Earthquake P-wave and S-wave Travel Time

Overview:
When the Earth’s crust quickly moves or snaps it produces an earthquake, releasing energy in the form of seismic waves that radiate out from the focus. The focus is where the crust broke. Seismic waves have different properties. The P-wave is the fastest wave, reaching distance seismographs first. Because it can travel through all phases of matter, it can travel completely through the Earth’s interior reaching the other side of the Earth. The arrival of the P-wave causes little damage, but it is a warning sign that the slower, more destructive S-wave is on its way. The S-wave causes much destruction due to its shearing action. The S-wave can only travel through solids, thus it is stopped by the liquid outer core.

Due to the differences in the speed of the P and S-waves, a separation time of these waves occurs. The farther a seismograph is from the epicenter of an earthquake, the greater the separation time will be for the arrival of the P and S-wave. Using the known speeds of the P and S-waves and the arrival time of these waves as recorded on a seismogram, a seismologist can determine the distance to the epicenter. Using seismograms from three seismographs from different locations, the location of the epicenter can be determined.

The Graph:
The Axis – The x-axis is the Epicenter Distance scale. The bold dark lines represent increments of 1000 km (1 x 10^3 km). The lighter lines represent intervals of 200 km. The y-axis is the Travel Time scale. The bold dark lines represent intervals of a minute, while the lighter lines represent intervals of 20 seconds.

The Graph – The bold graph lines represent the speed of the P and S seismic waves. When an earthquake occurs, the P and S-waves are generated at the same time. This is shown on the graph at minute 0. These waves immediately start to separate since the P-wave is faster. Thus, the two lines become farther apart as distance increases producing a separation time. To get the travel time for either wave for a certain distance, move upward from the given distance until it intersects the correct seismic line. At this intersection point, read over to the Travel Time axis. For example, a P-wave traveling 7200 km would take a travel time of 10:40 (10 min. 40 sec.) to go this distance. The slower S-wave would take 19:20 (19 min. 20 sec.) to go the same distance. Given the travel time of a seismic wave, the distance from the epicenter can be determined. For example, how far would a P-wave travel in 8:20? Locate this time on the Travel Time axis and move across to the P-wave line. At the intersection point, move directly down to the Epicenter Distance axis. The answer is 5000 km. For the same travel time, the slower S-wave would have only traveled 2400 km. So as you can see, these problems are “up and over” or “over and down” problems.

Epicenter Distance – If we know the arrival time of both waves, the distance to the epicenter can be determined. The arrival time of the P-wave and the S-wave may be given to you, or you may have to interpret them from a seismogram. Once you have determined the arrival time of both waves, subtract the P arrival time from the S arrival time. This is the separation time. Using the edge of a piece of paper, mark off this separation time using the Travel Time axis. You should have two marks representing the separation time. Take this paper with these marks to the graph, position it until the marks fit vertically between the P and S lines. Reading directly down from this “fitted” position to the x-axis will give you the epicenter distance.
Example 1  If the $P$-wave arrived at 10:20:10 and the $S$-wave arrived at 10:26:30, how far away is the epicenter?

Solution:  By subtracting, the separation time is 6:20. Using a piece of paper, mark off this time interval from the Travel Time axis. Move this paper, with the two marks, until these marks fit vertically between the $P$ and $S$ graph lines. Read directly down to the Epicenter Distance axis. If done correctly, the epicenter distance will be 4800 km ($\pm$200 km).

Example 2

![Seismogram Tracings]

From the above seismogram, what is the distance from Station A to the epicenter?

Solution:  The separation time of the $P$ and $S$-wave as shown on the seismogram is 7 mins 00 sec. This time marked off from the Travel Time axis fits vertically between the $P$ and $S$-wave graph lines at a distance of 5600 km ($\pm$200 km). Practice these problems until you feel comfortable with this procedure.

_Epicenter Location_ – The exact location of the epicenter is determined by using the epicenter distance from three seismic stations. By drawing three circles on a map with the radius of each representing the distance to the epicenter, there will be a common intersection point of the three circles. This intersection point is the location of the earthquake’s epicenter.

