Unit C The Changing Earth

Chapter 1: The Abyss of Time

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1. A possible analogy is that a jawbreaker candy is like Earth. The gum in the centre is like the core, and the hard candy layers are like the outer core, mantle, and crust.

2. Note the answers to this comparison table.

Earth's Layers		Density	Description	Thickness
atmosphere		least dense	• gaseous	300 km
lithosphere		↓	• solid • most rigid layer	75 km to 125 km
mantle	asthenosphere		• least rigid or most plastic layer of mantle	225 km to 275 km
	mesosphere		• more rigid than uppermost layer of mantle	2550 km
core	outer core		• liquid	2260 km
	inner core	most dense	• solid	1220 km

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3. The oceanic crust is denser than the continental crust.

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Knowledge

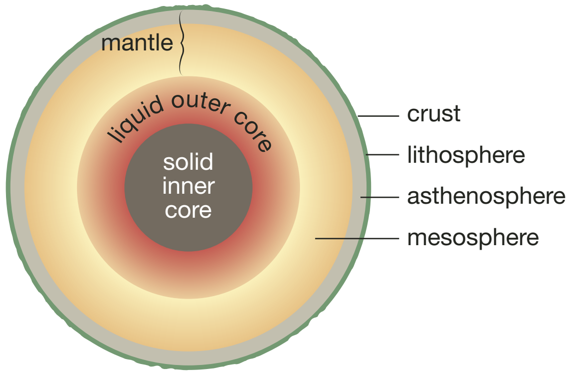
1. The first major section of time in Earth's history is the Precambrian Era. It began 4.5 billion years ago and ended 590 million years ago.

2. The oldest exposed rocks in Alberta are found at Slave River in northeastern Alberta.

3. An *outcrop* is a part of a rock formation that appears above the surface of the surrounding land.

4. *Deep time* is the theory that Earth has been through a long process of development and change for billions of years.

5. The following is a simple diagram showing a cross section of Earth.



6. Density is the main property that determines the composition of layers within Earth. During Earth's formation, elements like iron and nickel flowed to the centre of Earth due to their higher density. Lighter elements—including carbon, silicon, oxygen, sulfur, nitrogen, and hydrogen—migrated to the crust and atmosphere.

Applying Concepts

7. A bubble near the base of the lava lamp is heated. It becomes less dense, so it floats to the top. Near the top it cools and becomes denser. Once it becomes dense enough, it sinks to the bottom where it is heated again to complete the cycle.

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4. This calculation is just like a speed problem, with the following factors:

$$\text{thickness, } \Delta d = 11\ \cancel{\text{km}} \times \frac{1000\ \cancel{\text{m}}}{1\ \cancel{\text{km}}} \times \frac{100\ \text{cm}}{1\ \cancel{\text{m}}} = 1.1\times10^{6}\ \text{cm}$$

rate of sedimentation, $v = 1.0$ cm/a

time to build rock formation, $\Delta t = ?$

$$v = \frac{\Delta d}{\Delta t}$$

$$\Delta t = \frac{\Delta d}{v} = \frac{1.1\times10^{6}\ \text{cm}}{1.0\ \text{cm/a}} = 1.1\times10^{6}\ \text{a}$$

According to this information, it took 1.1 million years to deposit Alberta's Precambrian sedimentary rock strata.

5. The assumptions relate to the two data values substituted into the equation:

- The rate of sedimentation measured in the present is equal to the past's rate. It turns out that geologists have a difficult time measuring rates of sedimentation in the present. Geologists also find that rates are rarely constant.
- The 11-km sandwich of rock is perfectly preserved; there haven't been any periods of erosion that carried away some of the rock. An example is if the rock layers were actually 12 km thick (1 km eroded away), this would cause a calculation error.
- The rates of sedimentation are similar in all areas on Earth.
- There is no compression of the 1 cm/a sedimentation in the rock formation process.

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6. Photosynthesis uses the Sun's energy to build glucose from carbon dioxide and water.

7. The by-product of photosynthesis is oxygen.

1.2 Questions, page 305

Knowledge

1. Rivers erode rocks as they flow and deposit the sediments into an ocean. Geological processes eventually compress the sediments to become sedimentary rock. Chemical reactions in the ocean can also form solid precipitates that sink to the bottom and become part of the sedimentary rock.

