured onto the surface. The mountain ranges that stretch from western Alberta, and through British Columbia to the Pacific coast, are the remains of several processes. These include raising ocean beds, welding island arcs, and flowing magma from volcanic activity that all began in the Jurassic Period.



cordillera: an extensive chain of mountain ranges that forms the principal range of a continent

170 to 55 million years ago: formation of the Rocky Mountains

Figure C2.47: It took millions of years for the Rocky Mountains to form.

You will notice in Figure C2.47 that an inland sea was created on the east side of the mountains. The great weight of these mountains caused Earth's crust to sag. This allowed ocean water to rush into this sea from both the north and south. Over millions of years, sediment flowed into this sea from the Precambrian Shield to the east and from the rising mountains to the west, but this effect was offset by the gradual sinking of the basin due to the weight of rock sheets being added from the west. In the late Jurassic and Cretaceous periods, these sediments created a vast network of deltas, swamps, and forests that became home to a variety of different dinosaurs. By the late Cretaceous Period, another round of plate collisions on the west coast caused another period of compression.

The net effect was that the inland sea was uplifted and drained; the existing mountains were pushed up even higher; and the main ranges, front ranges, and foothills were formed. Huge faults moved slabs of rock more than 100 km and, in some cases, stacked older rocks on top of younger rocks. The folded rock layers you can see in many of the mountains near Banff and Jasper are the visible result of the compression caused by the collision of the two plates. By the late Cretaceous Period, the Atlantic Ocean was widening and the continents were starting to move toward their modern positions.

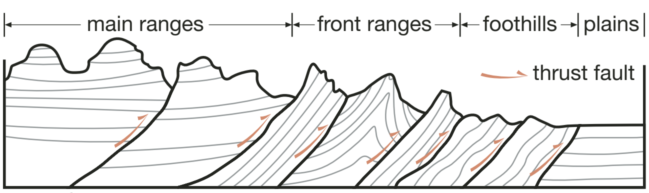


Figure C2.48: The Rocky Mountains became even higher.

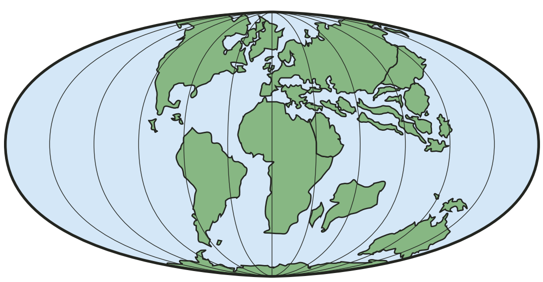


Figure C2.49: Scientists believe Earth's continents were positioned like this during the late Cretaceous Period.

Practice

25. A geologist predicts that the effects of subduction in present-day southern Alaska are likely to have also occurred in Mesozoic Alberta.

a. Concisely describe the nature of these effects and how they are caused by subduction.

b. Identify what principle the geologist is using when comparing the geological processes at work in southern Alaska today to those that took place in Mesozoic Alberta.

26. Although the process of subduction was at work, geologists suspect there were some differences between the process currently underway in southern Alaska and the method at work when the Rockies were formed. Figure C2.50 and Figure C2.51 illustrate some of the differences in these two processes.

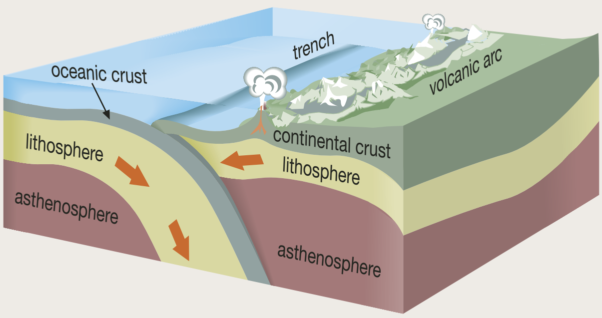


Figure C2.50: This model shows subduction occurring in present-day southern Alaska.

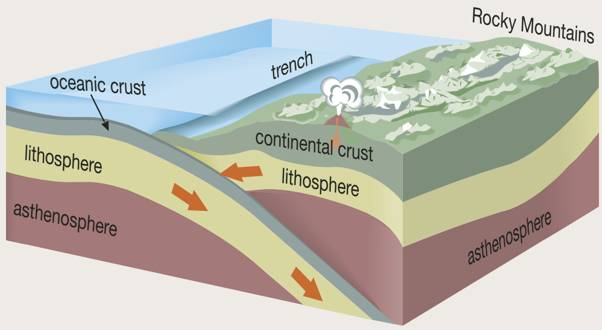


Figure C2.51: This hypothetical model reveals subduction that occurred 70 million years ago in Mesozoic Alberta.

a. Compare the process of subduction illustrated in both models.

b. Use features of the models to concisely explain why volcanic activity and mountain building occurred further inland for the building of the Rocky Mountains.

The Cretaceous/Tertiary Mass Extinction

The Cretaceous Period is the last period of the Mesozoic Era. Like the Triassic Period, the Cretaceous Period is marked by a mass extinction. The fossil record indicates that very nearly every land animal with a mass greater than 25 kg became extinct. In the oceans, this marked the end of the line for ammonites and the extinction of nearly half of the different varieties of plankton. The extinction of some plankton species is thought to have caused the collapse of some oceanic food chains.

2.4 Summary

Plate tectonics provide an essential context for many of the significant geological events that took place in both Paleozoic and Mesozoic Alberta. Boundaries between the current positions of the tectonic plates can be determined by plotting the locations of earthquakes and volcanoes on a world map. Geological evidence suggests that in the late Paleozoic Era, Earth's continental crust was fused into a single supercontinent called Pangaea.

When Pangaea began to break up in the Mesozoic Era, the North American Plate drifted toward the west and collided with arcs of volcanic islands riding on the Pacific Plate. The mountainous terrain of British Columbia and western Alberta are thought to be the direct result of these collisions. The fossil record indicates that the formation and eventual break-up of Pangaea occurred during the two largest mass extinctions in Earth's history. The possible causes for these mass extinctions remains an area of intense research.

2.4 Questions

Knowledge

1. Describe the two types of plate boundaries often characterized by volcanic activity.
2. List probable causes for the mass extinction that occurred at the end of the Paleozoic Era. Identify which cause (or causes) is most likely, given data trends on Figure C2.42.
3. Consider the following statement: "It was a mass extinction that gave dinosaurs an opportunity to flourish, and it was a mass extinction that marked their demise." Refer to the "Geological Time Scale" on page 312 as you explain this statement.

Applying Concepts

4. There is a Pacific Plate but no Atlantic Plate. Refer to Pangaea's break-up to explain the origins of the Atlantic Ocean.
5. Earlier in Chapter 2 you saw a photo of the folded layers of shale and limestone on the side of Mount Michener. Concisely explain how these layers of sedimentary rock—originally laid down in horizontal layers at the bottom of a shallow sea—became twisted and intricate designs far above sea level on the side of a mountain.
6. Explain how the Cretaceous/Tertiary Mass Extinction created an opportunity for the rapid diversification of mammals.

Chapter 2 Summary

In this chapter you studied life in the Paleozoic Era, and you learned how the remains of plant and animal life can be preserved for millions of years. You have seen not only how scientists can determine the underground structure of Earth through the application of science and technology, but how they use this information in the search for natural resources. You have seen how seismic waves can be used to locate the epicentre of an earthquake and to provide clues about the internal structure of Earth. In the Mesozoic Era, Alberta was a land of earthquakes and volcanoes as the Rocky Mountains formed due to crustal plates moving under the influence of plate tectonics. The fossil record indicates that life diversified, flourished, and also fell victim to mass extinctions during both of these eras.

In Chapter 3 you will learn about the rise of mammals and the continued cooling of Alberta. These developments led to a series of continental glaciations commonly called the Ice Age. You will see that people now live in what is known as an interglacial period, which is a time between glacial periods. You will be introduced to evidence suggesting that climate, for the first time, may be influenced by people.

Summarize Your Learning

In Chapter 2 you learned many new terms and concepts. Many of the concepts are related, and you will have an easier time recalling them if they are organized into patterns.

Since the patterns have to be meaningful to you, there are some options about how you can create this summary. Each of the following options is described in "Summarize Your Learning Activities" on pages 552 and 553. Choose one of these options to create a summary of the key concepts and important terms in Chapter 2.

Option 1:	Option 2:	Option 3:	Option 4:	Option 5:	Option 6:
Draw a concept map or a web diagram.	Create a point-form summary.	Write a story using key terms and concepts.	Create a colourful poster.	Build a model.	Write a script for a skit (a mock news report).

Chapter 2 Review Questions

Knowledge

1. Identify the event referred to as the Cambrian Explosion.
2. Briefly describe the importance of the Burgess Shale fossils.
3. Describe the position of Alberta on Earth's surface during the middle of the Paleozoic Era.
4. Briefly explain how geologists use seismology to determine the underground structures in an area.

5. Identify the supercontinent that existed in the early part of the Mesozoic Era.
6. Dinosaurs became extinct at the end of the _______________ Era.
7. Identify two geologic phenomena found near the boundary between two tectonic plates.
8. Identify the process believed to be responsible for sea-floor spreading at ocean ridges.
9. The continents of South America and Africa contain features that suggested to Alfred Wegener that they were once part of the same land mass but later drifted apart. Describe two of these features.
10. Identify the type of seismic wave generated by an earthquake that is the first to reach a seismic station.

Applying Concepts

11. A company obtains your address and sends you the following advertisement. Identify two scientific reasons why you should not purchase this fossil. Support your answer concisely.

12. The fossils of the Burgess Shale were caught in an underwater mud avalanche about 500 million years ago. Today, these fossils are accessible on the slopes of Mount Wapta in the Canadian Rockies. Include a geological time scale as you sketch a concise time line that describes the major geological events that had an effect on this fossil bed over time.
13. A geologist is studying the outcrop in Figure C2.52. You will need to refer to the "Geological Time Scale," and the "Radioactive Decay Curve." These can both be found on page 557.
    a. Determine the age of the basement rocks.

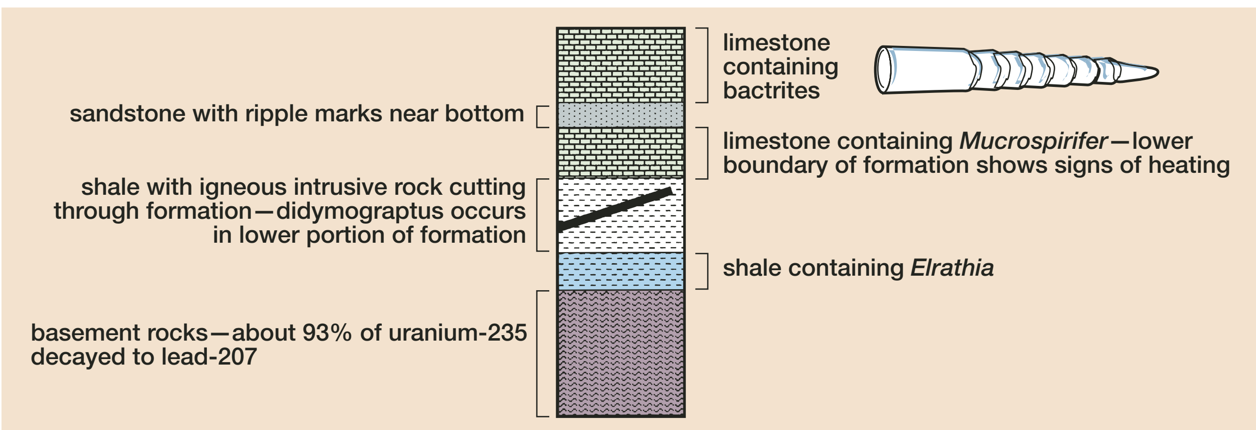
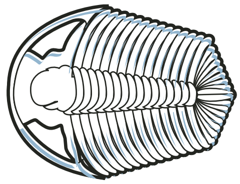
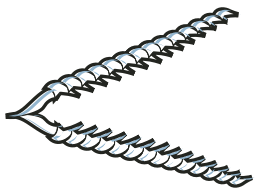
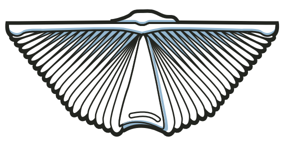
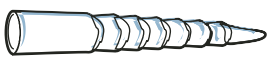


Figure C2.52: This is an example of an outcrop.

b. Use this table to determine the age of each of the other rock strata layers.

TABLE OF INDEX FOSSILS

Image of Fossil	Age	Type	Name	Comments
	Middle Cambrian	trilobite	*Elrathia*	widespread in Western Canada, including Burgess Shale–all trilobite species now extinct
	Ordovician	graptolite	didymograptus	once widespread throughout Earth's oceans—all species of graptolites now extinct
	Middle Devonian	brachiopod	*Mucrospirifer*	found throughout North America—about 300 species of brachiopods remain
	Permian	mollusc	bactrites	found in Alberta—more than 100 000 species of molluscs alive today

Use the following information to answer questions 14 to 18.

Figure C2.53 shows the sea floor at a typical ocean ridge. Notice that a trench is located on each side of the ocean ridge.

14. Figure C2.53 shows circulation within the mantle. Identify the proper name for this kind of circulation.

15. Identify the name of the geological process acting on the oceanic crust near each of the trenches.

16. Describe what geological phenomena would likely be observed on the continental crust beside each trench.

17. Describe two pieces of evidence that would allow you to measure the rate of sea-floor spreading in this area.

18. Studies have shown that the rate of sea-floor spreading and subduction are about the same. Why must this be so?

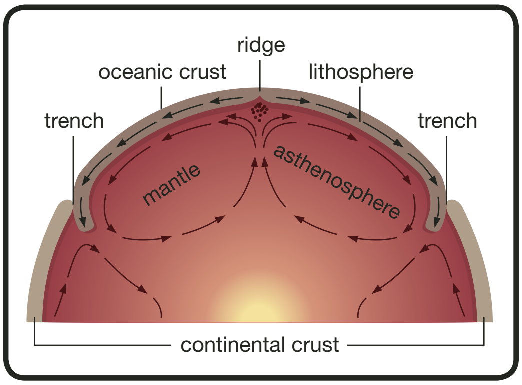


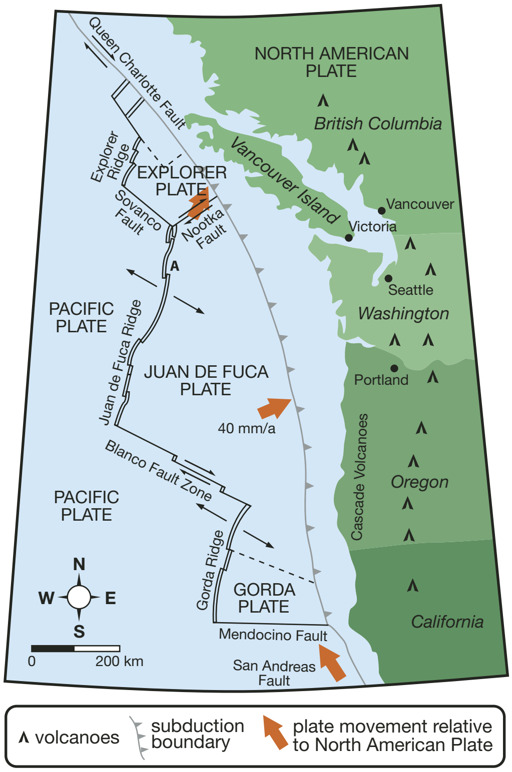
Figure C2.53: The sea floor of a typical ocean ridge is illustrated.

Use the "Tectonic Map of the West Coast" on page 363 to answer questions 19 to 23.

19. Consider the boundary between the Juan de Fuca Plate and the North American Plate. Identify which plate is the subducting plate and which one is the over-riding plate. Concisely support your answer.

20. Locate the Juan de Fuca Ridge. Note the small arrows that indicate the Pacific Plate is moving to the northwest, while the Juan de Fuca Plate is moving to the southeast. Describe the motion of the mantle material below the Juan de Fuca Ridge.

Tectonic Map of the West Coast



Use the following additional information to help answer questions 21 to 23.

Figure C2.54 shows the same details of the "Tectonic Map of the West Coast" as a cross section, instead of as a flat map. The cross-section map shown is an imaginary 200-km-deep cut into Earth. The cut runs along a line that extends the two arrows on the flat map of the Juan de Fuca Ridge all the way to the North American continent just south of Portland, Oregon. However, this cross-sectional diagram is missing labels, which have been identified with the letters in the boxes.

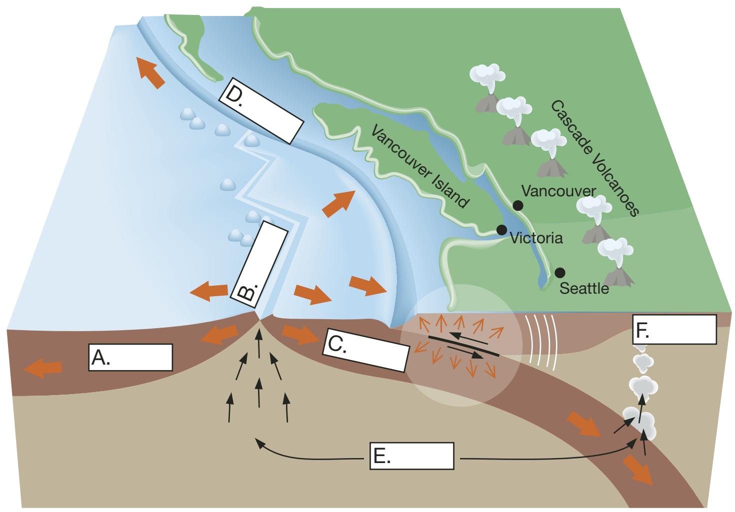


Figure C2.54: An imaginary cross-section map gives another view of tectonic plates.