_Additional Information:_

- During an earthquake there is a major area that surrounds the Earth that does not receive any $P$ or $S$-waves. This area is known as the shadow zone and is caused by the refraction and reflection of seismic waves as they encountered different density layers of our Earth.

- By studying the amplitude of the seismic waves, as recorded on the seismogram, the magnitude or strength of the earthquake can be determined. This becomes its Richter Scale number.

- Most of the knowledge of the interior of the Earth has been revealed by studying seismic waves.

- The origin time of an earthquake is the exact time that the earthquake occurred. The origin time can be determined by knowing the travel time of the $P$-wave to a seismic station. This time is then subtracted from the time that the seismograph recorded the arrival of the $P$-wave.

Example: A seismograph recorded the first $P$-wave at 10:10:40 and it was determined that the $P$-wave traveled 2,200 km. What was the origin time of the earthquake?

Solution: It takes 4:20 (4 min. 20 sec.) for a $P$-wave to travel 2,200 km. Subtract this time from 10:10:40, and the origin time would be 10:06:20.
1. How long would it take for the first S-wave to arrive at a seismic station 4,000 kilometers away from the epicenter of an earthquake?
   (1) 5 min 40 sec
   (2) 7 min 0 sec
   (3) 12 min 40 sec
   (4) 13 min 20 sec
   1_

2. An earthquake’s P-wave arrived at a seismograph station at 02 hours 40 minutes 00 seconds. The earthquake’s S-wave arrived at the same station 2 minutes later. What is the approximate distance from the seismograph station to the epicenter of the earthquake?
   (1) 1,100 km
   (2) 2,400 km
   (3) 3,100 km
   (4) 4,000 km
   2_

3. How far will a S-wave travel in 10 minutes and 40 seconds?
   (1) 3200 km
   (2) 3900 km
   (3) 5600 km
   (4) 7200 km
   3_

4. A P-wave takes 8 minutes and 20 seconds to travel from the epicenter of an earthquake to a seismic station. Approximately how long will an S-wave take to travel from the epicenter of the same earthquake to this seismic station?
   (1) 6 min 40 sec
   (2) 9 min 40 sec
   (3) 15 min 00 sec
   (4) 19 min 00 sec
   4_

5. The diagram below represents three seismograms showing the same earthquake as it was recorded at three different seismic stations, A, B, and C.

Which statement correctly describes the distance between the earthquake epicenter and these seismic stations?

(1) A is closest to the epicenter, and C is farthest from the epicenter.
(2) B is closest to the epicenter, and C is farthest from the epicenter.
(3) C is closest to the epicenter, and A is farthest from the epicenter.
(4) A is closest to the epicenter, and B is farthest from the epicenter.

5_
6. Approximately how far away from station Z is the epicenter?

(1) 1,300 km
(2) 1,800 km
(3) 3,900 km
(4) 5,200 km

6   6

7. The S-waves from this earthquake that travel toward Earth’s center will

(1) be deflected by Earth’s magnetic field
(2) be totally reflected off the crust-mantle interface
(3) be absorbed by the liquid outer core
(4) reach the other side of Earth faster than those that travel around Earth in the crust

7   7

8. Seismic station X is 800 kilometers from the epicenter. Approximately how long did it take the P-wave to travel to station X?

(1) 1 min 50 sec
(2) 2 min 50 sec
(3) 3 min 20 sec
(4) 6 min 30 sec

8   8

9. On the map, which location is closest to the epicenter of the earthquake?

(1) B–5
(2) G–1
(3) H–3
(4) H–8

9   9
10. Scientists have inferred the structure of Earth's interior mainly by analyzing
   (1) the Moon's interior
   (2) the Moon's composition
   (3) Earth's surface features
   (4) Earth's seismic data

13. The distance from an epicenter of an earthquake to New York City is 3,000 kilometers. What was the approximate travel time for the P-waves from this epicenter to New York City?
   (1) 1 min 20 sec
   (2) 5 min 40 sec
   (3) 7 min 30 sec
   (4) 10 min 00 sec

Base your answers to questions 11 and 12 on the earthquake seismogram below.