2. Alberta's Precambrian sedimentary rock formations help geologists map out the coastline as it appeared 1.5 billion years ago. These formations also provide hints about sea level and climate.

3. Stromatolite fossils are found near Alberta's ancient coastlines. By studying their living counterparts in western Australia, scientists know that the Alberta fossils must have required a hot, tropical, coastal environment.

4. Earth's first living creatures were probably single-celled bacteria that fed on hydrogen sulfide.

5. The earliest signs of life on Earth are 3.8 billion years old.

6. Earth's first creatures lived in hot oceans with temperatures exceeding 100°C.

7. Alberta's oldest fossils are stromatolites, which are mounds of limestone over 30 cm in diameter and up to 1 m in height. They were built by cyanobacteria—some of Earth's first photosynthetic organisms. Masses of bacteria grew and died, building up layer upon layer of limestone deposits.

Applying Concepts

8. a. These glacial deposits support the theory of Snowball Earth. In this theory, glaciers covered most of Earth.

   b. The limestone deposits show that for the limestone to have formed, the region must have eventually thawed and been submerged under warm water.

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Questions 8 and 9 are designed to explore the scientific method. You should be able to explain how observations lead to hypotheses, which can then be generalized to become theories. These theories can then be verified often enough to become scientific laws.

8. Steno reasoned that the rock surrounding the tooth fossils must have been in fluid form when it was deposited around the teeth. The fluid must have later hardened into solid rock. A modern explanation would be that the shark teeth sank to the bottom of the ocean and were later buried by sediment. As layers of sediment continued to fall, the weight increased to the point where sediments surrounding the shark teeth were compacted into solid rock.

9. The strata must have been deposited before the shark teeth because layers are built on top of one another. Lower layers are older than higher layers.

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10. The relative age of the layers from oldest to youngest must be oceanic basalt, sandstone (with shark fossils), shale, limestone, and then the intrusive basalt. The sedimentary layers must have been deposited one atop the other. The lower layers must have been deposited before the higher layers. What led Steno to this theory was his original hypothesis that the rock must have been originally deposited as a fluid. This theory has been verified so many times since that it is now called the law of superposition. This law states that a layer of rock is younger than the layers beneath it. The intrusive basalt is the exception to this rule since it is the youngest body of rock—having penetrated all of the pre-existing layers.

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Questions 11 and 12 allow you to practise using the law of superposition for simple examples. An understanding of this concept will be required in later activities.

11. The lava must be younger than the road because the lava is sitting on top of the road.

12. Absolute dates cannot be determined with the information given. Only the relative age can be determined.

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13. **a.** The oldest layers of rock are layers S and Z because these layers are the lowest.

b. The youngest layers of rock are layers P and W because they are above the other layers. This is in accordance with the law of superposition.

c. Layer Q is roughly the same age as layer X because they contain the same index fossil (ammonite).

1.3 Questions, page 313

Knowledge

1. Nicolas Steno was one of the first people to recognize that fossils are the remains of once-living organisms. He also proposed the now fundamental law of superposition, which states that younger layers are on top of older layers in a stratigraphic sequence. William Smith realized there is a predictable sequence of rock layers even in very different locations. He invented the idea of using index fossils to cross-reference rock strata. This idea led to the Geological Time Scale still used today. Smith also published the first complete geological map of England.

2. A useful index fossil only appears for a brief time in the fossil record, is common, and has a wide geographical distribution. As shown in "Matching Rock Strata from Different Locations," certain types of ammonite, graptolite, and placoderm fit this description.

3. The four eras—starting from the oldest—are the Precambrian, Paleozoic, Mesozoic, and Cenozoic.

Applying Concepts

4. **a.** Rounding all values to the nearest percent gives the following values.

$$\text{Precambrian} = \frac{(4500-590)}{4500} \times 100\% = 87\%$$

The Precambrian Era takes up 87% of Earth's history.

$$\text{Paleozoic} = \frac{(590-250)}{4500} \times 100\% = 8\%$$

The Paleozoic Era takes up 8% of Earth's history.