21. Which letters on Figure C2.54 should be labelled North American Plate, Juan de Fuca Plate, and Pacific Plate? Answer by matching each of these labels to the correct letter.

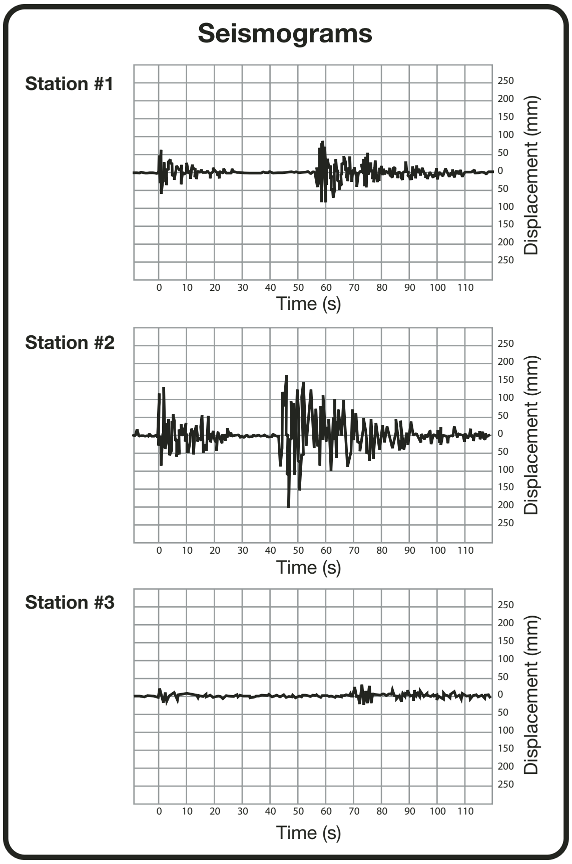
22. Which letters on Figure C2.54 should be labelled Juan de Fuca Ridge, trench, and sources of molten rock? Answer by matching each of these labels to the correct letter.

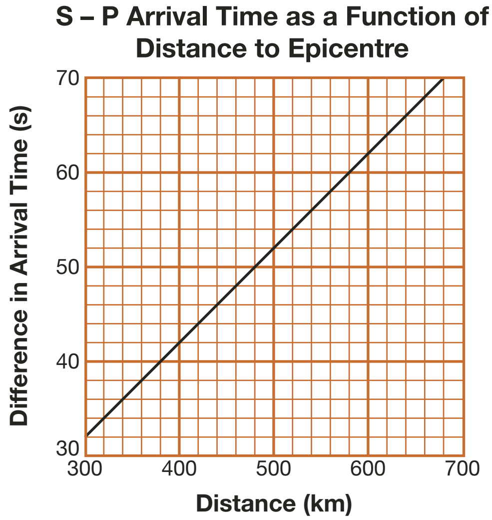
23. The labels missing from Figure C2.54 are the focus and epicentre of a major earthquake. Many geologists think this region actually has a risk of experiencing a significant earthquake. Investigations have led geologists to conclude that major earthquakes do occur in this region, but they are separated by hundreds of years. The last great earthquake was The Cascadia Megathrust Earthquake of 1700.

- **a.** One piece of evidence for a great earthquake occurring near Vancouver Island in 1700 was found in historical records from communities on the east coast of Japan. Using your knowledge of The Alaska Earthquake of 1964, explain the most likely method for The Cascadia Megathrust Earthquake of 1700 to affect Japanese coastal villages.
- **b.** Return to the "Tectonic Map of the West Coast." Identify the average speed for the Juan de Fuca Plate moving toward the North American Plate.
- **c.** Use your answer from question 23.b. to determine the total distance (in metres) the Juan de Fuca Plate moved between the years of 1700 and 2000.
- **d.** Juan de Fuca Plate motion continues to store energy in the elastic bending and buckling of the continental crust. What happens when this energy is suddenly released?
- **e.** During The Alaska Earthquake of 1964, the part of the North American Plate being flexed by the subduction of the Pacific Plate sprang back an average distance of 9 m. If the North American Plate around Vancouver Island were to spring back the distance that you calculated in question 23.c., determine if this earthquake would likely be smaller or larger than The Alaska Earthquake of 1964.
- **f.** Geologists estimate that the average time between major earthquakes that occur at the boundary between the Juan de Fuca Plate and the North American Plate is about 500 years. Refer to your previous answers to explain why a long time interval between earthquakes means that when an earthquake does occur, it will tend to be a very large one.
- **g.** Use the Internet to find out more about The Cascadia Megathrust Earthquake of 1700. What Richter magnitude number has been estimated for this event?

Use Figure C2.55 to answer questions 24 to 28.

An earthquake was recorded by three seismic stations. The seismographs at each station generated the seismograms in Figure C2.55 to describe this earthquake. The data on these seismograms can be used to determine the epicentre of an earthquake. This information can also be used to find the Richter magnitude number of the earthquake by using the S–P graph and the Richter nomogram.





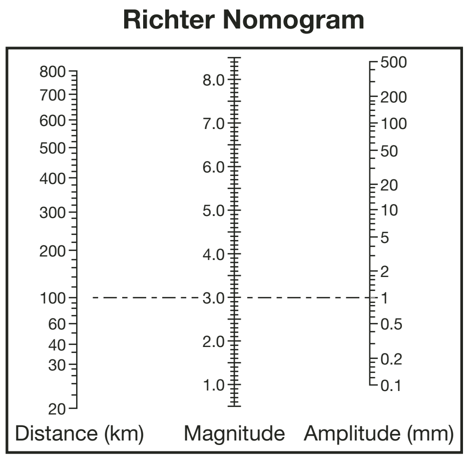


Figure C2.55: Seismograms, an S–P graph, and a nomogram are all used to determine earthquake information.

24. These seismograms show two waves arriving at each seismic station.

a. Identify which type of seismic wave is the first to arrive at each station.
b. Identify which type of seismic wave is the second to arrive.
c. Identify which type of seismic wave is not represented on these seismograms.

25. Determine the distance from the epicentre to each seismic station by using the seismogram for each station and the S–P graph.

26. By using your answer from question 25, it is possible to rank the distance of each seismic wave to the epicentre from closest to farthest. Concisely explain which feature on each of the seismograms confirms the order.

27. Explain how you would use a map and the distance from each seismic station to the epicentre to determine the location of the epicentre on a map.

28. Use the nomogram in Figure C2.55 to determine the Richter magnitude for this earthquake.

29. In Chapter 1 you began a time line to record key events that occurred in each era of geological time. Review Chapter 1 to ensure that you have included the significant entries from the Paleozoic and Mesozoic eras.

Use the following information to answer questions 30 to 33.

The Extinction Essays: A Research, Reporting, and Analysis Activity

The next questions are part of a self-directed activity in which you will research the most current theories that attempt to explain the Cretaceous/Tertiary Mass Extinction. This was the event that marked the disappearance of dinosaurs from the fossil record. In this chapter you were introduced to some of the theories that attempted to explain this mass extinction. You will now have an opportunity to extend your learning by exploring the latest research on three of these theories.

The following questions that outline this activity have three distinct phases:

- The first step is a research phase in which you investigate each of three distinct theories that attempt to explain the Cretaceous/Tertiary Mass Extinction.
- Next is a reporting phase where you write three concise essays to summarize key concepts that support each theory.
- The final phase involves an analysis of the three theories you investigated. You will write a fourth essay stating which of the three theories you think is most likely.

The standard for evaluating the research phase is as follows.

Score	Scoring Description
Standard of Excellence (4 marks)	The response demonstrates that each of the theories was thoroughly researched using several sources of information for each theory. The research identifies the relevant scientific evidence that supports each theory. The subsequent organization of the researched material allows for a thorough and accurate description of both the arguments that support each theory and the shortcomings of each theory.
Acceptable Standard (2 marks)	The response demonstrates that each of the theories was researched using more than one source of information for each theory. The research identifies some of the relevant scientific evidence that supports each theory. The subsequent organization of the researched material allows for a description of at least one argument that supports each theory and at least one shortcoming for each theory.

The standard for the essays is as follows.

Score	Scoring Description
Standard of Excellence (4 marks)	The response is well organized and accurately addresses the major points of the question. The student uses complete sentences that effectively employ scientific vocabulary. Relevant scientific and technological concepts and examples are identified, and interrelationships are explicit. The descriptions and/or explanations of these concepts reflect a clear and thorough understanding and consistent logical thought. When appropriate, descriptions and/or explanations are enhanced by suitable organizers, such as comparisons or graphics including diagrams, graphs, and tables.
Acceptable Standard (2 marks)	The response addresses most major points. The student uses complete sentences but is inconsistent in the employment of appropriate scientific vocabulary and graphic organizers. Relevant scientific and technological concepts and examples are identified, and interrelationships are shown. The descriptions and/or explanations of these concepts may be disorganized but demonstrate a correct understanding of the concepts.

30. Choose a theory that explains the Cretaceous/Tertiary Mass Extinction.

a. Use the Internet to research the answers to the following three questions:
(a) What is the basic premise of this theory?
(b) What scientific processes are involved in this theory?
(c) How does this theory explain the Cretaceous/Tertiary Mass Extinction?

b. Use your information from 30.a. to construct an essay that addresses these three questions.

31. Repeat the process outlined in question 30 to complete the research and construct an essay for the second theory.

32. Repeat the process outlined in question 30 to complete the research and construct an essay for the third theory.

33. Combine your answers from questions 30 to 32 to determine which theory you think is the most likely. Compare and contrast all three theories. Answer in the form of an essay.

Chapter 3 Changing Climates

An interesting place to visit in Alberta is the town of Okotoks, located south of Calgary. The name Okotoks comes from the Blackfoot name *okatoks*, which means “rock.” The name is certainly fitting because one of the town’s biggest tourist attractions is a house-sized rock, shown on these two pages, sitting in the middle of a farmer’s field. Big Rock, as it is called, is 41 m long, 18 m wide, 9 m high, and weighs 16 500 tonnes. For centuries it has been a famous landmark that helped First Nations travellers find an important river crossing. Each Nation has a different name for the crossing. The Sarcee Nation calls it *chachosika*, meaning “valley of the big rock.” The Stoney Nation calls it *ipabitunga-ingay*, meaning “where the big rock is.”

People of the Blackfoot Nation even have a story to explain the origin of the mysterious rock. As the story goes, one of the first people to live in the area was Napi, also known as The Great Spirit. Napi was strolling through what is now Waterton Lakes National Park in southwestern Alberta. Along the way, he loaned his coat to a large rock. When the rock refused to return the coat, Napi grabbed the coat back. Enraged, the rock chased Napi across the prairie. Fearing for his life, Napi sought the help of his animal friends. In Napi’s defence, flocks of birds descended, chipping away at the rock, until finally a nighthawk struck it dead where it now lies. Later in this chapter you will learn the scientific explanation of how Big Rock got to be where it is. You will learn that it did, in fact, travel a great distance to finally rest at its present location in the middle of a farmer’s field.

By the end of this chapter you will be able to generally describe the major characteristics and life forms of Alberta during the last 65 million years, cite evidence that Alberta has gone through repeated glaciations, and explain and evaluate theories concerning the causes of historical climate change. As well, you will know how to describe how concepts, models, and theories concerning climate change are combined with modern technology to predict future global climate changes.

Try This Activity

Ice Flows!

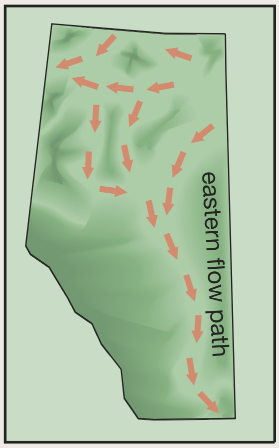
Science Skills

✓ Analyzing and Interpreting

Background

Scientists believe that during the last two million years, ice sheets advanced across most of Canada and then receded. This cycle was repeated many times. These icy periods are called glaciations. The last glaciation covered most of Alberta, reaching farthest south into northern Montana approximately 18 000 years ago. As the continental glaciers advanced and retreated, they shaped the land, much like water flowing over a beach shapes the sand. As water moves, it can carry sediment. Moving ice can carry giant boulders.

The Last Glaciation



Analysis

In groups, attempt to answer questions 1 to 5.

1. "The Last Glaciation" is a topographical map of Alberta showing the shape of the land's surface. Figure C3.1 is a photo of a wet, sandy beach. Describe any similarities you can see.
2. Explain what might have caused these similarities.
3. Explain how the comparison in question 2 is an example of uniformitarianism.
4. Look again at the photo of Big Rock on these two pages. The rock is made of quartzite, a material usually found only in the Rocky Mountains. Hypothesize the source of Big Rock, which is the largest rock in North America that was moved a great distance by a glacier.
5. Describe the path taken by Big Rock to its final resting place. Attempt to explain why Big Rock followed the path it did.

Figure C3.1: Like water flowing over a beach shapes sand, advancing and retreating glaciers shape land.

3.1 The Great Cooling

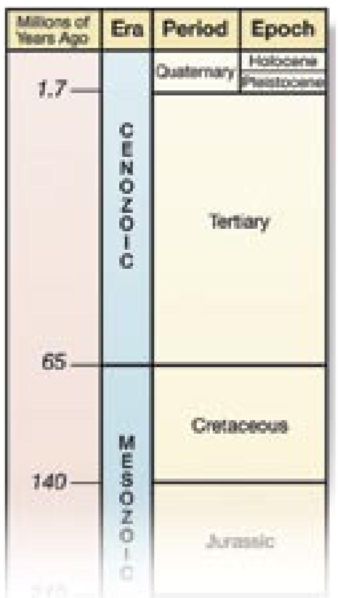
Figure C3.2: The Cypress Hills area includes sediments from the Cenozoic Era.

Cypress Hills Interprovincial Park rises above the surrounding prairies. It spans the southern border of Alberta and Saskatchewan. The park has been described as an island of forest within a sea of grassland. Due to its higher elevation, Cypress Hills receives much more precipitation than the surrounding areas. As a result of the extra moisture, this rich forest ecosystem attracts many tourists every year.

Cypress Hills provides clues about Alberta's geological past. The 600-m thick section of sedimentary rock that lifts this area above the surrounding grasslands was not removed by the advancing ice sheet during the most recent Ice Age. At that time, geologists suspect this area was an island of land in a sea of ice called a *Nunatak* (Inuktitut for "land apart"). This rare record of **Cenozoic Era** sediments provides scientists with an amazingly complete record of the last 65 million years of Alberta's history.

Cenozoic Era: the last 65 million years of Earth's history

The Cenozoic Era



Rising Mountains

The Cenozoic Era (65 million years ago to the present) is the last of the eras in Earth's history. It is divided into two periods—the Tertiary Period (from 65 million years ago to 1.7 million years ago) and the Quaternary Period (from 1.7 million years ago to the present). The Tertiary Period was much longer than the Quaternary Period, making up over 97% of the Cenozoic Era. Recall from Chapter 2 that at the beginning of the Cenozoic Era, the collision between the North American Plate and the Pacific Plate was at its most intense—this resulted in a rapid period of mountain building that finally ended about 50 million years ago. The result was the enormous Rocky Mountain Range. However, at the time these mountains were not so rocky. They were round-looking mountains covered with V-shaped valleys cut out by erosion.

Cenozoic Era: 65 million years ago to the present
Tertiary Period: 65 million years ago to 1.7 million years ago
Quaternary Period: 1.7 million years ago to the present

The relentless march of the tectonic plates not only resulted in mountain building—it also caused Alberta and the rest of North America to slowly migrate northward. As North America moved north, its climate got cooler. Eventually, it would end up in its present location with a climate cold enough to form glaciers. These glaciers would carve out the familiar jagged features of the Rocky Mountains. This icy process began approximately 1.7 million years ago.

A Retreating Sea

Near the beginning of the Cenozoic Era, the Bearspaw Sea retreated to the southwest—this left most of Alberta high and dry. During this time the Bearspaw Sea had dumped sediment on most of southern Alberta, which left the Bearspaw sedimentary rock formation. This formation is rich with dinosaur fossils and other fossils.

During the Cenozoic Era, a new source of sedimentary rock was the run off from the rising Rocky Mountain Range. Large rivers flowed down V-shaped valleys and dumped sediment into the foothills region of Alberta.

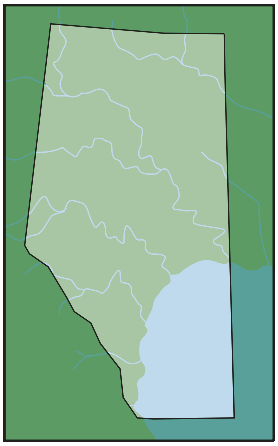


Figure C3.3: During the late Cretaceous Period, much of southern Alberta was submerged under the Bearspaw Sea.