11. Approximately how far away is the epicenter?
   (1) 2000 km
   (2) 2600 km
   (3) 3500 km
   (4) 4400 km

14. The cutaway diagram below shows the paths of earthquake waves generated at point X.

   Only P-waves reach the side of Earth that is opposite the focus because P-waves
   (1) are stronger than S-waves
   (2) travel faster than S-waves
   (3) bend more than S-waves
   (4) can travel through liquids and S-waves cannot

12. How many additional seismic stations must report seismogram information in order to locate this earthquake?
   (1) one
   (2) two
   (3) three
   (4) four

13
11
12
14
17. The epicenter of an earthquake is located 2,800 kilometers from a seismic station. Approximately how long did the $S$-wave take to travel from the epicenter to the station?

- (1) 11 min 15 sec
- (2) 9 min 35 sec
- (3) 5 min 20 sec
- (4) 4 min 20 sec

18. How far from an earthquake epicenter is a city where the difference between the $P$-wave and $S$-wave arrival times is 5 minutes and 00 seconds?

- (1) $1.7 \times 10^3$ km
- (2) $9.9 \times 10^3$ km
- (3) $3.5 \times 10^3$ km
- (4) $4.7 \times 10^3$ km

19. The seismogram below shows $P$-wave and $S$-wave arrival times at a seismic station following an earthquake.

![Seismogram]

The distance to the epicenter is approximately

- (1) 1,600 km
- (2) 3,200 km
- (3) 4,400 km
- (4) 5,600 km
Earthquake P-wave and S-wave Travel Time

Answers – Set 1

1. Locate 4000 km on the Epicenter Distance scale. From this position, move directly up until you intersect the S-wave line. At this intersection point, read over to the Travel Time axis. If done correctly, 12:40 should the time of travel for this distance.

2. The separation time between the P and S-wave is 2 minutes. Take a piece of paper and place it along the Travel Time axis. Mark off a 2 minute interval from this axis. Move this paper over to the graph, keeping it vertical, until the two marks representing the 2 min. interval fit between the P and S graph lines. Read down from this “fitted” position to the Epicenter Distance axis. If done correctly, 1100 km is the distance to the epicenter.

3. Go to the 10:40 line on the Travel Time axis. Move directly across until it intersects the S-wave line. Read down from this intersection position. If done correctly the answer should be 3200 km.

4. First find out how far a P-wave travels in 8:20. Go up the Travel Time axis to this given time. From this time, move directly across until it intersects the P-wave line. Reading down from this point, the distance to the epicenter is 5000 km. Using this distance, move straight up until it intersects the S-wave line. This intersection point is 15 minutes as read on the Travel Time axis.

5. The closer a seismic station is to the epicenter of an earthquake, the shorter the separation time between the P and S-waves will be. Station A has a separation time of 9 minutes, Station B has a separation time of 7 minutes, and Station C has a separation time of 5 minutes. Thus, Station C, having the smallest separation time, must be the closest station and Station A, having the greatest separation time, must be the farthest station from the epicenter.

6. The seismogram for station Z shows a 3 minute separation time between the arrival of the P-wave and the arrival of the S-wave. Take a piece of paper and place it along the Travel Time axis. Mark off a 3 minute interval from this axis. Move this paper over to the graph, keeping it vertical, until the two marks representing the 3 minute interval fits between the P and S graph lines. Read down from this “fitted” position to the Epicenter Distance axis. If done correctly, 1800 km is the distance to the epicenter.

7. The S-waves cannot be transmitted through liquids. When these waves reach the outer core they are stopped, being absorbed by the liquid outer core.

