Student's Name ______________________________ Date ____________ Class __________

Student Sheet: Self-Assessment

Directions: Use the space provided to prepare a KWL chart. In the first column, write things you already know about geologic processes. In the second column, write things you want to know. Leave the last column blank. You will fill in things you learned at the end of the unit.

K	W	L
What I Know	**What I Want to Know**	**What I Learned**

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class _________

Student Sheet 2.R: How Earthquake Resistant Is Your Home or School?

1. Imagine that you live in a high-risk area for earthquakes. Complete the checklist in Table 1 to determine how earthquake resistant your home or school is. Then, complete the checklist in Table 2 to determine things you should avoid if an earthquake hits.

Table 1. Checklist for Earthquake Resistance

Items to Check	Questions to Ask	Yes	No
Bookshelves	Are they secured to the wall?		
Cabinets	Are they built into or fastened to the wall?		
Heavy objects	If they are stored on shelves or in cabinets, are they stored low, so they are not above your head?		
Glass	Are there any mirrors or glass near your living area or classroom seating area?		
Television screens or computer monitors	Are they securely attached to a table, cabinet, or desk? If they are on a cart, are the wheels locked?		
Picture frames and wall hangings	Are they securely attached to the wall?		
Hanging plants	Are they in lightweight pots?		

Table 2. Checklist for Things to Avoid During an Earthquake

Brick chimney	
Outdoor decorations and large signs	
Large windows	
Free-standing walls	
Power lines	
Large trees	

2. Use the information on this sheet to create an earthquake-preparedness plan. What could you do to make your home or school more earthquake resistant? Where would you go if there were an earthquake? Write or draw your plan in your science notebook.

© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class __________

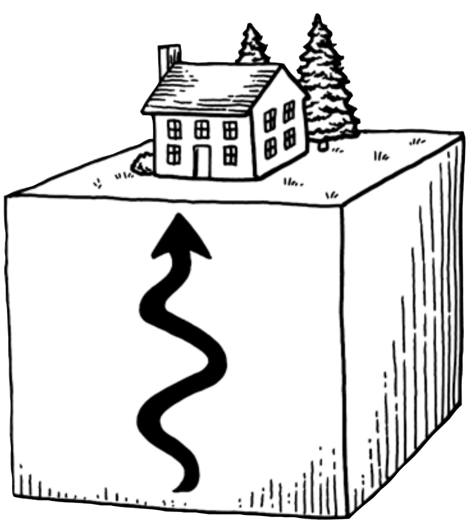
Student Sheet 3.1: Simulating the Motion of Earthquake Waves

Directions: Use the table below to record data during your investigation.

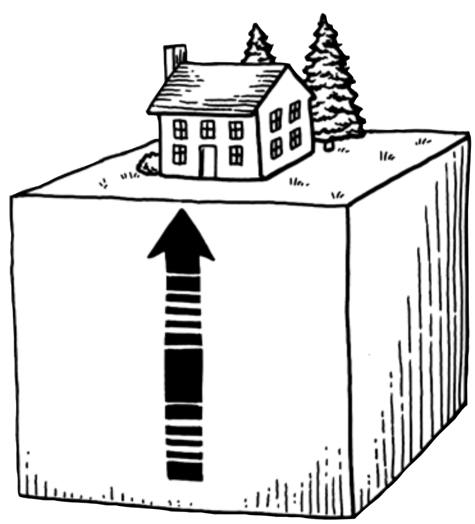
Table 1. Observing Simulated Earthquake Waves

Type of Earthquake Body Wave	Sketch of How Spring Moves	Time for Wave to Travel Back and Forth One Complete Trip			
		Trial 1	Trial 2	Trial 3	Average
Push and Pull (P-Wave)					
Side to Side (S-Wave)					

Directions: Below each picture, write whether the illustration shows a P-wave or an S-wave.