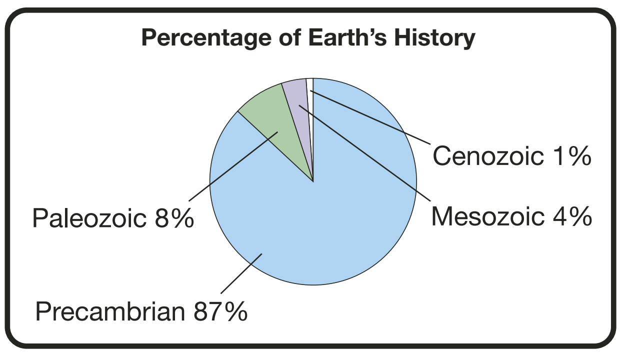
$$\text{Mesozoic} = \frac{(250-65)}{4500} \times 100\% = 4\%$$

The Mesozoic Era takes up 4% of Earth's history.

$$\text{Cenozoic} = \frac{(65-0)}{4500} \times 100\% = 1\%$$

The Cenozoic Era takes up 1% of Earth's history.

b. This pie chart shows the percentages of each era.



5. No, it is not drawn to scale. For example, the Precambrian Era is shown to take up about one-third of the Geological Time Scale. If it were drawn to scale, the Precambrian Era would take up 87% of the space.

6. The boundaries between eras are marked by noticeable changes in fossils present in the geological record.

7. Eras are divided into periods.

8. The Triassic Period is more recent.

9. Students are living in the Holocene Epoch.

10. The Pleistocene Ice Age occurred in the Quaternary Period.

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14. Layer F is the youngest because it is on top.

15. Layer B is older than A because it is beneath A.

16. A collision between crustal plates may have exerted enough force on the layers to bend them.

17. D is called an unconformity.

18. Erosion would likely have caused the unconformity. In this case, the unconformity was likely caused by an ice sheet. The layer above D appears to be mainly composed of gravel and boulders—this is typical of glacial deposits.

19. This magma created an intrusion that cut upward through the rocks from below, and then solidified.

20. Structure E must be younger because the layers of sedimentary rock must have been in place before the magma cut up through them. This is an example of an intrusion.

1.4 Questions, page 318

Knowledge

1. *Catastrophism* is the theory that violent catastrophes were the prime cause of geological features. These catastrophes operated in a manner and/or intensity different than the present processes.

2. *Uniformitarianism* is the principle that all geologic features can be explained in terms of observable processes still in operation.

3. James Hutton believed that the geological processes at work in the present comprised a perpetual, balanced cycle, and that Earth could continue in this balanced way forever.

4. Igneous rocks form when magma or lava cools and solidifies. Sedimentary rocks form when wind, water, or ice erodes bits of other rocks and deposits them in layers. Metamorphic rocks are formed by intense heat and pressure that doesn't melt the rock but, instead, alters its molecular structure.

Applying Concepts

5. According to the law of superposition, fossil B is older than fossil A because B is found in a lower layer.

6. The layers listed from oldest to youngest are as follows: J, I, H, G, and E.

7. The layers G, H, I, and J were tilted and then eroded. Layer E was deposited on top of the eroded surface. This is a possible explanation for the unconformity, labelled *F* in the diagram.

8. Layer I is approximately the same age as A because the trilobite fossils match.

9. Layers R, Q, P, and O were deposited as sedimentary rock layers. Great pressure later caused them to fold. Erosion then removed part of the folded layers. Next, layers K and M were deposited. Lastly, magma cut through all the layers up to the surface and formed the igneous intrusion labelled *L*.

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21. The orthoclase sample is 2.9×10^9 years old. (2.3 half-lives) (1.26×10^9 a/half-life) = 2.9×10^9 a

22. 100% total – 6% daughter = 94% parent

(0.09 half-lives) (4.88×10^{10} a/half-life) = 4.4×10^9 a

The minimum age of Earth is 4.4×10^9 years old.