8. Find this distance, 800 km, on the Epicenter Distance scale. From this position move upward until it intersects the graph P-wave line. From this intersection point, read over to the Travel Time axis. If done correctly, the time that it takes for this P-wave to travel this distance is 1:50.

9. The location of the epicenter of an earthquake is found by a common intersection point of three circles, representing the correct distance to the epicenter from each seismic station. On the map, all three circles have a common intersection at location H-3.
Overview:

If one could travel to the “Center of the Earth”, it would be a rough trip. You would enter four different and distinct layers - the solid crust, the mantle, having a plastic and larger solid stiffer section, the liquid outer core, and the solid inner core. As you travel downward, the density constantly increases, while the temperature would rise to over 6000°C, and the pressure would be measured in millions of atmospheres. Our understanding of the Earth’s interior is mostly based on indirect knowledge since we have never completely penetrated through the crust. This is why the title contains the word “Inferred” - our best guess. Most of the information on the interior of the Earth has been slowly revealed by the study of seismic waves. Released by earthquakes and traveling deep into the Earth’s interior, seismologists studying seismograms have detected changes in speed and direction as these waves enter different layers. Seismologists know that the seismic S-wave cannot pass through liquids. The S-wave is stopped at the beginning of the outer core, thus it must be a liquid. With more advanced technology, along with creative problem solving, new theories are being proposed and tested; giving better insight in the complexity and dynamics of the Earth’s interior.

Earth’s Cross-Section Chart:

The Crust – The Earth’s outermost layer is the crust. It is relatively cold, thin and brittle, yet it supplies us with the valuable resources that make life possible. Earthquakes occur in the crust, generating destructive seismic waves. As shown on the upper right side, the crust is divided into the less dense continental crust and the denser oceanic crust. The continental crust is much thicker compared to the oceanic crust. Under Density is the word MOHO. This term represents the boundary zone separating the crust from the rigid mantle.

The Lithosphere – The lithosphere (shown by two arrows) consists of the crust and the upper most part of the mantle referred to as the “rigid mantle.” These joined parts collectively make up the plates. The diagram (lower left) shows the Pacific Ocean plate colliding with the North American continental plate, forming the Cascade Mountain chain. At this convergent zone, a trench is produced as the denser Pacific Ocean plate subducts under the overriding less dense North American continental plate. This area is known as a subduction zone. Shown at the Mid-Atlantic Ridge are hot convection currents, represented by the arrows, breaking through the lithosphere. Here and along other ocean ridges new lava emerges, quickly solidifies becoming part of the ocean floor. At these divergent plate boundaries the youngest ocean floor is found.

The Mantle – Geologist have subdivided the mantle into different sections – the rigid mantle, the asthenosphere, and the stiffer mantle. As already mentioned, the rigid mantle is the lower part of the plates. Under the rigid mantle lies the asthenosphere. The asthenosphere is the soft plastic-like section of the mantle that the plates move over and/or through. Major convection currents are found here, as shown by the arrows in the diagram. Hot rising convection currents are associated with ocean ridges, while cool sinking convection currents are associated with subduction zones. The mantle is the largest layer of the interior of the Earth in mass and volume. As a whole, the mantle is a solid in which both the P and S seismic waves travel through.

The Cores – The outer core is a liquid, having a composition of mostly iron. This liquid core prevents the seismic S-wave from traveling through. The inner core, being under so much pressure, remains a solid with an iron-nickel composition.
Density – Along the right side is the density section is giving the density range for each layer. As the depth increases, so does the density.

The Graphs:
The Depth axis – Located at the bottom of this page, the x-axis is the Depth scale (in km) with 0 being at the surface. The divisions of each Earth layer are shown by dash lines running down to the Depth axis. Use these lines and this axis to arrive at the distance from the surface of the crust to the other layers. For example, the outer core starts around 2,900 km and ends around 5,200 km, were the inner core starts.