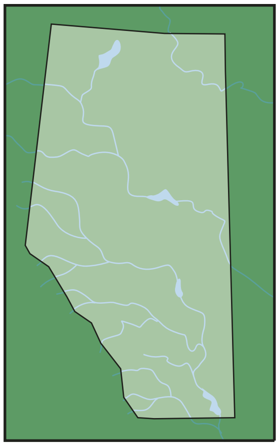


Figure C3.4: By the beginning of the Cenozoic Era, the Bearspaw Sea had retreated to the southeast.

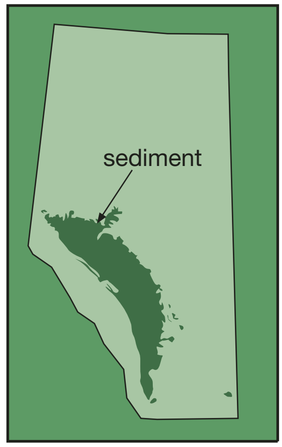


Figure C3.5: Cenozoic sedimentary rock outcrops are evidence of rivers pouring sediment from the Rocky Mountains.

Practice

1. Many geologists suspect that the draining of the Bearspaw Sea was a consequence of the final set of collisions between the North American Plate and a plate supporting arcs of volcanic islands. Explain how these final collisions could have caused the Bearspaw Sea to drain.
2. In Chapter 1 you learned that the Lethbridge area is rich in ammonite fossils. Explain the source of these fossils and the sedimentary rock that encases these fossil beds.

A Cooling Trend

The beginning of the Cenozoic Era was marked by the great Cretaceous Extinction. The large dinosaurs that had dominated Alberta for over 100 million years became extinct. Only the smaller, feathered dinosaurs—thought to be the ancestors of modern birds—survived to flourish in the Cenozoic Era. One of the factors that likely led to the Cretaceous Extinction was a drastic cooling of the global climate. This cooling trend continued into the Cenozoic Era.

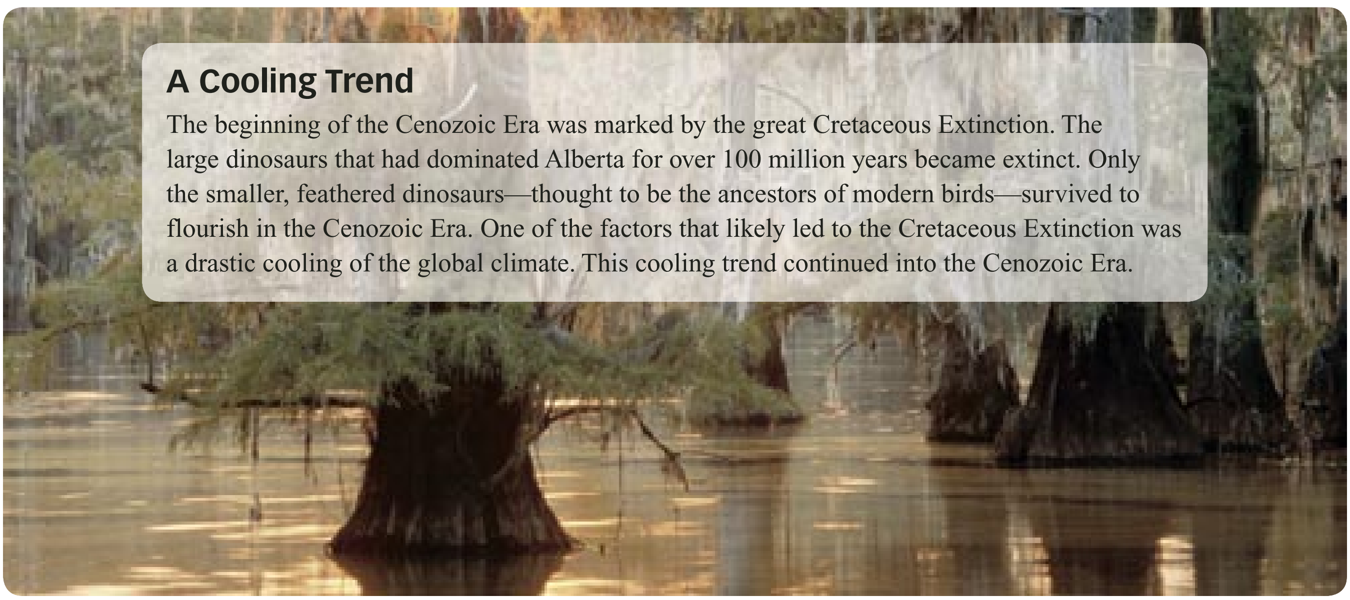


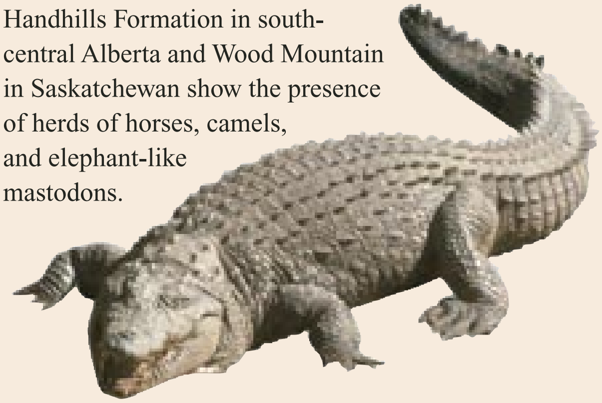
Figure C3.6: This swamp resembles early Cenozoic Alberta.

During the first 15 million years of the Tertiary Period, scientists believe there was a significant drop in average global temperatures. The cooling not only affected Alberta's animal life; it also caused a drastic change in plant life. The tropical rain forests gave way to more temperate evergreen forests scattered with rivers, lakes, and swamps. It was cooler than the Cretaceous Period, but still warmer than it is today. About two-thirds of the way through the Tertiary Period, Alberta is thought to have resembled present-day southern Louisiana.

Figure C3.7: Evergreen forests began to dominate the Tertiary Period in Alberta.

The Cypress Hills Fossils

The Cypress Hills Formation (35 to 42 million years old) in southeastern Alberta contains many fossils from the Tertiary Period. It shows an amazing array of mammals. The Cypress Hills fossils include mice, flying lemurs, bats, rabbits, dog-sized horses, giant pig-like mammals, and even rhinoceroses. Around 40 million years ago, geologists suspect that temperatures must still have been much warmer than they are today. Fossil evidence indicates that crocodiles terrorized these wetlands. Late Tertiary fossils (about 14 million years old) from the Handhills Formation in south-central Alberta and Wood Mountain in Saskatchewan show the presence of herds of horses, camels, and elephant-like mastodons.



The Rise of the Mammals

At the time of the Cretaceous Extinction, the surviving mammals were mainly small rodents. These furry creatures moved in on the territory of the extinct big dinosaurs. By 40 million years ago, many new forms of mammals appear in the fossil record—these were the ancestors of modern hooved herbivores, flesh-eating carnivores, and large-brained primates.

Figure C3.8: A 195-million-year-old fossil skull could be one of the earliest ancestors of modern primates. Believe it or not, this tiny fossil is noted for its relatively large brain!

65 million to 40 million years ago: mammals diversify and flourish

Grasses, Grazers, and Big Predators

Figure C3.9: The dense root structure of grasses allowed them to withstand the cooler and drier climate of the late Tertiary Period.

The spread of large herds of grazing species in the late Tertiary Period is believed to be closely linked to the dominance of grasses around the same time. Grasses are found in just about every type of environment around the world—there are about 9000 species of grasses worldwide. The first grass species appear in the fossil record early in the Tertiary Period but don't begin to dominate until late in the period when Alberta had become significantly cooler. As the climate became cooler and drier, the deep and dense roots of grasses helped them survive. The fossil record shows the gradual transition of the wetlands of the early Tertiary Period into drier woodlands and then eventually into grasslands.

One theory suggests that the new dominance of grasses was partly due to a new ability of hooved mammals to digest cellulose (the main component of plant cell walls). Mammals that can digest cellulose are called ruminants. New herds of grazing ruminants gave grasses a distinct survival advantage over other plants because they grow from the base, while other plants grow from the tip. The resistance of grasses to grazing is an adaptation that transformed the landscape of Alberta in the late Tertiary Period. It became grassland, which was home to giant herds of grazers and the predators that stalked them. More cooling was still to come.

Figure C3.10: Alberta farmers harvest grasses, such as wheat.

Practice

3. Explain why mowing a lawn does not kill the grass, but a cat can kill some house plants by chewing off too many leaves.
4. The description of the Tertiary grasslands relates giant herds of large grazing mammals stalked by predators. Identify an area on Earth's current landscape that could be described in a similar way.

Evidence for a Cooling Trend

Scientists believe there was an overall cooling trend during the Tertiary Period. This was just one of many climate changes in Earth's past. What evidence do scientists have of past climate changes? The evidence can be found in sedimentary rocks. For example, the presence of tropical plant and animal fossils in current-day polar regions indicate these places must have been much warmer in the past.

Conversely, the absence of tree pollen from current tropical landscapes indicates that the past climate was too cold for trees to survive. Similarly, the evidence found within sedimentary rock layers gives scientists many clues about the Tertiary cooling trend.

Figure C3.11: Current examples of pollen and pollination are shown in these three photos. Meanwhile, a lack of tree pollen from current tropical landscapes shows the past climate was too cold for trees to survive.

Investigation

A Record in Deep-Ocean Sediments

Purpose

You will explore a key line of evidence that has helped scientists develop theories about climate change.

Part A: Oxygen Isotopes in Shells

Problem

What is the relationship between the ratio of oxygen isotopes (oxygen-18: oxygen-16) and deep ocean temperature?

Background

Foraminifera is a group of organisms that lives in oceans around the world. These tiny, single-celled animals have calcium carbonate ($CaCO_3(s)$) shells and are found in a wide variety of marine environments.

Figure C3.12: *Foraminifera* live in oceans.

The oxygen present in the calcium carbonate of the shells comes from the oxygen in water ($H_2O(l)$). When *Foraminifera* die, they settle to the ocean's bottom and become part of the sediment. *Foraminifera* are frequently used by scientists to deduce information about ancient environments because these organisms have many favourable characteristics for these studies:

- Their hard shells tend to be well preserved.
- They are very abundant—up to a million individuals live in a square metre. This means that small samples of sediment can provide ample data.
- Since these organisms are single-celled, they respond quickly to environmental changes. Their shell chemistry can act as an indirect record of environmental changes.
- Some species of *Foraminifera* can only survive in water at specific temperatures. This provides additional environmental information.

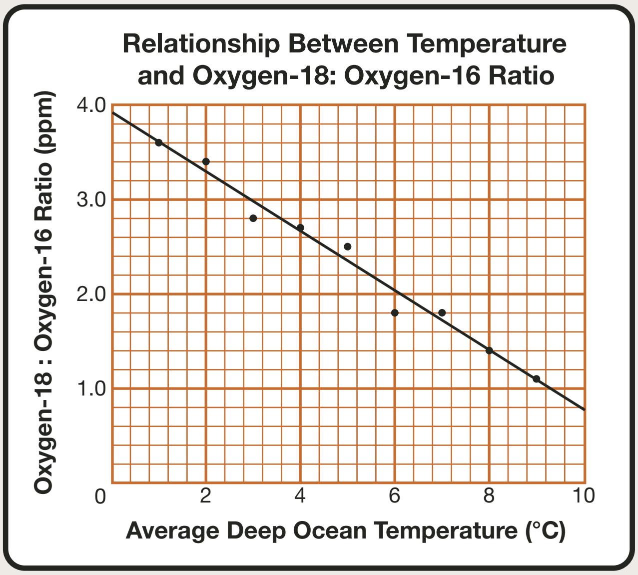
Science Skills

✓ Analyzing and Interpreting

Scientists can measure the amount of each oxygen isotope in the calcium carbonate layers. The ratio of the two stable isotopes—oxygen-18 (very rare) to oxygen-16 (very common)—has been found to indicate the average temperature of the deep-ocean water surrounding the *Foraminifera* as they build their shells. The ratio is measured in parts per million (how many atoms out of one million are oxygen-18).

Procedure

A scientist has conducted an experiment to test the relationship between the average deep-ocean temperature and the oxygen-18 ratio of *Foraminifera* shells. To do this, the amounts of oxygen-18 and oxygen-16 in *Foraminifera* shells and the temperature of the surrounding ocean water are measured. The results of this investigation are plotted on the following graph.



Analysis

1. Describe the overall trend in the data suggested by the "Relationship Between Temperature and Oxygen-18: Oxygen-16 Ratio" graph by completing this sentence:

   As the average deep-ocean temperature increases, the ratio of oxygen-18 to oxygen-16 ____________________.

2. Determine the slope of the best-fit line for this graph. Remember to include units.
3. Consider your answers to questions 1 and 2. Concisely explain how the answer to question 2 also includes the answer to question 1.

Part B: Oxygen Isotopes in Ocean Sediments

Problem

Can the oxygen-18 to oxygen-16 ratio data from *Foraminifera* fossils found in ancient sedimentary rock be used to determine the changes in average temperature during the Tertiary Period?

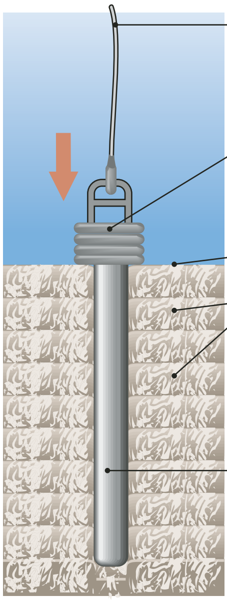


Figure C3.13: Heavy weights drive a hollow tube made of steel into the ocean floor. The core sample of sedimentary rock is then removed from the hollow tube for further study.

Procedure

As shown in the following table, an expedition travels to the North Atlantic Ocean and obtains a core sample of sedimentary rock from the ocean floor. The age and the ratio of oxygen-18 to oxygen-16 is then determined for each layer of sedimentary rock.

The following table data represents the first part of the data collection and analysis.

Time (10^6 a before present)	Oxygen-18: Oxygen-16 Ratio (ppm)	Average Deep-Ocean Temperature (°C)
50	1.0	
45	1.1	
40	1.9	
35	1.7	
30	2.2	
25	2.3	
20	2.4	
15	2.0	
10	3.3	
5	3.2	

Analysis

4. Create your own table. Use the graph from Part A to complete the table's blank column.
5. Plot a graph of this data with time on the horizontal axis and average deep-ocean temperature on the vertical axis. Remember to scale the horizontal axis so that 50 million years before the present is on the far left. Zero, representing the present, needs to be on the far right.

Conclusions

6. Describe the overall trend in average deep-ocean temperature during the Tertiary Period.
7. Does the graph show a constant decline in temperature or are there fluctuations?
8. Does the graph show all the fluctuations in average deep-ocean temperature during the Tertiary Period? Explain your answer.

3.1 Summary

The end of the Mesozoic Era was marked by the extinction of many of Alberta's life forms, including large dinosaurs. As the Tertiary Period—from 65 million years ago to 1.7 million years ago—of the Cenozoic Era began, Alberta was already a cooler, drier place than it had been during the age of dinosaurs. The Bearspaw Sea had drained to the southeast as a tectonic collision caused a relatively rapid period of mountain building. Small, rodent-like mammals flourished at the beginning of the Tertiary Period in an environment that resembled the modern-day southern part of Louisiana. Fossil evidence shows that the average global temperature fluctuated throughout the Tertiary Period but overall underwent a cooling trend. By the end of the Tertiary Period, many new forms of mammals were living in a much cooler Alberta. Due to the new dominance of grasses, large herds of grazing mammals roamed the landscape. Many people would be surprised to know that rhinoceroses, camels, giant pigs, and elephant-like creatures were part of Alberta's past.

3.1 Questions

Knowledge

1. What evidence of climate change can you identify near Okotoks, Alberta?
2. Describe how the Blackfoot Nation explanation of Big Rock's origins is both similar to and different from the scientific explanation.
3. Describe how water erosion and ice erosion are similar processes.
4. What event marked the beginning of the Cenozoic Era?
5. Why is Cypress Hills Interprovincial Park significant to the study of the Cenozoic Era?
6. What two periods make up the Cenozoic Era?
7. What percentage of the Cenozoic Era is made up of the Tertiary Period?
8. What caused the rapid period of mountain building that took place during the first 15 million years of the Tertiary Period?
9. Describe the appearance of the Rocky Mountains before glaciation.
10. Relate one possible reason for the overall cooling trend during the Tertiary Period.
11. After the extinction of the big dinosaurs, which two groups of animals moved in on their territory?
12. Did all dinosaurs become extinct? Explain.
13. Explain why the Tertiary Period could be described as the rise of the mammals.
14. Give two possible reasons why grasses became dominant plants in Alberta during the late Tertiary Period.

