Lecture-Tutorials

For Introductory Geoscience

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# Plate Tectonics and Earth's Interior

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Part 1: Divergent Boundary

A divergent boundary in the center of an ocean is shown below with arrows showing the direction the crust is moving.

1) Where is the oldest crust found?
   A  B  C

2) If each plate is moving at a rate of 2 cm per year, roughly how long did it take for Rock C to reach its current location?
   0 years  2 years  4 years  8 years

3) What is the age of the rocks at location B?
   0 years old  2 years old  4 years old  8 years old

4) What is the age of the rocks at location C?
   0 years old  2 years old  4 years old  8 years old

5) Why should your answers to Questions #2 and #4 match? Revise your answers if necessary.

6) A map of the Atlantic Ocean is shown to the right. Where are the oldest rocks in the Atlantic found?
   D  E

   Briefly explain your answer.

7) Two students are debating about the relative ages of the rocks in the Atlantic Ocean.

   Student 1: The oldest rocks are located at E because it is the farthest from a continent. The rocks would take a really long time to get to the middle of the ocean.

   Student 2: But this ocean has a divergent boundary in the center. This means that rocks at E are really young. D is farthest from the divergent boundary, so that’s where the oldest rocks are.

   With which student do you agree? Why?
Part 2: The Atlantic Ocean
Examine the map of the ages of the seafloor in the Atlantic Ocean.

8) Does the pattern of ages match your answer to Question 6? Revise your answer if necessary.

9) Draw a line along the divergent boundary.

10) What is the age of the oldest rocks in the Atlantic Ocean?

11) Approximately how long ago did the Atlantic Ocean begin to form?

12) Why should your answers to Questions #10 and #11 match? Revise your answers if necessary.

13) You are reading a proposal requesting money to search for evidence of a crater that caused a mass extinction on Earth 245 million years ago. The team is proposing to search a poorly explored area of the floor of the Atlantic Ocean between South America and northern Africa. Would you fund this project? Use the ages of the seafloor to support your answer.

Compare your answer of the last question to the answers of other groups.
Part 1: Subduction Features
The cross section below shows a subduction zone at an ocean-continent convergent boundary. The ocean surface is indicated by a dashed line.

1) Draw arrows showing which way the plates are moving.

2) On the diagram, label every feature that geologists can see on the Earth’s surface related to plate tectonics. A feature is a thing you can see and not something that is happening.

3) Two students are discussing the features they labeled on the diagram.

   **Student 1:** I labeled the ocean plate, the continental plate, volcanoes, and mountains.
   **Student 2:** I labeled those, plus the ocean trench and subduction.

   **Student 1:** I like that you labeled the trench, but I don’t think you can label subduction. **Subduction is an action of something happening, and it’s not a feature.**
   **Student 2:** But you can see it on the diagram where the ocean plate is being pushed under the continental plate, so I think you can label subduction as a feature.

With which student do you agree? Why?

4) Could you go to a convergent plate boundary and watch subduction happening?  yes  no

5) If you can watch subduction happening, what would you see? If you cannot watch subduction happening, what can you look for to indicate that subduction is happening?

6) Sketch what happens when two ocean plates move towards each other. Label the trench and volcanoes.
Part 2: Movement Over Time
The cross sections below show subduction zones at an ocean-continent convergent plate boundary.

7) Where was ● in the past? A B C D E same place
8) Where will ● be in the future? A B C D E same place

9) Where was ■ in the past? J K L M N same place
10) Where will ■ be in the future? J K L M N same place

11) Two students are discussing how the ■ on the continental plate will move over time relative to the volcano.

Student 1: I think that the square will stay in the same place relative to the volcano because the ocean plate is the plate that is subducting and is destroyed. The continental plate isn’t destroyed, so the square doesn’t move.

Student 2: But it’s a convergent boundary, and the plates are moving together. Because I can draw arrows showing the plates moving together, that means that the square is moving towards the ocean plate and away from the volcano.

With which student do you agree? Why?

12) Will ■ and ★ be next to each other in 50 million years? yes no

Explain your answer.
13) Two students are discussing whether □ and ★ will be next to each other in the future.

**Student 1:** I think they will still be next to each other because it’s a convergent boundary, and the ocean plate is subducting. Everything is moving down, so they’ll move down together.

**Student 2:** They won’t be next to each other because the star is on the ocean plate, which is subducting. But the continental plate is not, so the square stays in the same place.

With which student do you agree? Why?