Pressure graph – As the depth increases so does the pressure. For this graph, pressure is measured in millions of atmospheres. The dark graph line represents the pressure as the depth increases. To find the pressure at a specific layer, locate the dash line for that layer and follow it down until it intersects the pressure graph line. Read over to the Pressure axis for the answer. For example, what is the pressure at the start of the outer core? Following the dash line down from this position, it intersects the pressure graph line at 1.5 millions of atmospheres. To find the pressure at a certain depth, use the Depth (km) axis located at the bottom of the page. At the proper depth, move upward until it intersects the graph pressure line, then read over to the Pressure axis for the answer. For example, the expected pressure at 5000 km would be very close to 3 million atmospheres.

The Temperature graph – As the depth increases, so does the temperature. The graph line, labeled Actual Temperature, starts near 0°C at the crust and increases to 6700°C at the Earth’s center. Use the same procedure with this graph as we went over with the pressure chart. For example, what would the temperature be at the boundary between the stiffer mantle and the outer core? Locate this position and follow the given dash line downward until it hits the temperature graph line. At this intersection point, read over to the Temperature axis. The correct answer is 5000°C. The inferred melting point line is also plotted on this graph shown as a dash line. Within the mantle, the melting point line is higher than the actual temperature line. For this given condition, the mantle would be a solid. What about the outer core? Since the actual temperature line is higher than the melting point line, the outer core has experienced melting, becoming a liquid. In the inner core, the hottest temperature is found. However, due to the tremendous pressure, the inner core cannot melt and remains a solid.

Additional Information:
• The composition of most meteorites is iron and nickel. Scientists feel that the Earth’s inner core would have a similar composition as meteorites.
• MOHO is named after its discoverer, Andrija Mohorovicic.
• We have very little direct evidence about the Earth’s interior.
• The speed of seismic waves increase as they enter denser material.
• Astronauts left a working seismograph on the moon. From minor moonquakes (from space impacts), it has been revealed that the moon is completely solid throughout.
1. Earth’s outer core is best inferred to be
   (1) liquid, with an average density of approximately 4 g/cm³
   (2) liquid, with an average density of approximately 11 g/cm³
   (3) solid, with an average density of approximately 4 g/cm³
   (4) solid, with an average density of approximately 11 g/cm³ 1 _______

2. Which cross-sectional diagram of a portion of the crust and mantle best shows the pattern of mantle convection currents that are believed to cause the formation of a mid-ocean ridge?
   (1) _______
   (2) _______
   (3) _______
   (4) _______ 2 _______

3. At which depth below Earth’s surface is the density most likely 10.5 grams per cubic centimeter?
   (1) 1,500 km   (3) 3,500 km
   (2) 2,000 km   (4) 6,000 km  3 _______

4. What is the approximate temperature at the mantle-outer core boundary?
   (1) 1,500°C   (3) 5,000°C
   (2) 4,500°C   (4) 7,000°C  4 _______

   Base your answers to questions 5 through 7 on the diagram below.

   (Not drawn to scale)

5. The arrows shown in the asthenosphere represent the inferred slow circulation of the plastic mantle by a process called
   (1) insolation  (3) conduction
   (2) convection  (4) radiation  5 _______

6. The temperature of rock at location A is approximately
   (1) 600°C   (3) 2,600°C
   (2) 1,000°C   (4) 3,000°C  6 _______

7. Which part of Earth is composed of both the crust and the rigid mantle?
8. Compared to Earth's crust, Earth's core is believed to be
   (1) less dense, cooler, and composed of more iron
   (2) less dense, hotter, and composed of less iron
   (3) more dense, hotter, and composed of more iron
   (4) more dense, cooler, and composed of less iron

9. What is the density of the continental crust?
   (1) 3.0 g/cm³   (3) 2.7 g/cm³
   (2) 2.5 g/cm³   (4) 6.2 g/cm³

10. The accompanying cross section shows a portion of Earth's interior. Layer X is part of Earth's interior. Identify the part of Earth's lithosphere represented by layer X.

11. Which part of the given cross-section would large convection currents be located in?

12. The diagram shows South America, the ocean between them, and the ocean ridge and transform faults. Locations A and D are on the continents. Locations B and C are on the ocean floor.