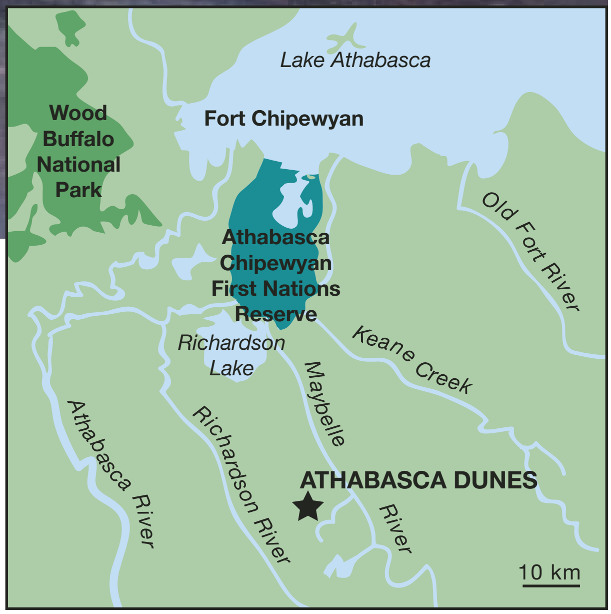
Applying Concepts

15. As the graphic in Figure C3.14 shows, there are many types of *Foraminifera*, which is a group of tiny marine organisms. *Foraminifera* have shells that contain calcium carbonate. Calcium carbonate is a main component of limestone. The interior plains of Alberta have mainly limestone-rich soils. What does the presence of limestone within Alberta's soil indicate about Alberta's environment during much of the province's past?

Figure C3.14: *Foraminifera* is a group of tiny marine organisms.

3.2 The Icy Epoch

Figure C3.15: The Athabasca Dunes is Alberta's largest actively migrating sand dune.



You may be surprised to know that this photograph was taken in northeastern Alberta, close to the Athabasca River. The Athabasca Dunes is a surprising field of sand piled in the middle of green forests. This is Alberta's largest actively migrating sand dune. This huge deposit of sand is actually growing! At 7 km long, 1.5 km wide, and up to 35 m deep, standing in the middle of it could make you feel like you were lost in the Sahara Desert! Prevailing winds kick up sandstorms, causing the dune to migrate southward at a rate of 1.5 m per year. This advancing sand slowly buries everything in its path, including trees, ponds, streams, and lakes. A seemingly lifeless desert is left behind.

What process could have created this strange and rare environment? Where did all that sand come from? The answer is surprising: Ice! A sheet of ice more than 1 km thick flowed across Canada and buried nearly everything in its path. In fact, over the last 1.7 million years, moving ice has shaped Alberta's landscape more than anything else. Ironically, this wall of advancing sand mimics the ice sheet that created it more than 18 000 years ago.

1.7 million years ago: glaciers begin to advance on Alberta

The Big Freeze

As you learned earlier in this chapter, a cooling trend that began in the Cretaceous Period continued throughout the Tertiary Period. By the end of the Tertiary Period—1.7 million years ago—the climate became so cold that snow began to accumulate year after year in polar regions. This marked the beginning of the icy Pleistocene Epoch (from 1.7 million years ago to 10 000 years ago).

During the early Pleistocene Epoch, as layer upon layer of snow fell in polar regions, the weight caused lower layers of snow to become compacted into ice, which began the formation of **glaciers**.

glacier: a large river of ice that forms on land and moves under the influence of gravity

Earth's largest glaciers can be found in the polar regions—the Greenland and Antarctic **continental ice sheets**. During the Pleistocene Epoch, when ice sheets like these reached a critical mass, they began to slowly flow outward toward the equator like a viscous fluid.

continental ice sheet: a very large glacier, often more than 1 km in depth, that forms in polar regions

mountain glacier: a glacier that forms in mountainous regions at high elevations

Figure C3.16: The continental ice sheet covers most of Greenland.

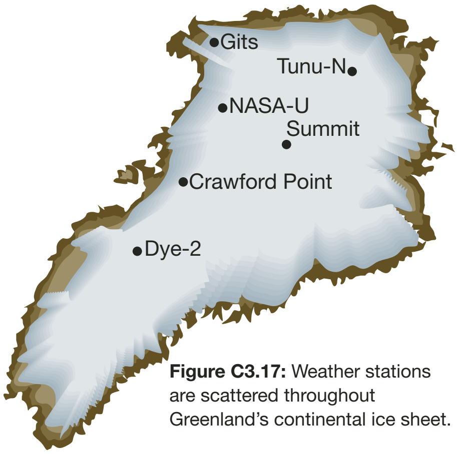


Figure C3.17: Weather stations are scattered throughout Greenland's continental ice sheet.

Earth's current massive continental ice sheets cover nearly all of Antarctica and Greenland. Ice accumulates at their centres to depths of over two kilometres, then flows outward, eventually reaching the sea. Huge chunks of ice break off and float away as icebergs in a process called calving—as if the ice sheet were giving birth.

During the Pleistocene Epoch, snow also accumulated in mountainous regions and resulted in **mountain glaciers**. These glaciers reached a critical mass and began to form in the mountains and stretched into the valleys below.

Figure C3.18: An iceberg is born through the calving process on the coast of Greenland.

Moving ice continues to shape the face of Alberta to this day. If you take a drive through the Rocky Mountains, you can see masses of ice high on mountains. Although they are moving very slowly, these mountain glaciers are scraping and gouging the rock below them, giving the Rockies their characteristic jagged shape.

Utilizing Technology

Antarctica: A Flying Tour of the Frozen Continent

To really get a feel for what the Antarctic Ice Sheet is like, watch the narrated animation applet of a flyby over Antarctica. The applet titled "Antarctica: A Flying Tour of the Frozen Continent" can be found on the Science 20 Textbook CD. This animation was generated using a computer program to "drape" satellite radar images over a digital topographical map. The data was collected by the Canadian Space Agency's satellite, RADARSAT-1.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Analysis

1. This satellite's ability to map the distribution of sea ice is particularly valuable to Canada because of the proximity of many Canadian ports to the North Pole. This allows for the planning of safe shipping routes and the monitoring of large iceberg flows. Concisely explain how this satellite, designed to monitor ice around the North Pole, was able to capture radar images of the Antarctic Continental Ice Sheet.
2. Many students are surprised to learn not only that Canada has a thriving aerospace industry but also that Canada is a world leader in satellite technology.
   a. Why is satellite technology particularly important to a country like Canada?
   b. Internet Search: You can learn more about the Canadian aerospace industry, take virtual tours of facilities, and view the latest images from Canadian satellites by visiting the Canadian Space Agency's website. Use your search engine to locate this site and then follow the links. Concisely record some interesting things you learned.

Are We in an Ice Age Right Now?

It depends on which definition you're using. An **ice age** is technically defined as a period when ice sheets cover parts of the Northern and Southern Hemispheres. Under this definition, Earth is in an ice age right now! Enormous ice sheets cover Antarctica in the south and Greenland in the north. Usually what people mean when they say *ice age* is a time period during which continental ice sheets advance to cover large regions of North America and northern Europe. These periods are more correctly called **glaciations**. Scientists believe that during the Pleistocene Epoch, there were at least four major glaciations.

ice age: a period during which ice sheets cover parts of the Northern and Southern Hemispheres

glaciation: a period during which polar ice sheets advance to cover large regions of North America and northern Europe

Giants of the Pleistocene

During the chilly Pleistocene Epoch, large mammals had the advantage. Fossils that were collected near Medicine Hat, Alberta, and in Walsh Valley, Saskatchewan, reveal that mammoths, modern horses, llamas, reindeer, camels, and scavenger dogs roamed the Pleistocene landscape. Vicious predators, such as American lions, short-faced bears, sabre-toothed cats, and birds with 8-metre wingspans, stalked herds of these large, grazing mammals. Some of the more exotic of these Pleistocene giants included woolly mammoths and woolly rhinoceroses.

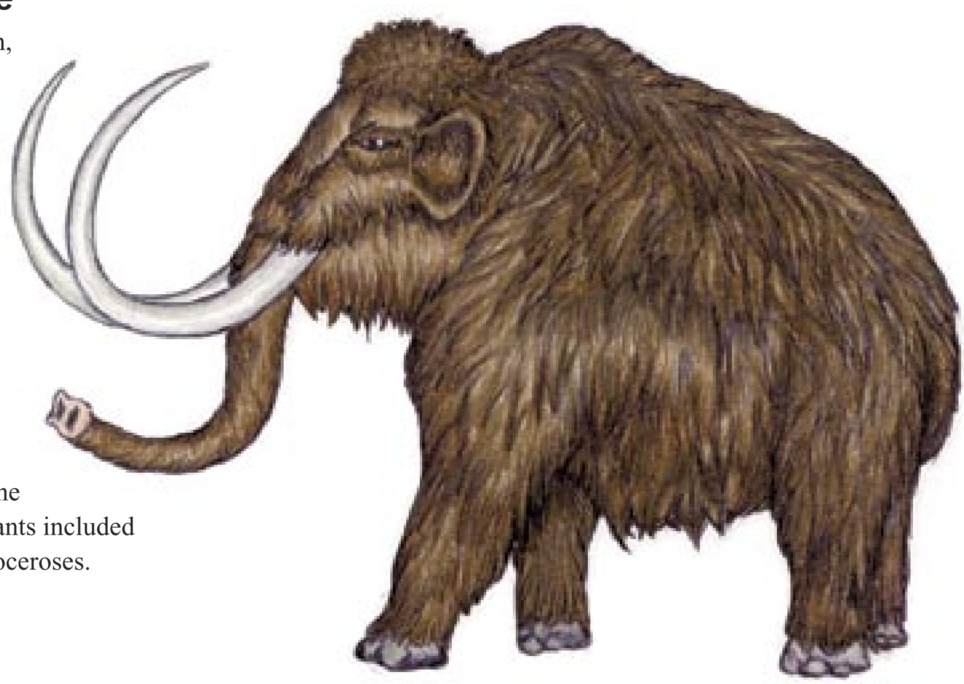


Figure C3.19: Woolly mammoths thrived during the Pleistocene Epoch.

Investigation

A Record in the Ice

Problem

Can ice-core data be used to show climatic changes over the past 160 000 years?

Background

In 1998, a Russian research team travelled to Lake Vostok, a salty glacial lake buried under thousands of metres of Antarctic ice. They made this difficult journey to study changes in Earth's past climate.

Figure C3.20: Two scientists make a small drill core in the Canadian Arctic to study previous atmospheric conditions.

They drilled to extract an ice core that was 2083 m long. Once they had removed the drill core, they analyzed tiny bubbles of the ancient atmosphere trapped in the annual ice layers. The researchers measured concentrations of carbon dioxide, methane, and dust particles and determined the average temperature at the time each layer formed by using oxygen-18: oxygen-16 ratios.

Figure C3.21: A scientist prepares to analyze a section of a drill core from a storage bank.

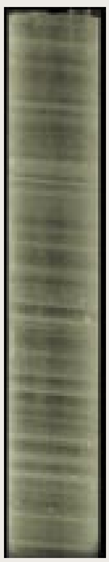


Figure C3.22: Annual snowfall layers are visible in ice cores.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Using these measurements, scientists have constructed a chronological record of Earth's atmosphere for the last 420 000 years! Good scientific practice involves sharing your data with other scientists from around the world. This encourages an open exchange of information that promotes a confirmation of results and the development of consensus among scientists. During this investigation, you will analyze raw data from the Vostok Ice Core by using the power of a computer spreadsheet program.

Collecting the Data

Open "Vostok Spreadsheet and Data" on the Science 20 Textbook CD, and save it on your computer.

Procedure

Notice that the Average Temperature column in the spreadsheet is empty. You will need to complete this column using the data provided. A proportional relationship has been established for oxygen-18 in ice formed recently in areas around the world. From this relationship, an equation has been developed for you to use.

step 1: Select cell B3 and enter the following equation:

$$= -55.5 + (C3 + 440)/6$$

This equation is based on the linear relationship between oxygen-18 ratios and average temperature.

step 2: Press Enter.

step 3: Select cell B3 again. Click on the lower right corner of the cell and, while holding down the mouse button, drag the cursor to the bottom of the column. This should apply the formula for average temperature to each line in the column.

Now, you can graph the average temperature over the past 160 000 years.

step 4: Select the Age of Ice Layer and the Average Temperature column (cells A2 to B196).

step 5: Open the Chart Wizard.

step 6: Choose XY (Scatter). Also, choose the sub-type with the data points connected by smoothed lines without markers.

step 7: Click the Next button.

step 8: Preview the graph; then click the Next button.

step 9: Format your graph by adding graph and axes titles, gridlines, and so on. Simply review the formatting under each tab in this window.

step 10: Click the Next button.

step 11: Select the radial button that will save the graph on a different sheet. Title the sheet "Graph."

step 12: Click the Finish button. Your graph will appear on a new sheet in the spreadsheet file.

Note: You can do additional formatting to the graph by simply double-clicking the area you wish to change, such as the background or the scale of each axis.

Save your spreadsheet. You will be referring to it later in this chapter.

Conclusion

1. List the advantages and disadvantages of using a spreadsheet to analyze data compared to using a pencil and paper.
2. Describe the relationship between time and the average temperature at Vostok over the past 160 000 years, as shown by the graph you created.
3. These days, the average temperature in Vostok is a chilly –55.1°C. Draw a dashed line across your graph and label it "current temperature."
4. According to the graph, how many time periods were there in Vostok during the last 160 000 years when the average temperature consistently stayed above the current temperature?
5. The cold periods indicate the last two glaciations (commonly called ice ages). Use the graph to answer the following.
   a. When did the most recent major cooling trend begin that led to glaciation?
   b. When did the last glaciation reach its maximum (e.g., coldest) temperature?
   c. When did the temperature finally return to near-current values?
6. What significance does the end of the last glaciation have in terms of the Geological Time Scale?
7. Based on your graph, infer one of the following predictions. The temperature over the next 10 000 years will do one of these things.

   A: stay roughly constant for the next 10 000 years

   B: undergo another decrease

   C: increase
8. Explain why it is important for scientists around the world to share data and conclusions with each other.

The Wisconsin Glaciation

The last glaciation is often called the Wisconsin Glaciation to indicate how far south the ice advanced before it stopped. The Wisconsin Glaciation reached its maximum size approximately 18 000 years ago. The largest of the advancing ice sheets was the Laurentide Ice Sheet. This ice originated just west of where Hudson Bay is now, and it spread out in all directions. This wall of advancing ice entered Alberta from the northeast and continued to spread down through the province until it was deflected south by mountain glaciers. The mountain glaciers were moving east as they came down the mountains. The Laurentide Ice Sheet made it all the way to northern Montana before it stopped advancing and started to melt. The Laurentide Ice Sheet fully receded approximately 10 000 years ago to mark the end of the Pleistocene Epoch and the beginning of the Holocene Epoch.

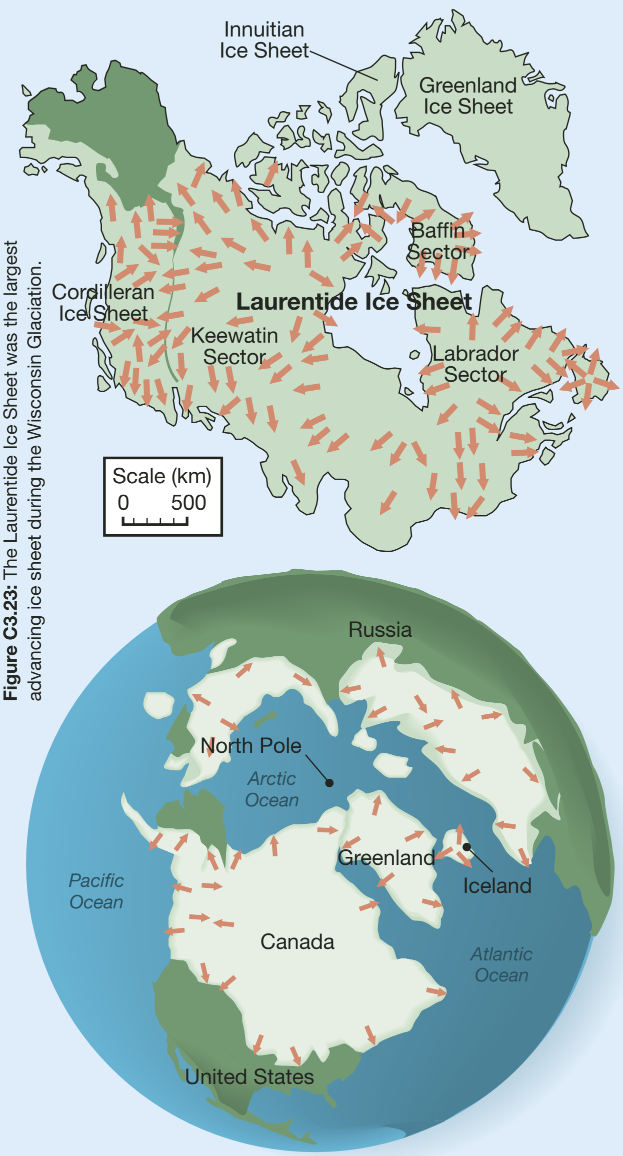


Figure C3.23: The Laurentide Ice Sheet was the largest advancing ice sheet during the Wisconsin Glaciation.

Glacial Footprints

If Alberta were indeed covered by a giant ice sheet, it must have left behind a lot of evidence. It did leave proof. In fact, Alberta's topography is dominated by the effects of the Wisconsin Glaciation. As a continental ice sheet advances and then retreats, it leaves behind characteristic landforms, as shown in Figures C3.24, C3.25, and C3.26.