23. Figure out how many uranium-235 half-lives have elapsed.

$$\left(\frac{7.13\times10^{8}\text{ a}}{\text{half-life}}\right)=\left(\frac{1\text{ half-life}}{7.13\times10^{8}\text{ a}}\right)=1$$

$$\left(\frac{1\text{ half-life}}{7.13\times10^{8}\text{ a}}\right)\left(\frac{100\times10^{6}\text{ a}}{1}\right)=0.140\text{ half-lives}$$

Read the percentage of parent (uranium-235) remaining.

The percentage of uranium-235 remaining = approximately 90%.

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24. (0.90 half-lives) (5.73×10^3 a) = 5.2×10^3 a

The age of the hunter is 5.2×10^3 a.

25. For carbon-14 dating, 45 000 years is getting near the 8-half-life mark. Carbon-14 is a trace isotope as it is. At a certain point, it is too hard to detect traces of carbon-14 even when using a mass spectrometer.

1.5 Questions, page 324

Knowledge

1. Relative dating with respect to the Geological Time Scale was well established. Geologists could tell the order of events (the relative age) but they could not determine the absolute age. In other words, they were unable to add numbers to their time scale.

2. The oldest rocks in Canada are tiny crystals called zircons. They are found embedded north of Yellowknife in the Acasta Gneiss.

3. The rate of radioactive decay remains the same no matter what. It is impervious to extreme heat, pressure, and time. Each element has a measurable half-life that ticks by in uniform increments, like a clock.

4. Carbon-14 dating is used to determine the age of organic remains.

Applying Concepts

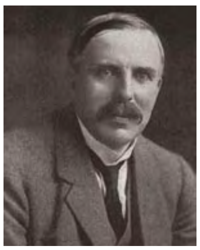
5. a. The dinosaur skeleton fossil must be younger than 77 million years and older than 74 million years.

   b. The ammonite fossil must be younger than 74 million years.

   c. The dinosaur date is better determined (within three million years) because it is between two known layers. The ammonite is above a known layer but below a possible unconformity, as indicated by the glacial deposits. The likely erosion prevents a precise age determination.

6. This is one way to show the development of geological thought and technologies.

Time	Event
1638–1686 	Nicolas Steno suggests tonguestones are shark teeth fossils and proposes the law of superposition. This new law enables the relative dating of rock strata.
1726–1797 	James Hutton realizes that a great deal of time is needed for the observable forces of the present to have constructed complex geological histories. He cites subterranean heat as the slow driving force behind geological change. His work leads to an understanding of intrusions, unconformities, and the modern rock cycle. His theories are later combined to be called uniformitarianism. They stand in opposition to contemporary catastrophic theories. His work has little impact on the geological community as a whole, because his books are really hard to read.
1769–1839 	William Smith publishes the first complete geological map of England. His success is due to his discovery of index fossils as a way to correlate rock strata. This concept leads to the assembly of the Geological Time Scale with all of its eras, periods, and epochs. Interestingly, Smith is a catastrophist, believing that England's rocks had been deposited in a series of deluges.
1797–1875 	Charles Lyell popularizes the work of Hutton. He galvanizes support for the theory of uniformitarianism, and he is a strong opponent of catastrophes as the main driving force.

1867–1934 	Marie Curie discovers that several substances exhibit a property she calls radioactivity, including two brand-new elements (radon and polonium). She helps show radioactive decay is unaffected by its surrounding conditions.
1871–1937 	Ernest Rutherford discovers radioactive substances spontaneously decay in a uniform way. The radioactivity is cut in half in a uniform interval of time called a half-life. He discovers that elements can change identity. During radioactive decay the parent nuclide transforms into a different element called the daughter nuclide. Rutherford measures the energy released during radioactive decay and supports Hutton's original suggestion that there must be a great source of heat deep within Earth. He is unable to achieve accurate radioactive dating because he lacks the ability to precisely analyze the percentage of parent and daughter nuclides in a sample.
1918 to present 	The mass spectrometer is capable of a precise and sensitive analysis of the elements present in rock samples. It provides the percentages of parent and daughter nuclides necessary for radioactive dating. It continues to be one of the most useful instruments in nearly all areas of science.
early 1980s to present	Modern equipment can detect trace amounts of radioisotopes from tiny crystals, such as zircons. It enables geologists to date rocks more quickly and accurately. This has allowed geologists to date Earth at 4.5 billion years old.