   The hottest crustal temperature measurements would most likely be found at location
   (1) A   (3) C
   (2) B   (4) D

13. What is the pressure at the center of the Earth?
   (1) 3 millions of atmospheres
   (2) 3.2 millions of atmospheres
   (3) 3.5 millions of atmospheres
   (4) 5200 millions of atmospheres

14. What is the depth to the boundary of the outer core and the inner core?
   (1) 5200 km   (3) 2900 km
   (2) 6300 km   (4) 5000 km

15. State the density of the oceanic plate.

   ______________________ g/cm³.
Inferred Properties of Earth’s Interior

Answers

Set 1

1. 2 In the Density area (right side of chart) it shows that 11 g/cm³ is in the range of the outer core. The seismic S-wave cannot pass through a liquid. By studying numerous seismograms of major earthquakes, it was determined that S-waves were being stopped by the outer core, making it a liquid.

2. 4 In the Inferred Properties of the Earth’s Interior, notice the pattern of the convection arrows at the Mid-Atlantic Ridge. These warm currents flow upward through the asthenosphere. At Mid-Ocean ridges they diverge (split), moving away under the lithosphere eventually cooling and sinking.

3. 3 The density of 10.5 g/cm³ fits in the outer core density range as shown by the Inferred Properties of Earth’s Interior chart. This density value would occur near the beginning of the outer core. Locate the stiffer mantle – outer core boundary line. Follow this dash line downward until it intersects the Depth axis. If done correctly 3500 km is a correct choice within the outer core.

4. 3 Locate the boundary line of the stiffer mantle and the outer core. At this position, follow the dash line downward until it intersects the temperature line. The temperature at this position is close to 5000°C.

5. 2 In convection, heat is transferred in fluids (liquids and gases) by convection currents. When a fluid becomes warmer, the density decreases and the warmer fluid rises upward being displaced by the cooler fluid, producing a convection current. Conduction is the transfer of heat in solids.

6. 3 Open the Inferred Properties of Earth’s Interior chart. Location A, in the diagram, corresponds to a point near the top of the stiffer mantle near the Mid-Atlantic Ridge. From this point, follow along the curved line downward representing the top of the stiffer mantle until you intersect the temperature line on the lower graph. The intersection occurs at about 2600°C.

7. Answer: The lithosphere.

   Explanation: The lithosphere is composed of the crust and the rigid mantle. Together they make up the plates that move over and/or through the asthenosphere. Go to the cross section diagram of the Earth and notice that the lithosphere is shown with two arrows, one for the crust and one for the rigid mantle.
Overview:

The Earth’s crust consists of major tectonic plates that are being pushed/pulled by forces within the Earth. The net results of this "bumper car" action are earthquakes, volcanoes and mountain ranges, along with many other geologic processes that have their origin with the movement and collisions involving these plates. Three major plate boundaries are recognized:

(1) *A Divergent Plate Boundary* – “The spreading boundary” – Along this boundary two plates are moving apart, thus forming a ridge where lava exits, creating new ocean floor. The Mid-Atlantic Ridges is a well-known and studied divergent boundary. At all ocean ridges, the newest rocks of the ocean floor are made as the molten rock (lava/magma) surfaces and quickly solidifies into igneous basaltic rocks. Moving away from these ocean ridges, the ocean floor (ocean plate) gets increasingly older.

(2) *A Convergent Plate Boundary* – “The collision of plates” – Along this boundary two plates are moving toward each other. Geologists have classified plates as being either oceanic or continental. The ocean plate, consisting of mostly basalt, is thinner but denser than the continental plate. At a convergent boundary, the denser (oceanic) plate will dive or sink under the other plate.
This produces a subduction zone, making an ocean trench. The subducting plate will eventually melt as it enters the hot mantle, recycling this ocean floor into new magma. Some of this magma may reach the surface above this subducting zone, producing volcanoes. When two continental plates collide, instead of subducting, they undergo uplifting (being less dense than an ocean plates), producing large folded mountains that reach heights over 20,000 feet. The Himalayas, the highest mountain range in the world, was formed by this process.