Figure C3.24: This strangely shaped hill, called a drumlin, is one of a cluster of teardrop-shaped hills found at Morley Flats west of Cochrane, Alberta. Geologists believe the glacier that flowed over these hills travelled from the blunt end toward the tapered end.

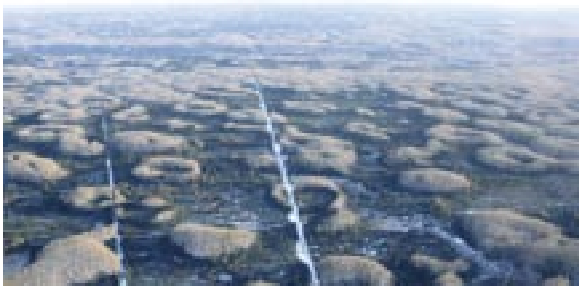


Figure C3.25: Between the towns of Slave Lake and Fort Vermilion in northern Alberta, there are many small round hills, called kames, and scattered ponds. These small hills, many of them shaped like doughnuts, are collections of rocky debris that were slowly dropped by a glacier chunk thought to have been stranded from the larger ice mass. Since these glaciers were stalled and left to melt in place, these deposits lack the streamlined effect of Figure C3.24.

Figure C3.26: The Athabasca Dunes, featured in the Lesson 3.2 introduction, is a giant pile of sand deposited by water. This sand dune is glacial lake sediment. The origin of the sand is granite, gneiss, and sandstone located in the Canadian Shield area of northeastern Alberta. The advancing ice sheet plucked up enormous amounts of fine, clean sand as it scraped and gouged its way across these rocks. When the ice sheet melted, sandy water poured into a glacial lake. Later, the lake drained and left this huge deposit of sand.

Practice

5. Identify the event that marked the end of the Pleistocene Epoch and the beginning of the Holocene Epoch.

6. Identify three examples of landforms that provide evidence of glaciation in Alberta's past.

Mountain Make-Over

What gives the Rocky Mountains their characteristic jagged shape? The Rockies started out more rounded in shape, except for V-shaped valleys formed by water erosion. The jagged shapes that inspired the name Rocky Mountains came from the glaciers of the Pleistocene Epoch. During the Wisconsin Glaciation, as in previous glaciations, the mountains were covered with glaciers. There are still many places in the Rockies where the winter snowfall exceeds the summer melting. Under the influence of gravity, the accumulating snow is compacted to become ice. At a critical mass, the ice begins to flow like a very slow river down the mountain and into the valleys below.

As the mountain glacier flows, it scrapes and gouges the mountain. This drastically changes the mountain's appearance. Once the ice reaches a lower elevation, where it gets warmer in the summer, the ice melts. The melted ice is replaced by ice flowing down from the zone of accumulation. Fresh meltwater from the zone of ablation runs into streams, which converge to form rivers. If you live in Alberta, chances are good that the water coming out of your tap is glacial meltwater.

Investigation

Fresh Water

Glaciers hold 75% of Earth's fresh water. When water freezes, it forces out dissolved salt. So, when ice melts, it is usable as drinking water by plants and animals, including humans. Many scientists are interested in monitoring this vast resource and projecting changes in Earth's future ice volume. Use the Internet or other sources to conduct research on this issue. Use questions 1 to 8 to guide your research. Include diagrams and/or pictures to illustrate your answers. A good place to start your research is by finding the website of your local drinking-water utility.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Questions

1. Where does your drinking water come from? Is it a river? If so, which one?
2. Is the river that supplies your drinking water fed by a glacier? If so, which one?
3. Over the past century or so, has that glacier been growing or shrinking?
4. Are mountain glaciers and ice sheets around the world growing or shrinking? Provide evidence.
5. What methods do scientists use to measure changes in glacier size?
6. Why do many scientists believe the last century is just the beginning of a large glacial melt?
7. What could the consequences be if the glacier that supplies your drinking water melts completely?
8. What could some consequences be if most of Earth's glaciers and ice sheets melt?

3.2 Summary

The Tertiary Period experienced a drastic cooling trend, which continued into the Quaternary Period. The coldest times came during the first epoch of the Quaternary Period—the Pleistocene. Glacial landforms and ice-core data show evidence of repeated glaciations starting 1.7 million years ago and lasting until the end of the most recent glaciation (known as the Wisconsin Glaciation) 10 000 years ago. Ice continues to shape the world to this day as enormous ice sheets dominate Antarctica and Greenland and mountain glaciers continue their slow grinding in Alberta's Rocky Mountains. The many retreating glaciers and ice sheets around the world may be indicators of a warming trend in recent years, which could lead to challenges in the future, such as rising sea levels and fresh water shortages.

3.2 Questions

Knowledge

1. Define the following terms. Include times and major events.
   a. the Quaternary Period
   b. the Pleistocene Epoch
   c. the Holocene Epoch
2. What percentage of the Quaternary Period is taken up by the Pleistocene Epoch?
3. Describe Earth's climate during the Pleistocene Epoch.
4. Describe the animals that lived in Alberta during the Pleistocene Epoch.
5. Define the following terms, describe how they form, and give one example of each term.
   a. continental ice sheet
   b. mountain glacier
6. Explain how ice cores are used to study Earth's past climate.
7. Describe how Earth's average temperature has changed over the past 160 000 years.
8. Compare and contrast the two main methods of tracking Earth's average temperature from the distant past—deep-ocean sediment cores versus ice cores.
9. Explain how, over the past century, glaciers have provided evidence of the effects of global warming.

Applying Concepts

10. Figure C3.27 shows a photo of a glacial landform.
    a. Explain how it formed.
    b. Sketch a quick drawing of this landform. Use an arrow to indicate the direction of ice-sheet flow.

Figure C3.27: This is an example of a glacial landform.

11. Figure C3.28 shows a photo of a glacial landform. Explain how this highlighted feature formed.

Figure C3.28: This large bowl was carved out by a glacier.

3.3 Explaining and Predicting Climate Change

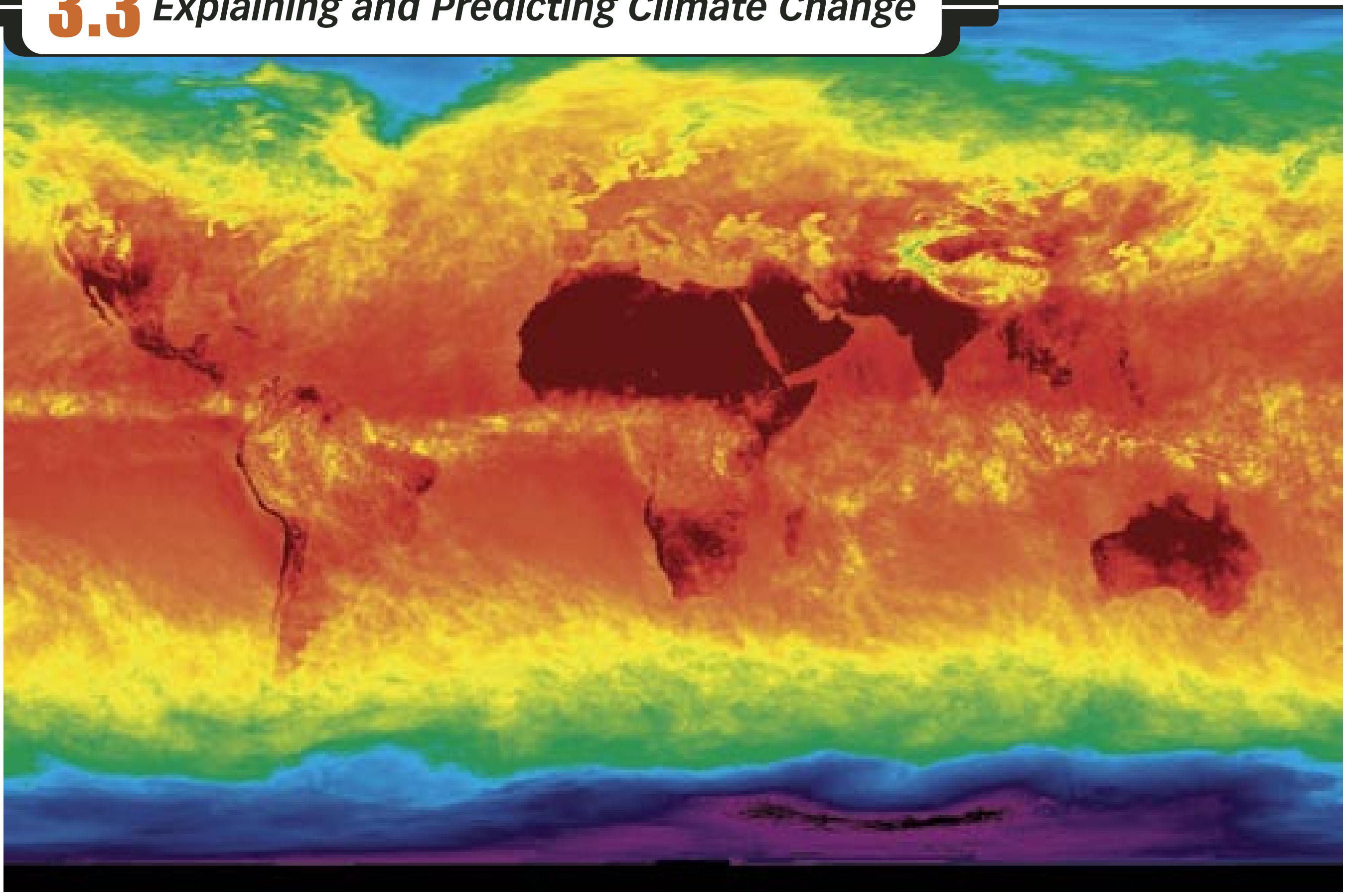


Figure C3.29: A detector mounted on a satellite orbiting Earth measures surface temperatures across the entire globe. This image is an average for the month of April 2003.

For many people, part of their morning routine involves checking the radio, newspaper, TV, or Internet to find out what the **weather** will be like that day.

The predictions made by meteorologists are not always perfect, especially if they are long-term forecasts. Earth's **climate** system is complex—this makes it difficult for atmospheric scientists to make reliable weather forecasts for a vicinity, even with the most powerful weather-simulating computers at their disposal. Predicting changes in Earth's climate is even more challenging.

Figure C3.30: The world's most powerful supercomputer, the Earth Simulator, is used to model processes such as plate tectonics and deep ocean currents to help scientists predict future changes to Earth's climate.

weather: the state of the atmosphere in terms of variables such as temperature, cloud cover, precipitation, and humidity for a particular place at a particular time

climate: the average of daily and seasonal weather events that occur in a region over a long time period

A Story of Change

So far in Unit C you have witnessed an amazing story of changing landscapes and climates. This remarkable environmental diversity is matched only by the variety of organisms that have lived on Earth. These include stromatolites soaking up the sun in shallow beach-front pools, bizarre creatures inhabiting a tropical coral reef, dinosaurs roaming rain forests and deep seas, and herds of large grazers and woolly giants surviving repeatedly advancing ice sheets. And, finally, after all of this change, after four tumultuous eras filled with survival and extinction, you have come to the recent part of the story—the Holocene Epoch.

The Epoch of Recent Time

The Holocene Epoch began approximately 10 000 years ago at the time of the great melt that followed the last glaciation. By that time, people were inhabiting North America. The oldest signs of the existence of people on this continent are stone tools found in the Bluefish Caves in the Yukon—these are determined to be approximately 16 000 years old. Scientists may indeed find older evidence of humans in North America. The rapid melting of the Laurentide Ice Sheet opened up an ice-free corridor extending south through Alberta, providing North America's early northern residents with a passage south.

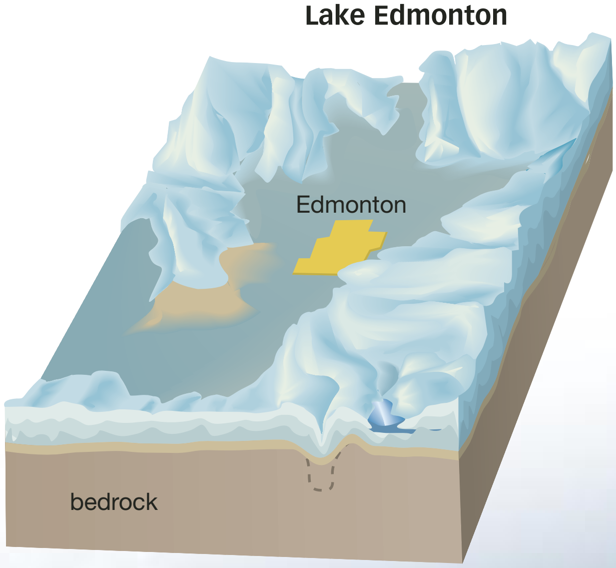


Figure C3.31: North America is shown as it appeared about 11 000 years ago.

Traditional stories of First Peoples speak of a world of water out of which the Great Spirit created the land. Indeed, as the Laurentide Ice Sheet completely disintegrated, it did release a great deal of water. This filled enormous glacial lakes, such as the 150-km-long glacial Lake Edmonton, which submerged the Edmonton area 12 000 years ago.

16 000 years ago: oldest archaeological evidence of humans living in North America

Weather Events: Cause, Correlation, and Probability

Before continuing with your work on climate change, it is important to understand the relationship between cause, correlation, and probability. These terms are important when evaluating the validity of theories concerning Earth's climate. In Practice questions 7 to 11, you will apply these ideas to the study of a small-scale weather event before applying them to a long-term global climate trend.

Practice

It doesn't matter whether you are going to a soccer practice, having a family picnic, or just mowing the lawn. Thunderstorms are a natural event that must be respected when it comes to summertime activities in Alberta. Many signs indicate a thunderstorm is coming, including a darkening sky and a noticeable drop in temperature. A sign that rain is just moments away is the sudden appearance of strong wind gusts.

Figure C3.32: A thunderstorm is approaching.

To sort these things out, it is important to keep these words in mind: **cause**, **correlation**, and **probability**.

- **cause:** a phenomenon that brings about an effect or a result
- **correlation:** one phenomenon that accompanies another
- **probability:** a measure of how likely it is that an event will occur

7. Explain the difference between cause and correlation.
8. Attempt to prove or disprove the statement, "In the summer it always seems to get cooler just before it rains. Therefore, a decrease in temperature must cause rain."
9. Does the occurrence of rain and a drop in temperature have a causal relationship or a correlational relationship?
10. Explain how you could use your answers to questions 8 and 9 to make predictions about the likelihood of rain. What level of certainty would you have in your prediction?
11. Based on this exercise, infer two elements that determine the level of certainty you can have in a prediction.

Fluctuating Climate

The current epoch—the Holocene—is just one time period of warming following one of several glaciations that occurred in the Quaternary Period. If this pattern of repeated glaciation continues, Alberta will experience its next glaciation within the next 100 000 years. Looking back over Earth's history before the Quaternary Period, there were several blocks of time containing repeated glaciations that date all the way back to Snowball Earth in the Precambrian Era. In this lesson you will learn about some theories concerning the causes of these cold periods and the repeated glaciations they contained. Before learning about these theories, you need to review the global climate record during Earth's history. Some changes in climate seem to be chaotic in nature, while others seem to follow a pattern.

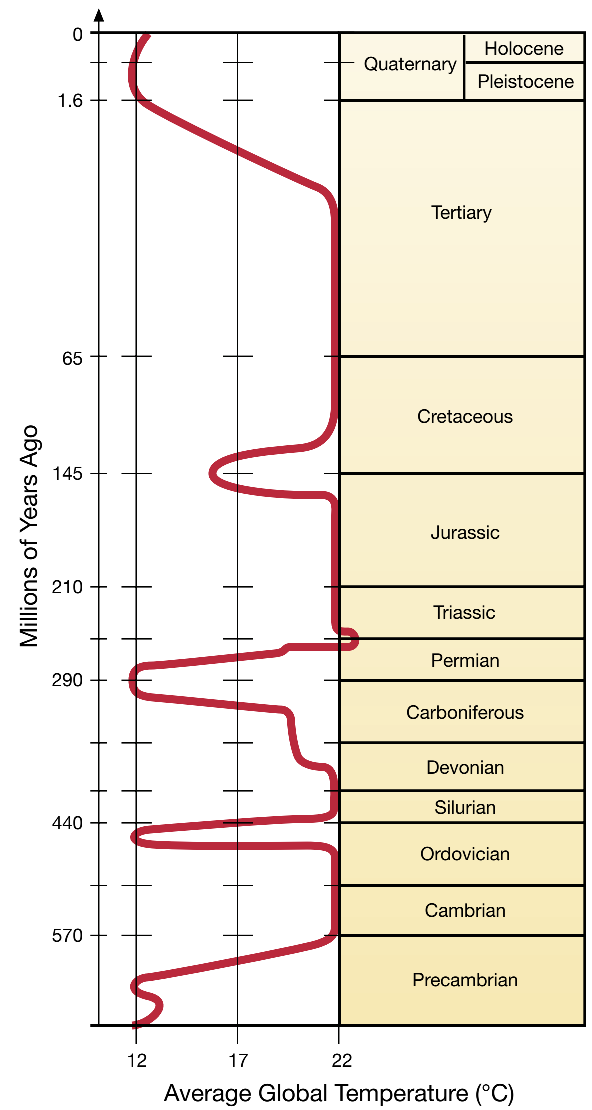


Figure C3.33: Evidence contained in rock strata around the world indicates that during most of its history, Earth was warmer than it is today. During these warmer times, it is unlikely that continental ice sheets like those in Antarctica and Greenland could stay frozen. However, this hot climate was punctuated by several long cold periods, each lasting millions of years. Today, Earth is experiencing one of these major cold periods. Remember that this is a very simplified graph. Much evidence is still being gathered.