14) Did the rocks at □ and ★ originally form next to each other?  yes  no

Explain your answer.
Part 1: Earth's Layers
The Earth can be divided into three layers based on composition (what it is made of): the crust, mantle, and core. The core is divided into two layers based on phase: the liquid outer core and the solid inner core.

<table>
<thead>
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<th>Layer</th>
<th>Depth of Top</th>
<th>Depth of Bottom</th>
<th>Phase and Composition</th>
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<tbody>
<tr>
<td>Crust</td>
<td>0 km</td>
<td>65 km</td>
<td>Solid, rock</td>
</tr>
<tr>
<td>Mantle</td>
<td>65 km</td>
<td>2900 km</td>
<td>Mostly solid, metal-rich rock</td>
</tr>
<tr>
<td>Outer Core</td>
<td>2900 km</td>
<td>5100 km</td>
<td>Liquid, metal</td>
</tr>
<tr>
<td>Inner Core</td>
<td>5100 km</td>
<td>center of Earth</td>
<td>Solid, metal</td>
</tr>
</tbody>
</table>

1) Sketch and label the four layers of the Earth on the diagram below. The inner core has been drawn and labeled for you.

2) What is the best comparison for the thickness of the crust?
   a. The crust has the same relative thickness as the skin of an apple.
   b. The crust has the same relative thickness as the peel of an orange.
Part 2: Origins of Magma
Rocks melt with a combination of high temperature and low pressure. If the temperature is too low or the pressure is too high, rocks will not melt.

The outer core has the right combination of temperature and pressure to be molten. The other location where the temperature and pressure are just right to melt is 15 to 100 km below the surface. This depth is where pockets of most volcanic magma are formed.

3) On the diagram of the Earth, draw a star at the depth of the source of magma.

4) What layers melt to form magma?
   Crust       Upper (Outer) Mantle       Lower (Inner) Mantle       Outer Core       Inner Core

5) According to your diagram, can the molten outer core erupt as a volcano? Explain.

6) Two students are debating whether or not the molten outer core could erupt as a volcano.
   Student 1: No, I don’t think it could because the magma would have to travel thousands of kilometers through the mantle to reach the surface, and I don’t think it could go that far through the mostly solid mantle.
   Student 2: But since the outer core is molten and there’s a lot of it in the Earth, I think that if there is a big enough crack, the material from the molten outer core could erupt at the surface.

With which student do you agree? Why?

7) How does the composition of the outer core compare to the composition of erupted lava (which is molten rock)? According to this information, does the molten outer core erupt as a volcano? Explain.

8) Check to make sure your answers to Questions 5 and 7 agree.

9) An evil scientist threatens to explode a huge nuclear bomb in the center of the Earth, triggering volcanoes around the world to erupt, unless he is paid a large amount of money from the world’s leaders. Do you recommend the world’s leaders pay him the large ransom? Why or why not? (hint: The Hiroshima atomic bomb caused damage up to 20 km away but did most of its destruction within a couple kilometers of where it exploded)
Part 1: Forming Minerals
The size of minerals in an igneous rock is determined by how long the magma takes to cool. To illustrate, everyone should stand up and scatter throughout the room.

1) You have 2 seconds to form groups as big as possible. How many per group? _______

2) Scatter again. Now you have 10 seconds. How many per group? _______

3) Two students are debating about how this activity relates to mineral size in rocks.

Student 1: It seems to me that with a longer amount of time, it is possible for all the atoms to form really large minerals.

Student 2: I don’t know, I would think that more time, means that more minerals will form, and only a little bit of time means only a few big minerals will form.

With which student do you agree? Why?

Part 2: Mineral Formation Location
Two bodies of magma are shown in cross section below. One is above ground and the other is deep within the crust. The arrows represent heat escaping from the molten rock as it cools.

4) Which will cool faster? Lava erupted onto the surface Magma deep underground

5) The igneous rocks granite and gabbro have large minerals. In which location would they have formed?
   on the surface deep in the crust

6) The igneous rocks rhyolite and basalt have minerals so small it is difficult to distinguish them with the naked eye. In which location would they have formed?
   on the surface deep in the crust
7) Circle the two rocks that formed deep in the crust.

Granite  Rhyolite  Basalt  Gabbro

Check your answer with your answers for Questions 5 and 6.

Part 3: Porphyry

8) The igneous rock to the right has large, light colored minerals and many small, dark minerals. You can tell it is an igneous rock because the minerals inside are rectangular and not rounded like sediments. How might the igneous rock shown to the right have formed?

9) Two students are debating about the cooling rate of this rock and the formation of the large minerals.