(3) A Transformed Plate Boundary – “The slipping boundary”- Along this boundary, two plates are moving past each other. The most famous one is in California, known as the San Andreas Fault line. Here the North America Plate and the Pacific Plate are slipping by each other. The trouble associated with these boundaries is that the plates become stuck, building up much pressure. Eventually, when the plates move, they release huge amounts of energy, causing major earthquakes, as California knows all too well.

How were the plate boundaries discovered and mapped? The answer to this took years of research by many contributing geologists and scientists. A simple but efficient answer was by plotting the location of earthquakes. The boundary regions of plates are constantly grinding and moving, setting off numerous earthquakes. Volcanoes and mountain ranges are also located along plate boundaries.

The Map:

The Key Area – On the bottom are located different symbols used on the map. Notice that the divergent plate boundary has two key symbols, one with the arrows showing the spreading action and one representing the Mid-Ocean Ridge. The key for the convergent plate boundary shows which plate is the overriding plate (the less dense one) and which plate is the subducting plate (the denser one). For example, at the Aleutian Trench (by Alaska), the overriding plate is the northern part of the North American Plate and the subducting plate is the Pacific Plate. This subducting Pacific Plate has produced the Aleutian Ocean Trench, a very deep part of the ocean floor. The transform plate boundary key shows the slippage of the plates by two arrows side-by-side going in opposite direction. Although the most famous one is in California - the San Andres Fault line - the map shows another transform plate boundary at the southern end of the African Plate.

The World Map – On the world map are outlined the major known plate boundaries. The given arrows are showing the direction of the plate’s movement. Along these plate boundaries major earthquakes, volcanoes and mountain ranges are found. The Himalayan Mountains were formed when two continental plates collided, producing a convergent plate boundary. This boundary is shown on the map in northern India.

Hotspots – This chart shows five hotspots. A hotspot is a volcanically active area that often is not on a plate boundary. Hotspots remain in the same position generating lava and producing volcanoes, while the plate drifts over this area. Over time, as the plate moves, the volcano will be move off the hotspot and become extinct. However, a new volcano will slowly be formed over the hotspot as magma rises from the hotspot. This is how the Hawaiian Island chain developed.
**Additional Information:**

- Moving away in both directions from the ridge at a divergent plate boundary, the ocean floor increases in age and magnetic reversal patterns are found here. This same magnetic reversal pattern appears on opposite sides of the ridge. This is a major proof of seafloor spreading.

- Latitude and longitude readings are given along the map edge. Remember, latitude is measured N and S from the equator while longitude is measured E and W from the Prime Meridian (0 degree line). When giving the coordinates of a position, always give the latitude reading first.

- The term “The Ring of Fire” is referring to the volcanoes located around the Pacific Ocean. The abundance of these volcanoes are due to the many convergent boundaries that surround this ocean.

- Iceland was formed on the Mid-Atlantic Ridge and is labeled a Hot Spot. Active volcanoes, earthquakes, and hot springs can be found in Iceland.

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**Set 1 — Tectonic Plates**

1. Seafloor spreading is occurring at the boundary between the
   (1) North American Plate and the Pacific Plate
   (2) Nazca Plate and South American Plate
   (3) Indian–Australian Plate and the Antarctic Plate
   (4) Indian–Australian Plate and Eurasian Plate

2. Which feature is commonly formed at a plate boundary where oceanic crust converges with continental crust?
   (1) a mid-ocean ridge
   (2) an ocean trench
   (3) a transform fault
   (4) new oceanic crust

3. The cross section below shows the direction of movement of an oceanic plate over a mantle hot spot, resulting in the formation of a chain of volcanoes labeled A, B, C, and D. The geologic age of volcano C is shown. What are the most likely geologic ages of volcanoes B and D?