Possible Causes of Glaciation Periods

It was mentioned earlier in this lesson that the most powerful supercomputers are used to create mathematical models that attempt to describe Earth's climate. These models involve studying links between the amount of solar radiation reaching the planet and each layer of Earth itself: the atmosphere, the lithosphere, and the **hydrosphere**.

hydrosphere: all the water at or near Earth's surface

Because these links are so numerous, and because the interactions are so intricate, the most powerful computer hardware and software available struggle to generate reasonably accurate models. As you read through the following possible causes of glaciation, you must keep this complexity in mind. Rather than wondering which of these theories is the correct explanation, it would be more helpful to think about which combination of these effects is most likely to play a significant role.

Continents Heading North

The timing of long periods of repeated glaciations, such as those that happened in the Precambrian Era, Jurassic Period, and Pleistocene Epoch, appears to be random. This may be due to the random nature of plate tectonics, which is their most probable cause. One theory concerning the cause of these cold snaps is that they occur when Earth's tectonic plates are in certain positions. It seems now that large land masses must be near the poles, such as Antarctica and Greenland, for a period of repeated glaciations to occur. This is because continental ice sheets must form on land to cause glaciations. As snow and ice begin to accumulate, the forming ice sheet takes on a climate of its own. Because an ice sheet is white, it reflects most of the solar energy that hits it back into space. This has an overall cooling effect on the planet.

The Ocean Is a Heat Pump

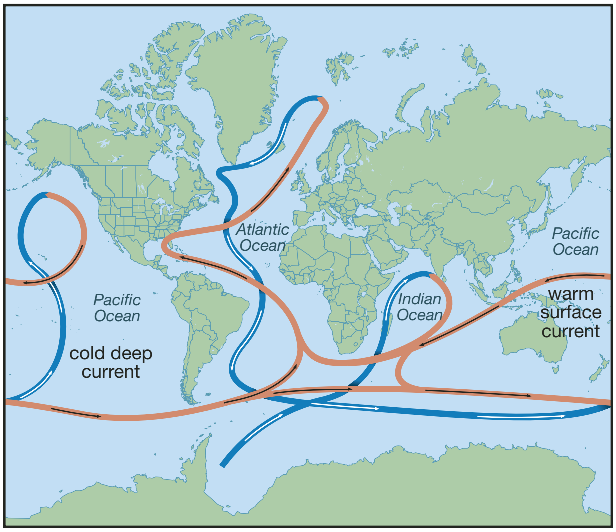
Do you know how your refrigerator works? A refrigerant fluid circulates through tubes. The fluid circulates, picking up heat from the inside of your fridge and dumping it into your kitchen. The oceans have giant convection currents that transport heat in a similar way. Collectively, they are called the **global conveyor**. The global conveyor currently has a warming effect on some parts of the world and a cooling effect on others. For example, in the North Atlantic Ocean, the conveyor transfers heat from the warm tropics and moves it between Iceland and Scotland. Much of the released heat is carried to Europe by prevailing winds. This explains why most European countries are warmer than Canada even though they are just as far north as Canada.

There is the opposite effect in Antarctica. An ocean current encircles Antarctica, which reduces the amount of heat the continent can receive from the southern tropics. This explains why Antarctica is the coldest place on Earth. Changes in the flow of ocean currents may explain the Pleistocene Epoch cold snap. Forty million years ago, Australia separated from Antarctica—this created the Indian Ocean and allowed the ocean current to circulate around Antarctica. The cooling effect encouraged the formation of the Antarctic Ice Sheet that led to the Pleistocene Glaciations.

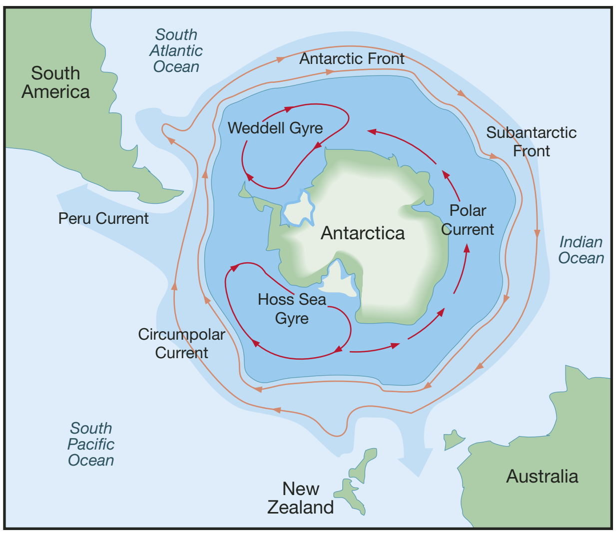
global conveyor: the system of ocean currents that circulates warm water away from the tropics near the ocean's surface

The system also recirculates the cold water of the polar regions using currents that flow in the opposite direction in the deep ocean.

The Global Conveyer



Antarctica's Ocean Current



The Long and Short of Volcanoes

Old volcanic activity may have contributed to long-term climate change. As discussed in Chapter 2, volcanoes are believed to have been a major contributor to the extinction of many species in the Permian Period. Volcanoes can also contribute to short-term fluctuations in climate, as demonstrated by the temporary cooling effect caused by the 1991 eruption of Mount Pinatubo in the Philippines.

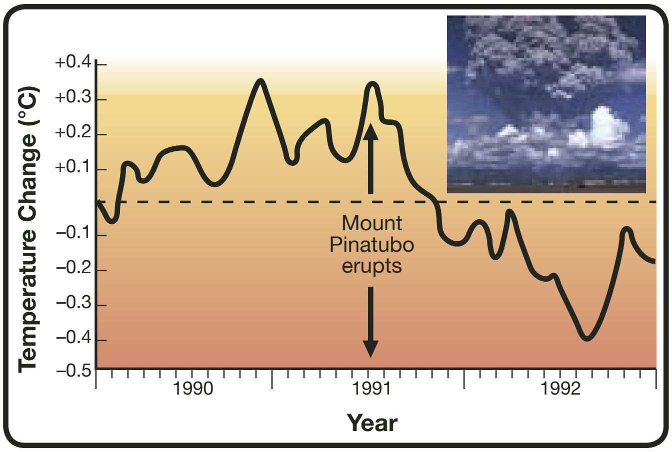


Figure C3.34: The eruption of Mount Pinatubo in 1991 had an effect on the world's climate.

Wobbly Earth

During each of the major cold periods in Earth's history, ice sheets have advanced and retreated several times. The repeated glaciations that have occurred during major cold periods seem to match changes in Earth's orbit around the Sun and Earth's rotation on its axis. This is called the Milankovitch Theory, after the scientist who first suggested this correlation between changes in Earth's orbit and the occurrence of glaciations. Milutin Milankovitch found that Earth's orbit varies in three ways: the shape of the orbit (called eccentricity), the tilt of the axis of rotation, and the wobble of the axis of rotation. Each of these three variations in orbit and rotation affects the amount of solar radiation reaching Earth's polar regions. When the variations are combined, they correlate quite well with the timing of the Pleistocene Glaciations, as shown by ocean sediment cores. Scientists believe that Milankovitch Cycles are not in themselves the cause of the overall cold period but rather that they control the timing of the glaciations.

Our Moody Sun

Scientists have discovered that the Sun doesn't always shine with the same intensity. These changes in the intensity of solar radiation seem to follow a regular pattern determined by the frequency of sunspots. During times when there are more sunspots, additional energy is released by the Sun. Most climatologists consider variations in the sunspots to have only a minor impact on climate change because the differences in energy output are small (0.1% to 0.2%). However, there appears to be a correlation between the Maunder Minimum from 1645 to 1715—a time of very low sunspot occurrence—with an unusually cold period that occurred during the Little Ice Age in Europe. However, more recent theories about the causes of the Little Ice Age tend to be based more on changes in the North Atlantic Ocean's circulation current than on sunspots. One theory suggests a release of fresh water into the North Atlantic Ocean slowed down the circulation current that normally warms Europe.

Figure C3.35: Europe has been subjected to periods of cold temperatures at several times in its history.

Practice

12. The table in this question summarizes possible causes of glaciation. The causes are listed in the left column. The possible effects of each cause on Earth's layers, as well as the amount of solar radiation received on Earth's surface, are the headings across the top of the table. No answers are required for boxes with Xs.

POSSIBLE CAUSES OF GLACIATION AND THEIR EFFECTS

Possible Causes of Glaciation	Effects on Earth's Atmosphere	Effects on Earth's Lithosphere	Effects on Earth's Hydrosphere	Effects on Solar Radiation Received on Earth's Surface
Plate Tectonics	X			
Global Conveyor				X
Volcanic Activity		X	X	
Milankovitch Cycles	X	X	X	
Variations in the Sun's Energy Output	X	X	X	

Complete this table by adding a description of how each cause of glaciation affects both Earth's layers and the amount of solar radiation received on Earth's surface.

13. Consider the table you completed in question 12. Which causes of glaciation show the greatest degree of interconnectedness by the effects they have upon Earth?

Investigation

Return to Vostok

Science Skills

✓ Analyzing and Interpreting

Problem

Is there a correlation between the average temperature and atmospheric carbon dioxide concentrations over the last 160 000 years?

Background

In Lesson 3.2 you analyzed ice-core data from Lake Vostok, Antarctica. You constructed a graph showing average temperature fluctuations over 160 000 years. Refer to "Vostok Spreadsheet and Data" from the Science 20 Textbook CD, and obtain the "Temperature and Carbon Dioxide over 160 000 Years" handout.

Analyzing Data

Analyze the graph showing average temperature and carbon-dioxide concentrations over the past 160 000 years.

1. Using the data, identify whether there is a correlation between the two variables of average temperature and carbon dioxide concentration. Provide evidence.

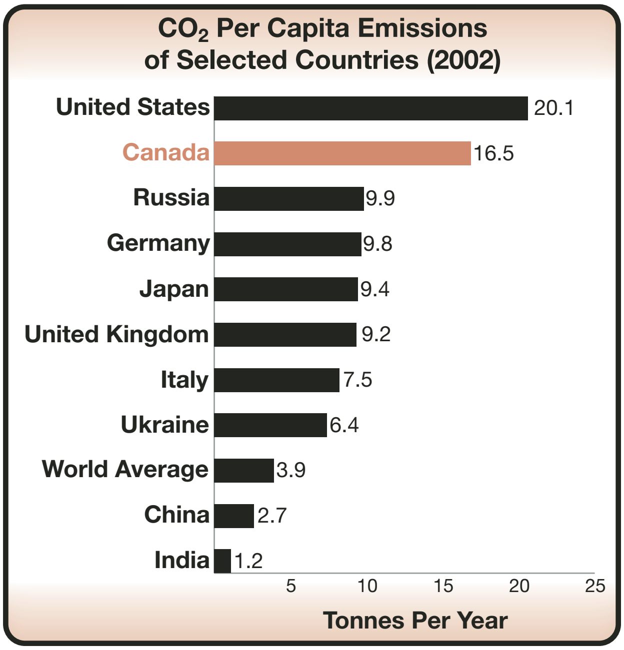
Conclusion

2. Does this mean that changes in the concentration of atmospheric carbon dioxide actually cause the changes in average global temperature?
3. Determine if changes in the amount of atmospheric carbon dioxide correlated with the last two glaciations are caused by human activities.

The Enhanced Greenhouse Effect

Earth's atmosphere contains gases, such as carbon dioxide and methane, that trap heat near Earth's surface. Without this natural insulating effect, Earth would be much colder than even the coldest ice age. As you saw when you analyzed the Vostok ice-core data, carbon dioxide in the atmosphere can change drastically. This can occur due to natural events, including volcanic activity and the weathering of carbonate rocks. These variations appear to correlate with changes in the average global temperature over the past 160 000 years. Changes in carbon dioxide, in combination with other factors such as the Milankovitch Cycles and global ocean circulation, may have amplified the effect on the atmosphere's temperature.

In more recent times, there has been a sharp increase in the concentration of carbon dioxide in the atmosphere. This increase coincides with an exponential increase in the emissions of carbon dioxide since the Industrial Revolution. The largest human-caused source of atmospheric carbon dioxide is the burning of fossil fuels. Many scientists believe this increase is enhancing Earth's natural greenhouse effect, shown by a significant increase in the average global temperature during the last century (see Figure C3.36). Computer models predict that as carbon dioxide emissions continue to rise, the effect will be further increases in the average global temperature. Canada and Alberta are contributing more than the global per person average share of these emissions due to the use of energy sources that produce carbon dioxide emissions as well as poor energy efficiency. Because many of the activities that lead to carbon dioxide emissions are under the control of people, there is a possibility that global climate change can be reversed.



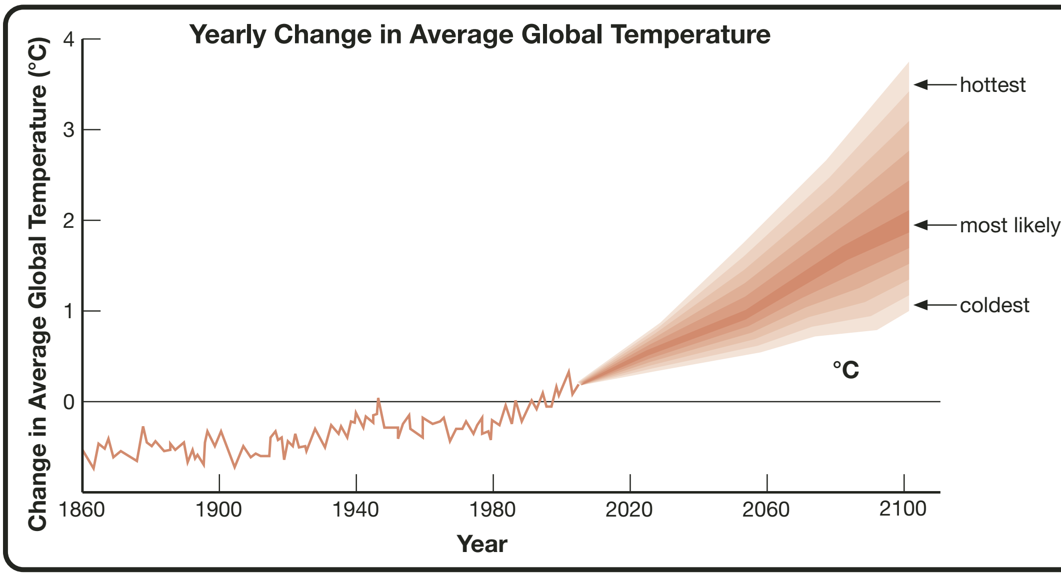


Figure C3.36: Scientists believe that greenhouse gas emissions caused by people are creating an increase in the average global temperature. Computer models based on the global climate system predict a continued increase for decades to come. This graph shows a summary of various computer model projections.

Could Global Warming Cause Global Cooling?

This question may seem strange, but some current models of climate change actually predict this. The prediction that global warming could end up causing a drastic cooling demonstrates the complex nature of Earth's climate system. As Earth warms due to the enhanced greenhouse effect, mountain glaciers and continental ice sheets are melting. Over the past several decades, the Greenland Ice Sheet has been shrinking in size and releasing fresh water into the North Atlantic Ocean. If the atmospheric temperature were to get hot enough, the rate of melting of the Greenland Ice Sheet would increase. If enough fresh water is added to the North Atlantic, it could slow down warming tropical currents. The result could be similar to what may have occurred to cause the most recent ice age: less heat being pumped toward the poles from the tropics. This could have a rapid cooling effect, which could result in advancing ice sheets in the north. Changing one variable in the complex system of Earth's climate, for example the amount of carbon dioxide, can have an unexpected effect on the whole system.

Utilizing Technology

The North Atlantic Conveyor

An applet titled “North Atlantic Conveyor” is available on the Science 20 Textbook CD. This animation shows the North Atlantic Conveyor in action, pumping heat up from the tropics to Canada and northern Europe.

Science Skills

✓ Analyzing and Interpreting

Analysis

1. Describe the effect of adding large volumes of cool fresh water from Greenland to the North Atlantic Conveyor.
2. Explain why the outcome is somewhat paradoxical.

3.3 Summary

The Holocene Epoch is the final page in this story of Alberta. It began approximately 10 000 years ago and is still in progress. The foundations established by scientists, like James Hutton and Charles Lyell, have revealed that to understand the past, people must rely on processes observable in the present—theories must carry the burden of evidence. This same line of thought applies to projecting future changes. Scientists strive to understand the processes that have caused climate changes in the past and hope to apply this knowledge to predict future climate change. You have seen that this can be a difficult and complex task, as many theories and processes combine in complicated ways. When predicting outcomes in a complex system like Earth, total certainty can never be reached. A lack of certainty should not prevent people from acting.