Student 1: The magma must have gotten large pieces of sediments that we can see trapped in it, and the sediments didn’t melt even though they were in the magma. So, this rock formed because large pieces of sediment got picked up by lava, and then that lava cooled quickly.

Student 2: This is an igneous rock, so everything started off as magma. The large minerals must have formed deep underground when the magma was cooling slowly, like in a magma chamber. But the rest of the rock has very small minerals, so they cooled quickly at the surface.

With which of these students do you agree? Why?

10) Student 2 said that the large minerals formed deep underground, like in a magma chamber, and the small minerals formed at the surface. Describe what actually happened to form the rock. In other words, what story does this rock tell about its history?

(hint to Question 10: in what situation is magma from a magma chamber moved to the surface?)
Part 1: Creating Sedimentary Rocks
1) From the choices, list the steps necessary for a parent rock to become a detrital or chemical sedimentary rock. Each step will be used once.

**DETRITAL (e.g. shale/mudstone)**
- transportation (water, wind, ice)
- parent rock is broken into smaller pieces
- deposition of detrital sediments
- compaction and cementation into rock

**CHEMICAL (e.g. limestone)**
- transportation (dissolved in water)
- parent rock is dissolved
- precipitation as rock
- precipitation as shells
- shells are deposited, compacted and cemented

Parent rock is broken into smaller pieces  
(chemical weathering)

Parent rock is dissolved  
(changed composition = chemical weathering)

**Part 2: Changing from Sediments to Sedimentary Rocks**
2) Sandstone is a detrital sedimentary rock made up of sand-sized pieces. Examine the four steps and draw arrows to where they are occurring in the diagram.

- parent rock is broken into sand-sized pieces  
  (sediments)
- sand-sized sediments are transported
- sand-sized sediments are deposited
- deposited sand is compacted and cemented into sandstone (no longer sediments)
Part 3: Sediments Vs. Sedimentary Rocks

3) One of these photos is a photo of pebble-sized sediments, the other is of a single sedimentary rock. Label the photos.

![Photo 1](image1.png)  ![Photo 2](image2.png)

4) What needs to happen so that pebble-sized sediments become a sedimentary rock?

5) Two students are debating about the pebbles in the image on the left and what type of rock the pebbles are.

**Student 1:** In the photo on the left, it is clear that the rocks there are all pebble sized. I think that each pebble is a sedimentary rock because the pebbles have been broken from much larger rocks and they were transported to this new area.

**Student 2:** I don’t agree. Each pebble can be any type of rock – igneous, metamorphic, or sedimentary. Because they have not yet been compacted and cemented together, they have not yet been turned into a sedimentary rock like in the photo on the right.

With which student do you agree? Why?

6) Explain why you would not call pebbles on a beach a sedimentary rock.
Part 1: Earthquake Patterns
The USGS map below shows the locations of earthquakes around the world over a 6 year period.

1) Describe the pattern or arrangement of earthquakes scattered around Earth’s surface.

2) Do earthquakes occur around the coastlines of all oceans?  Yes  No
   Give an example of an ocean with no earthquakes around the edges.

3) Do earthquakes occur just along coastlines?  Yes  No
   Give an example of an area where earthquakes occur in the middle of an ocean, not on a coastline.

4) Do earthquakes occur just in hot climates?  Yes  No
   Give an example of a cold area that experiences earthquakes.

5) Why do earthquakes occur where they do?
6) Two students are debating about why earthquakes occur where they do.

**Student 1:** *Earthquakes occur where the faults are, so areas that have lots of faults also have lots of earthquakes. For example, California has a lot of faults, so it has a lot of earthquakes as well.*

**Student 2:** *That only partly answers the question because we need to know why faults occur where they do. Most faults occur along plate boundaries, so most earthquakes also occur along plate boundaries. It’s the plate boundaries that determine where earthquakes occur.*

Do you agree with one or both students? Why?

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**Part 2: Earthquakes and Plate Tectonics**

Convergent boundaries occur along the edges of continents or along island chains, and divergent boundaries mostly occur in the centers of oceans. Use the map on the first page to answer these questions,

7) What type of plate boundary produces more earthquakes?

- Convergent
- Divergent

8) What type(s) of plate boundary is(are) associated with the Atlantic Ocean?

- Convergent
- Divergent
- both
- neither

9) What type(s) of plate boundary is(are) associated with the Pacific Ocean?

- Convergent
- Divergent
- both
- neither

10) What coast(s) of North America is(are) on a plate boundary?