   ![Cross section diagram](image)
   (1) B is 5 million years old and D is 12 million years old.
   (2) B is 2 million years old and D is 6 million years old.
   (3) B is 9 million years old and D is 9 million years old.
   (4) B is 10 million years old and D is 4 million years old.
4. Which cross section below best represents the crustal plate motion that is the primary cause of the volcanoes and deep rift valleys found at mid-ocean ridges?

(1) (2) (3) (4) 4

Base your answers to questions 5 through 7 on the cross section below, which shows the major surface features of Earth along 25° S latitude between 75° W and 15° E longitude. Points A, B, and C represent locations on Earth’s crust.

5. Identify the crustal feature located at point A.

6. Identify the tectonic plate motion that is causing an increase in the distance between South America and Africa.

7. Bedrock samples were taken at the mid-ocean ridge and points B and C. On the grid, draw a line to show the relative age of the bedrock samples between these locations.
8. Beneath which surface location is Earth's crust the thinnest?
(1) East Pacific Ridge
(2) the center of South America
(3) Old Forge, New York
(4) San Andreas Fault

9. According to tectonic plate maps, New York State is presently located
(1) at a convergent plate boundary
(2) above a mantle hot spot
(3) above a mid-ocean ridge
(4) near the center of a large plate

10. Which evidence causes most scientists to believe that seafloor spreading occurs at the mid-Atlantic Ridge?
(1) Oceanic crust is oldest at the ridge.
(2) Large sedimentary folds exist in the mantle near the ridge.
(3) Oceanic crust on both sides of the ridge is less dense than continental crust.
(4) Oceanic crust on both sides of the ridge shows matching patterns of reversed and normal magnetic polarity.

11. Which diagram best shows the type of plate boundary found between the Eurasian Plate and the Philippine Plate?

   (1) Transform
   (2) Divergent
   (3) Convergent
   (4) Complex

12. Compared to oceanic crust, continental crust is generally
(1) older and thinner
(2) older and thick
(3) younger and thinner
(4) younger and thicker

13. In which Earth layer are most convection currents that cause seafloor spreading thought to be located?
(1) crust
(2) asthenosphere
(3) outer core
(4) inner core
14. The diagrams below show four major types of fault motion occurring in Earth’s crust. Which type of fault motion best matches the general pattern of crustal movement at California’s San Andreas Fault?

Base you answers to questions 15 and 16 on the diagram below which shows a cross section of a portion of Earth. The inferred motions of crustal plates are shown. Letters A through D represent locations at Earth’s surface.

15. Which letter represents the location of the mid-Atlantic Ridge?
   (1) A  (2) B  (3) C  (4) D

16. The diagram shows convection currents. What are their roles with plate tectonics?

17. Give the latitude and longitude of the Canary Islands Hot Spot.
   _______________ latitude  _______________ longitude

18. Identify the type of tectonic plate boundary that exists on the western side of the Juan de Fuca plate.

19. Why does Iceland experience major volcanic activities?
Review Packet Answer Key

Set 1 and 2: Earthquake P-wave and S-wave Travel Time
1) 3  2) 1  3) 1  4) 3  5) 3  6) 2  7) 3  8) 1  9) 3
10) 4  11) 2  12) 2  13) 2  14) 4  15) 3  16) 1  17) 2  18) 3
19) 3

Set 1 and 2: Inferred Properties of Earth’s Interior
1) 2  2) 4  3) 3  4) 3  5) 2  6) 3  7) Lithosphere  8) 3
9) 3  10) Rigid Mantle  11) Plastic Mantle  12) 3  13) 3  14) 4  15) 3.0

Set 1 and 2: Tectonic Plates
1) 3  2) 2  3) 1  4) 3  5) Ocean Trench  6) Diverging
7) it would be a "V" shape  8) 1  9) 4  10) 4  11) 3  12) 2  13) 2
14) 1  15) 3  16) plate movement  17) 35 °N, 18 °W (plus/minus 3°)
18) Divergent  19) Hot spot on a divergent plate boundary