3.3 Questions

Knowledge

1. Copy and complete the table, and fill it in using brief descriptions. Make sure to give yourself enough room.

Time Frame	Description of Average Temperature Fluctuations	Theory of Cause	Description of Theory
Earth’s Entire History		Plate Tectonics	
		Volcanic Activity	
Pleistocene and Holocene		Milankovitch Cycles	
		Natural Carbon Dioxide Fluctuations	
Little Ice Age		Variations in Solar Intensity	
Last 100 Years		Enhanced Greenhouse Effect	

2. Define the term *Holocene Epoch*.
3. Explain why 100% certainty cannot be achieved when making climate predictions.
4. What major theme dominates the story of Alberta?

Applying Concepts

5. The issue of climate change involves the intersection of science with technology and society. Create a table that starts with these categories by listing the aspects of this issue that fall into each category. Show connections by using circles and arrows.

Science	Technology	Society

Chapter 3 Review Questions

Knowledge

1. Explain the origin of the Big Rock at Okotoks, Alberta.
2. Use the "Geological Time Scale" on page 312 to sketch a diagram showing how the Cenozoic Era is broken down into periods and epochs. Include the start and end time of each time period.
3. Describe how glaciers move.
4. Explain why the Cenozoic rock formations at Cypress Hills are still intact, whereas Cenozoic rock formations in other parts of Alberta and Saskatchewan have been disturbed.
5. Explain what caused the draining of the Bearspaw Sea near the beginning of the Cenozoic Era.
6. Define the term *glaciation*.
7. Describe how the Rocky Mountains appeared before they experienced the glaciations of the Pleistocene Period.
8. Describe the climate change during the Tertiary Period. Infer a possible reason for this change.

9. Identify what two groups of animals took the place of large dinosaurs as the dominant life forms of Alberta in the early Tertiary Period.
10. Describe Alberta in the late Tertiary Period.
11. Explain how scientists have been able to measure the average global temperature change during the last 65 million years.
12. Describe how the climate during the Quaternary Period was different than the climate during the Tertiary Period.
13. Describe how each of the following features form. Give an example of each.
    a. continental ice sheet
    b. mountain glacier
14. Describe how glaciers have shaped the land as shown in Figure C3.37 and Figure C3.38.

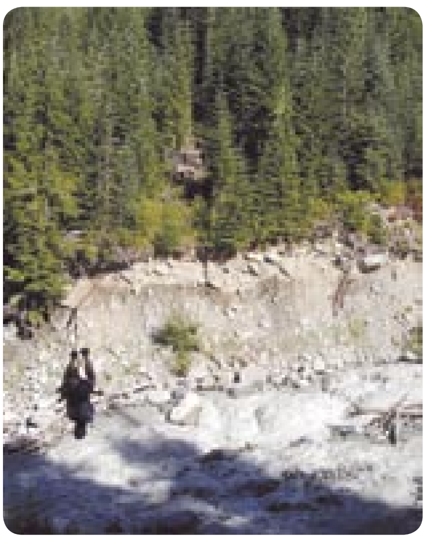


Figure C3.37: An ecotourist uses a zip line to cross a glacier-fed creek near Whistler, B.C.

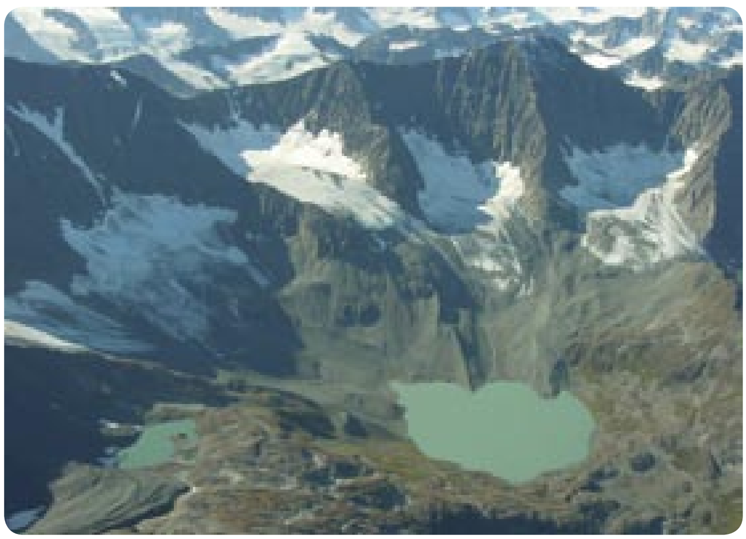


Figure C3.38: Glaciers have shaped the Chugach Mountains area of Alaska.

15. Describe how the most detailed information concerning average global temperature was collected and analyzed to determine Earth's climate over the past 420 000 years.
16. Describe the Wisconsin Glaciation.
17. Explain how scientists can determine in what direction the Laurentide Ice Sheet flowed during the Wisconsin Glaciation.
18. Explain how scientists can determine how far south the Laurentide Ice Sheet advanced.
19. Describe how mountain glaciers have changed the appearance of the Rocky Mountains.
20. Explain how glaciers help provide a basic need for many communities.
21. How is the trend in increasing average temperatures around the world affecting mountain glaciers and ice sheets?
22. Explain the difference between weather and climate.
23. Explain how scientists are working to reduce uncertainty about their predictions concerning global climate change.
24. Briefly summarize the changes in Earth's average global temperature over the course of its 4.5-billion-year history.

25. Explain how continental drift caused by plate tectonics can lead to climate changes.
26. Once an ice sheet forms, explain how it reduces the amount of solar radiation absorbed by Earth.
27. Explain how the Milankovitch Variations on Earth's orbit and rotation affect Earth's climate.
28. Explain what evidence shows a correlation between atmospheric carbon dioxide concentration and average temperature.
29. Describe the current impact of people on the global climate.
30. Explain how the enhanced greenhouse effect could actually lead to a cooling of Earth's northern regions.

Applying Concepts

31. Refer to Figure C3.39. What inference could you make concerning past climates if you found fossils of angiosperms with pointed leaves in Canada's Arctic?

Figure C3.39: Angiosperms (flowering plants) with pointed leaves are found in warmer climates, while angiosperms with rounded leaves are found in cooler climates.

Use the following information to answer questions 32 to 34.

Locate the video clip called "Career Profile: Columbia Icefield Tour Guide" on the Science 20 Textbook CD. Play the video. Use the information provided to answer questions 32 to 34.

32. Describe the process that produces glacial ice.
33. Explain why glacial ice is said to have the properties of a plastic.
34. Identify three uses for the fresh water that flows from glaciers.

Use this article to answer questions 35 to 41.

Researcher computes climate change

By Chris Smith

June 17, 2003 – A University of Alberta professor who studies computerized climate modelling has found that his field of research is in the middle of a brewing controversy. Dr. Andrew Bush specializes in paleoclimate modelling and supercomputing in the U of A Department of Earth and Atmospheric Sciences.

To help others understand his research, Bush begins by explaining the difference between climate and weather. "Climate includes all the processes that give us our weather," he said. "There is a fundamental difference between climate prediction and weather prediction."

Weather prediction occurs regionally and over the short term; climate is the average of all the weather events over a longer time period. For Bush's climate models, this goes back 21 000 years to the end of the last glacial advance.

Using such models, as well as arctic ice core samples and historical weather data, the United Nations Intergovernmental Panel on Climate Change (IPCC) concluded that although there are uncertainties in the ultimate cause of climate change, all indications point to human influence as a contributing factor.

Quickly following the release of the 2001 IPCC report, the results produced by computer modelling were devalued after they became the center of controversy and misunderstandings. "It's easy to be skeptical of something that can never be predicted with 100 percent accuracy. A lot of my work has been on simulating the climate and then comparing the model results to the data records," said Bush.

This kind of verification is essential because, Bush said, "the models are an approximation of reality; they are not reality itself . . . . The IPCC (report) is the best statement of our current knowledge, and that knowledge is certainly going to change in the future." Just how our knowledge will change will depend on more accurate data and better climate modelling on faster computers. This challenge has been wholly taken up by the Earth Science Center in Japan, which designed and built the Earth Simulator. The fastest computer ever built, the Earth Simulator operates at 40 Terra flops per second, or 40 trillion computations per second, which is five times faster than the previous best.

"Climate research is limited by the hardware," Bush said. "The number of computations involved in climate modelling necessitates the use of leading edge supercomputers."

Global climate change has presented supercomputing and climatologists, like Dr. Bush, with a great challenge. Armed with better computer hardware and climate modelling techniques, scientists' understanding of the climate system and identification of the human contribution to climate change may determine how we can avoid further environmental damage.

"Climate modelling is our best and only tool for predicting the future of our global environment, as well as the consequences of our actions as a species," Bush said. "Can climate modelling save the world? No—all it can do is tell us why the world is changing. Saving it is up to all of us."

35. What is the brewing controversy referred to in the article's first sentence?

36. Summarize the conclusion made by the United Nations Intergovernmental Panel on Climate Change (IPCC).

37. Explain the significance of the conclusion made by the IPCC.

38. What reason does Dr. Bush give for people being skeptical about computer modelling?

39. How do scientists verify computer models used to predict future climate changes?

40. Does Dr. Bush consider scientific knowledge to be static or changing? Justify your answer.

41. Describe the world's leading technology in the area of climate modelling.

Unit C Review Questions

1. Now would be a good time to review the story of Alberta. Watch the applet "Geomorphology," on the Science 20 Textbook CD. Copy the following table row by row, so that you will have enough space. As you view the applet, fill in the table. Remember, you can pause and rewind as much as you wish. The first row is done for you. Note that the Tertiary Period is basically skipped in the applet—you will have to provide the information for this one on your own.

Era	Period	Time Frame (Millions of Years Before Present)	Environmental Conditions	Events and Life Forms	Societal Connection (Fossil Fuels)
Precambrian		4500 to 590	volcanic, hot	• life begins in sea • algae, bacteria, primitive worms	none
Paleozoic	Cambrian				
	Ordovician/ Silurian				
	Devonian				
	Carboniferous				
	Permian				
Mesozoic	Triassic				
	Jurassic				
	Cretaceous				
Cenozoic	Tertiary				
	Quaternary				

2. The following table summarizes the important concepts of Unit C. Copy this table into your notebook. Go row by row, so you end up with enough room. The first entry is done for you.

Concept	Explanation	Examples	Connection to Technology and/or Society
challenges of investigating changes to Earth's crustal plates	Earth's history has occurred over billions of years and is recorded all across the planet in sedimentary rocks thousands of metres thick.	• most rocks and fossils from early in Earth's history destroyed by rock cycle	• new technological advances—ground-penetrating radar, GPS satellites, radiometric-dating techniques—help scientists overcome challenges
evolution of geological process theories			
energy released by earthquakes			
layers for Earth's internal structure			
plate tectonics			
driving force for plate tectonics			
determining absolute age			
fossilization			
determining relative age			
evidence of past climates in rocks			
life forms affect atmosphere's composition			
evidence of repeated glaciations in Alberta			
ice cores show evidence of warming, cooling			
several theories about causes of climate change exist			

Use Figure C3.40 and the paragraph that follows to help you answer questions 3 to 15.

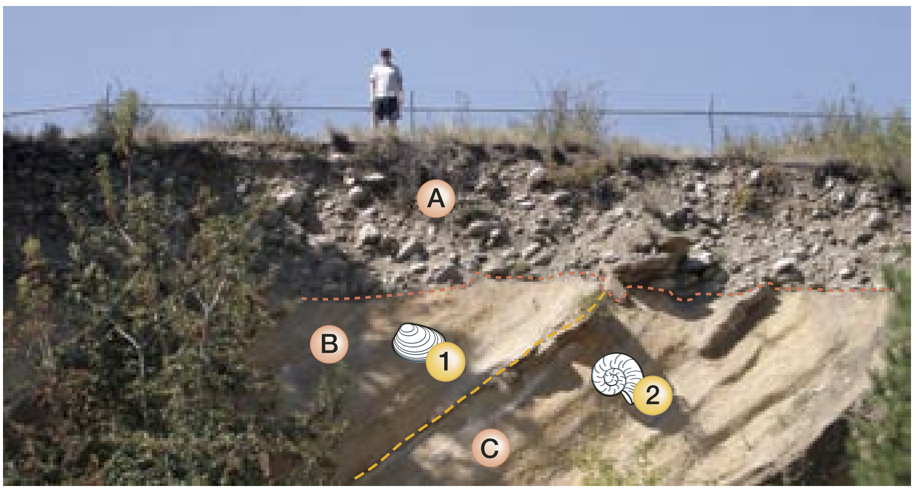


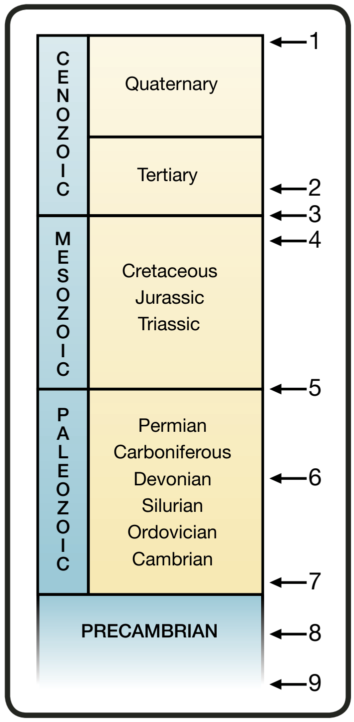
Figure C3.40: This is one of the many interesting landforms you see when travelling through Canada.

When travelling through Alberta and the rest of the country, you might see interesting landforms that make you wonder how they formed or what information they hold. Suppose that during a summer road trip to Vancouver, you stopped for lunch at a diner in Princeton, B.C. Right beside the parking lot was a stunning outcropping that made you think of a James Hutton painting. You began to wonder about the story recorded in these rocks.

Although you were unable to truly investigate this outcropping, questions 3 to 16 explore some possibilities and will help you review key concepts from Unit C. Note that the fossils in Figure C3.40 are not drawn to scale.

3. Identify which important theory James Hutton is credited with originating.
4. Explain Hutton's theory.
5. List layers A, B, and C in Figure C3.40 in order from oldest to youngest.
6. Infer the scientific law you had to apply to answer question 5.
7. Suggest how this rock formation formed.
8. Which fossil is younger—fossil 1 or fossil 2?
9. Fossil 1 is called *Vernericardia*. It's an index fossil from the Tertiary Period. Which era is the Tertiary Period part of?
10. Fossil 2 is an ammonite from the Cretaceous Period. Using the information provided in Unit C, determine the range of possible ages for layer C.
11. Explain what may have occurred at the boundary between layers A and B.
12. If layer C contains 93% uranium-235 and 7% lead-207, what is its age?
13. Is the date you determined in question 12 relative or absolute?
14. Describe how layer A shows evidence of glaciation.
15. When was layer A likely deposited?
16. Match each of the following events to the correct number on the table titled "The Geological Column." The column is not drawn to scale.
    - **a.** Burgess Shale
    - **b.** extinction of dinosaurs
    - **c.** greatest mass extinction
    - **d.** last ice age
    - **e.** break-up of Pangaea
    - **f.** age of fishes
    - **g.** first appearance of life
    - **h.** when mammals first became abundant
    - **i.** oldest rocks on Earth

The Geological Column



Use the information in Figure C3.41 to answer multiple-choice questions 17 to 19.

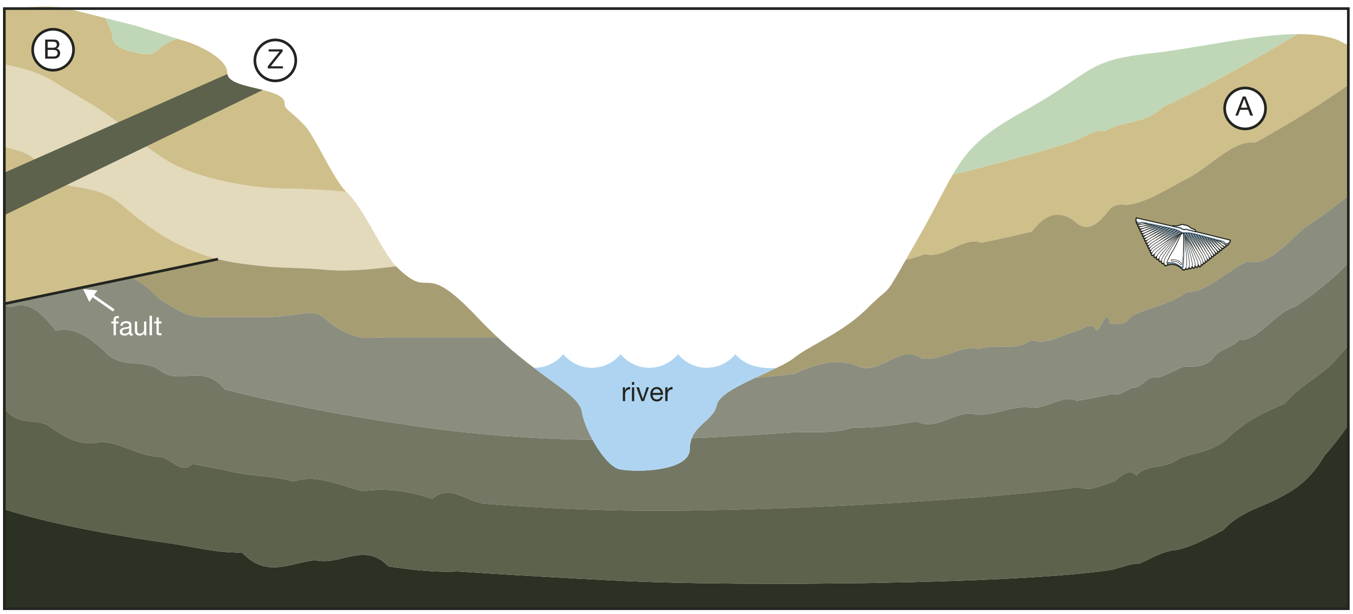


Figure C3.41: This cross section of rock strata surrounds a river.