- West coast
- East coast
- both
- neither
11) Two students are debating the locations of plate boundaries around North America.

**Student 1:** Both the West and East coasts are plate boundaries because for each coast the ocean crust is touching the continental crust.

**Student 2:** I think the West coast is on a plate boundary, but the East coast is not. There are almost no earthquakes that occur on the East coast.

**Student 1:** What about the divergent boundary in the middle of the Atlantic? The East coast is on that plate boundary.

**Student 2:** That divergent boundary separates the eastern half of the Atlantic Ocean from the western half. It does not separate the ocean crust of the Atlantic from the continental crust of North America.

Do you agree with one or both students? Why?

12) Explain why there are more earthquakes in California than in New York.
Part 1: Carbon Dioxide in the Atmosphere

Compare the chart to the right showing the amounts of different elements in the atmosphere with the graphs below showing the carbon dioxide concentrations and temperature anomalies over the last 250 years.

1) Look at the left graph. What is the carbon dioxide concentration today? __________ ppm

2) What is the trend in carbon dioxide concentration? increasing decreasing constant

Use that trend in the graph to estimate the concentration of carbon dioxide in the atmosphere in 10 years and 100 years. People begin having headaches when carbon dioxide levels reach around 0.5% (5,000 ppm).

3) Will people be able to breathe in 10 years? Yes No

4) Will people be able to breathe in 100 years? Yes No

A temperature anomaly is how much the temperature is warmer or colder than normal. Note that it is measured in degrees Celsius.

5) Look at the graph on the right. What is the temperature anomaly today? __________

6) Therefore, is today warmer or colder than normal? warmer colder

7) What is the trend in temperature anomaly? increasing decreasing constant

8) Based on the graph, what will the temperature anomaly be in 50 years? __________

9) What is the relationship between carbon dioxide and temperature anomaly?
Part 2: Comparison of Today to the Past
Below are graphs showing the levels of atmospheric carbon dioxide and the temperature anomaly for the past 400,000 years.

10) Use your answer to Question 1 to plot a point on the left graph indicating the carbon dioxide concentration today (note the different scale). How does the carbon dioxide concentration today compare to the concentrations in the past?

11) Use your answer for Question 5 to plot the current temperature anomaly on the graph above (note the different scale). How does the temperature anomaly today compare to the anomalies in the past?

12) Think about how hot it would need to be before humans could not survive. Did the temperature in the last 400,000 years get so hot that humans could not survive? Yes / No

13) Based on past data, do you think the Earth is going to warm up so much in the next 500 years that people cannot survive? Why or why not?

As we have seen, humans do not need to worry about breathing or heat stroke issues. The problem we need to be concerned about is the effect increased temperatures will have on the global climate. For example, changing precipitation patterns will affect agriculture, and reduced ice on the ice sheets result in higher sea levels.
Part 1: Hypotheses
A scientific hypothesis needs to
1) be supported by the majority of current data
2) be testable.

An alien on Earth is wondering why a rubber ball falls back down to the ground after it is thrown into the air. It comes up with several ideas about the ball.

a. Gravity is pulling the ball to the ground.

b. A mystical force that cannot be measured is pushing the ball down.

c. The Earth’s magnetic field is pulling on the rubber ball.

1) Which statement is NOT a hypothesis because it is not testable?  a  b  c

2) Which statement is NOT a hypothesis because it is not supported by current data?  a  b  c

3) Which statement IS a scientific hypothesis?  a  b  c

Part 2: Dinosaur Extinction
Below are possible scenarios explaining the extinction of the dinosaurs.

a. Dinosaurs were killed off by a virus.

b. A large meteorite impact caused the climate to change so some plants and animals could no longer survive.

c. Volcanic eruptions caused the climate to change so some plants and animals could no longer survive.

d. Mammals ate all the dinosaur eggs.

4) Determine if each statement above is a valid hypothesis. Be sure to explain your answer.

a. Yes  No  because…

b. Yes  No  because…

c. Yes  No  because…

d. Yes  No  because…
5) Two students are debating the hypotheses of dinosaur extinctions.

**Student 1:** I think that the meteorite and volcano statements are valid hypotheses, but the other two are not. You can’t test the fossil record to find out if they are true, and they don’t explain animals other than dinosaurs going extinct.

**Student 2:** I think that all of the statements are all valid scientific hypotheses explaining dinosaur extinctions. I saw all of them on a dinosaur program on TV, and they all seem possible. No person was there to watch the dinosaur extinction, so all of the scenarios are hypotheses.

With which student do you agree? Why?