17. The fossil on the right-hand side of the cross section is from the Devonian Period. Which of the following is a possible period for layer A?

A. Precambrian
B. Cambrian
C. Silurian
D. Permian

18. The igneous rock unit labelled Z has been radioisotope-dated at 62 million years. The range of ages for B is most likely to be

A. 65 million to 225 million years old
B. younger than 62 million years old
C. between 62 million and 65 million years old
D. the same age as formation A

19. The igneous rock unit labelled Z is called

A. an intrusion
B. a ridge
C. a subduction zone
D. a plate boundary

20. Describe a circumstance that would increase the chances of an animal's remains fossilizing.

Use the information from this paragraph and Figure C3.42 to answer questions 21 to 23. Scientists discovered two cliffs on different continents that were separated by an ocean. From the geological record, the scientists concluded the continents were—at one time—joined together and then separated. The geological evidence is shown in the geological columns in Figure C3.42.

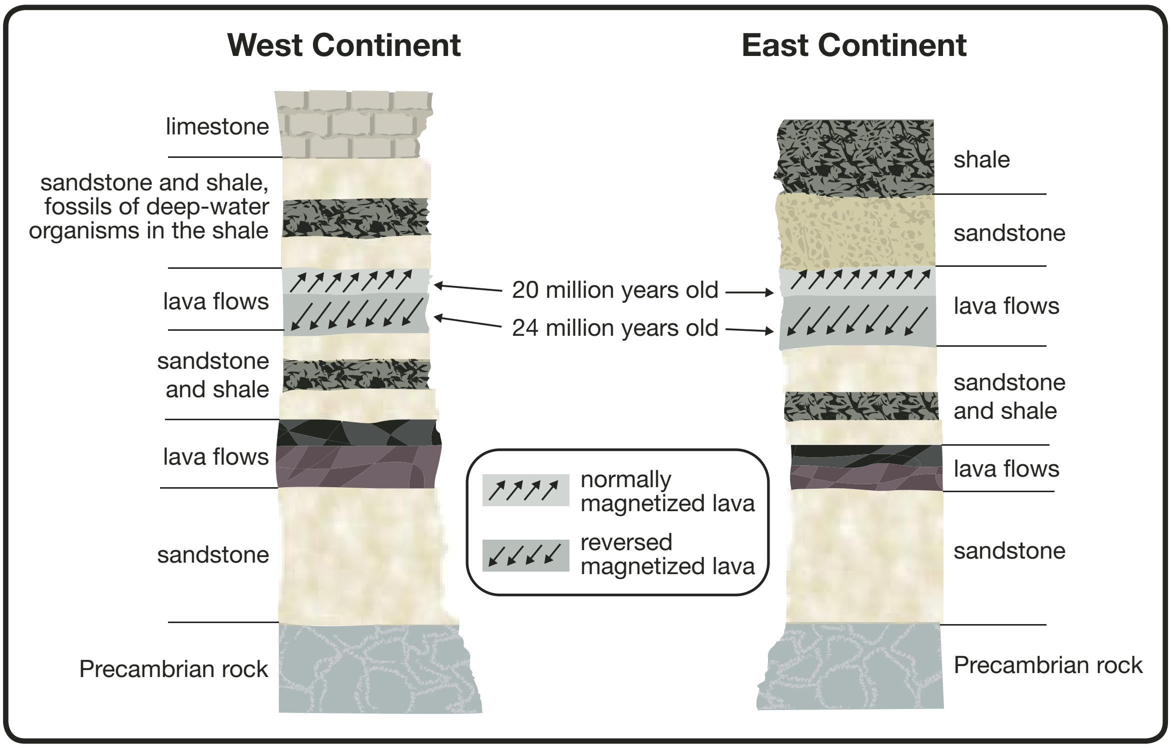


Figure C3.42: Rock strata on two continents are separated by an ocean.

21. Describe two different types of evidence that indicate that the two continents were once joined.

22. The 24-million-year-old lava flows are thicker than the 20 million-year-old lava flows. What could be responsible?

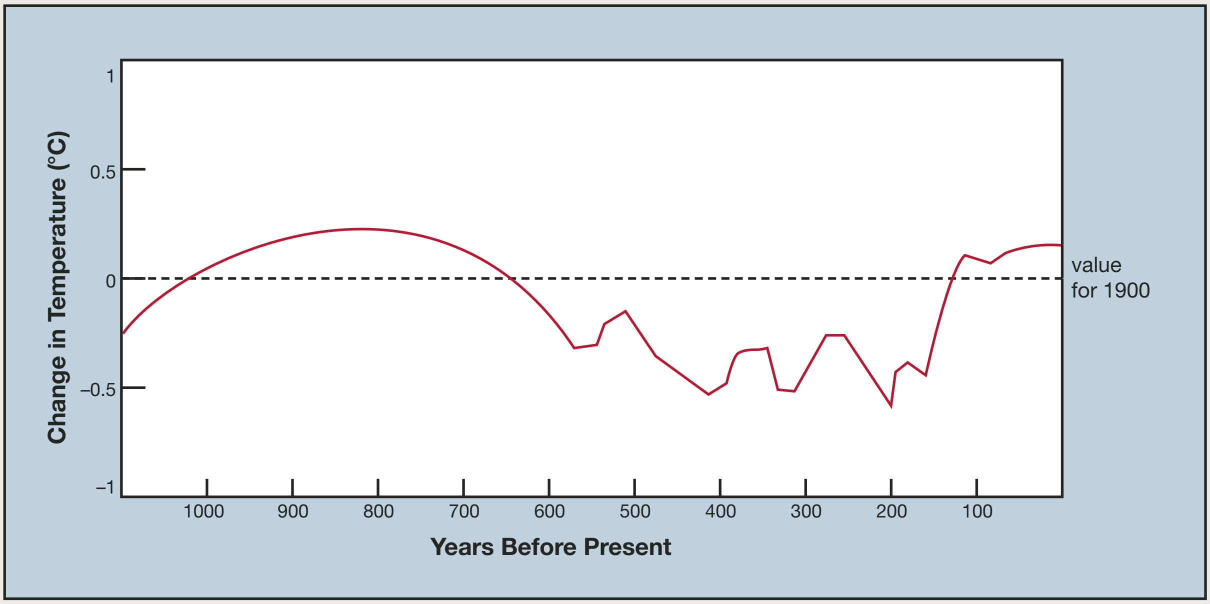
23. The age of the continental separation was dated to be approximately 20 million years ago. Describe the evidence in the geological columns that supports this date.

Use “Changes in Earth’s Surface Temperature Versus Time” to answer question 24.

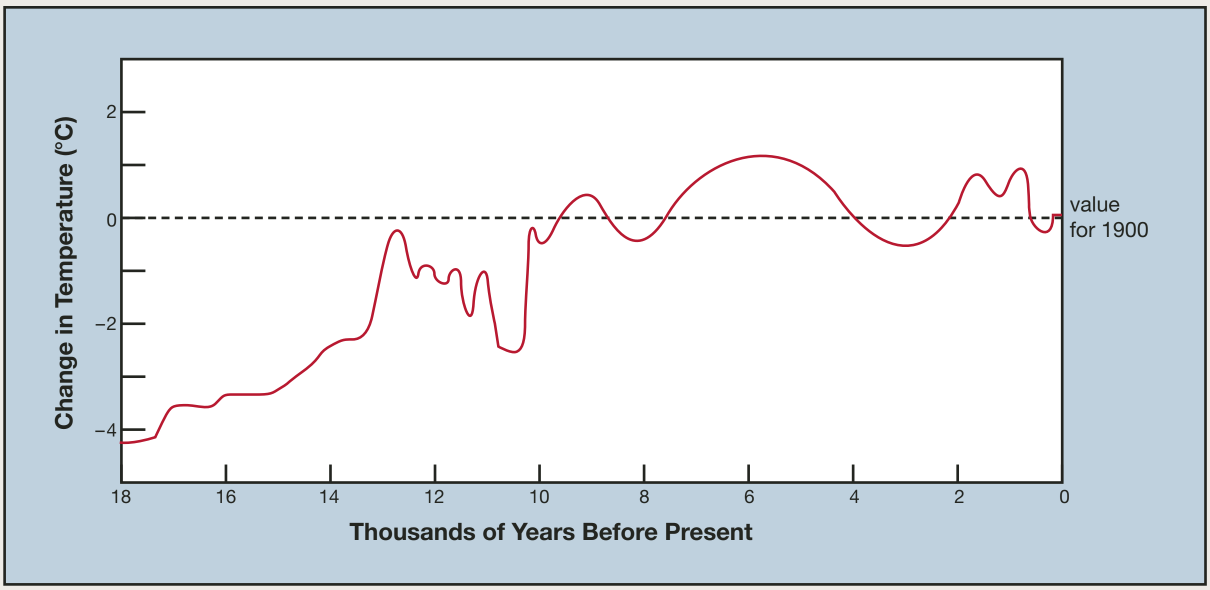
Changes in Earth’s Surface Temperature Versus Time

The following graphs indicate how the mean temperature for Earth’s surface changes over time. For all four graphs, in order from short term to very long term, the change in the mean temperature of Earth’s surface is referenced to the value from 1900 as the base value. In other words, the temperatures for the different time periods have been compared to the 1900 value. The graphs differ in the time scale displayed on the horizontal axis. Note that the different time scales required different data-collecting techniques. This has led to some inconsistencies, but the overall data trends are essentially the same.

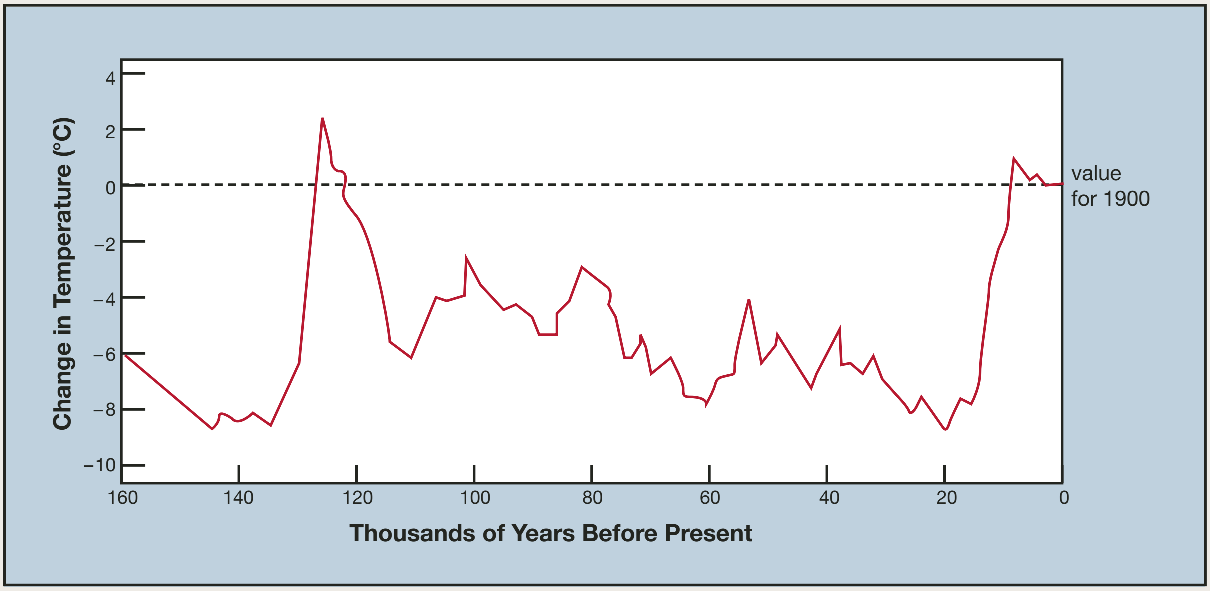
Graph I



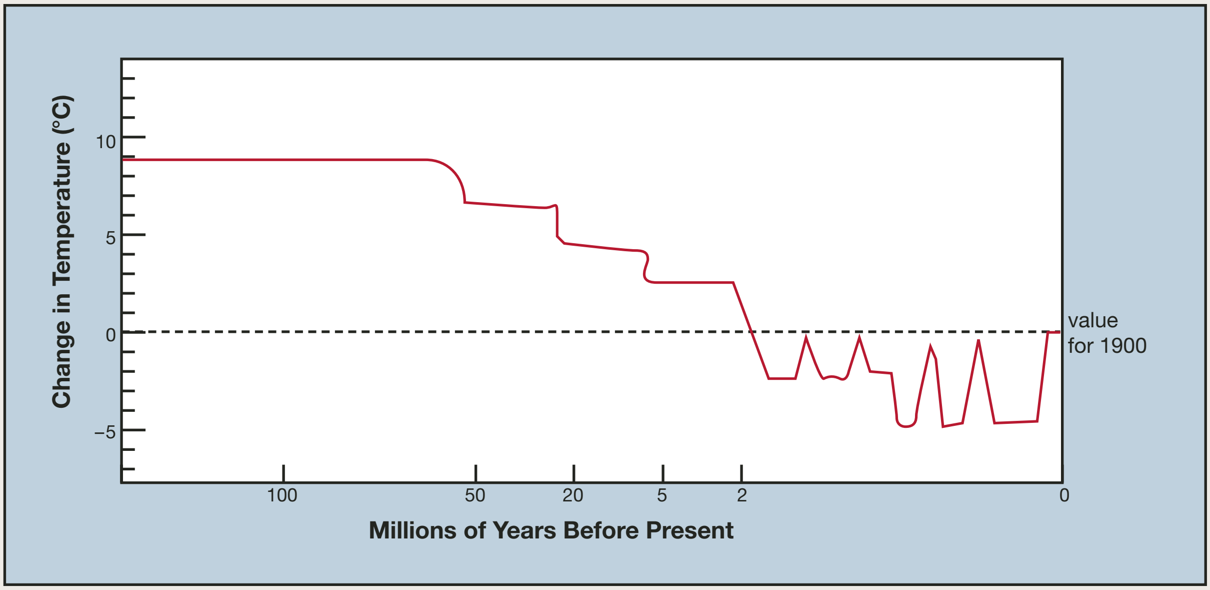
Graph II



Graph III



Graph IV



24. Each graph provides information about the change in average temperature at Earth's surface relative to the temperature value for 1900. The major differences between the graphs are the time scales presented on the horizontal axes for the graphs. Choose which graph could best be used to help investigate each of the following research topics.

a. An analysis of ice-core data from Greenland indicates that a sudden global cooling event triggered climatic changes in northern Europe about 8200 years ago. Archaeological research suggests that the human population living in these places experienced a significant drop in numbers during the 200 years of sudden cooling. Once temperatures returned to pre-cooling values, new people moved into these areas from Asia and the Middle East. It is thought that these people brought an advanced culture of settled villages to northern Europe that made use of domesticated plants and animals.

b. Geological evidence suggests that 70 000 years ago, a violent volcanic eruption occurred on Mount Toba on the present-day Indonesian island of Sumatra. Evidence suggests so much material was spewed into the atmosphere that Earth was plunged into a six-year volcanic winter and a 1000-year instant ice age. Archaeological evidence from Blombos Cave in South Africa reveals that humans at this time had developed tools for fishing, and they also carved abstract symbols on cave walls. Some archaeologists have theorized that the harsh climate may have forced these early humans to be more creative in order to survive.

c. The Ancestral Pueblo or Anasazi were people who lived in the canyons of the American Southwest. These people built multi-room, masonry dwellings known as pueblos, which is Spanish for "village." These people developed elaborate water catchments for the corn crops that were the staple food of their agricultural society. A global warming period that began about 1000 years ago may have caused a prolonged, severe drought in this area. A lack of rainfall may have been the key event that triggered the decline of both the society and culture of the Ancestral Pueblo people. By the year 1300, their elaborate masonry homes had been abandoned.

25. Refer to the information presented in question 24. Choose one of the three research topics presented and perform an Internet search to investigate the connections among climate, human activity, and culture suggested by each topic.

26. Use the following standard to complete a self-evaluation of your time line.

Score	Scoring Description
Standard of Excellence (4 marks)	The response is well organized and accurately describes the events in Alberta's history. The description of events reflects a clear and thorough understanding and consistent logical thought. The descriptions are accompanied by a suitable organizer, such as the time-scale handout or a logical and/or creative organizer designed by the student.
Acceptable Standard (2 marks)	The response addresses most major events. The descriptions may be inconsistent in the employment of appropriate scientific vocabulary, and the graphic organizer may be poorly used. The descriptions may be disorganized, but they demonstrate a correct understanding.

Figure C3.43: Pueblos were built by the Ancestral Pueblo or Anasazi people.