A. ____________________________



B. ____________________________

© Smithsonian Institution

Student's Name ____ Date ______________ Class ___________

Student Sheet 3.4: Locating the Epicenter of an Earthquake (page 1 of 2)

Directions: Three different seismic stations (A, B, and C) recorded an earthquake. During your investigation, use Figure 1 and the steps in the Student Guide to complete Table 1. When completing Table 1, estimate times to the nearest minute.

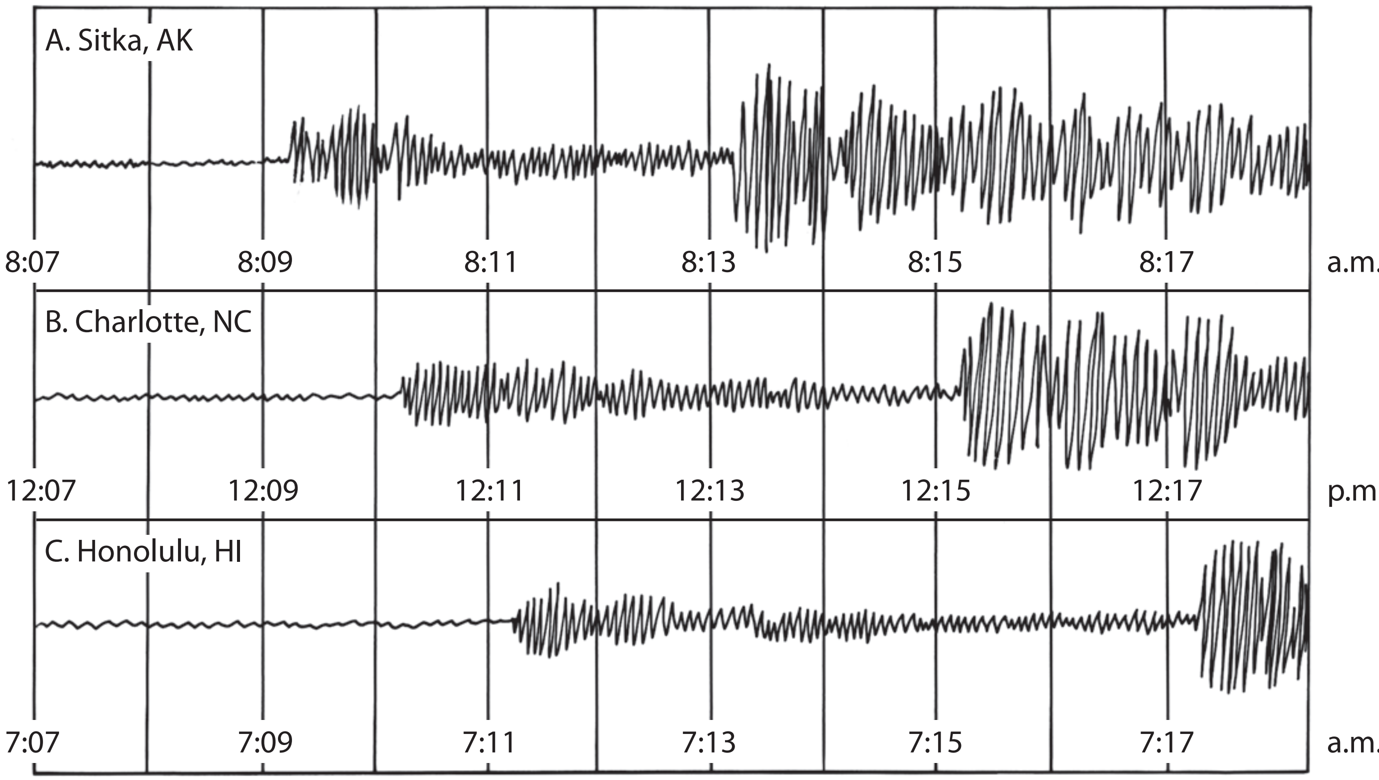


Figure 1
Seismogram records for three stations

Table 1. Earthquake Data

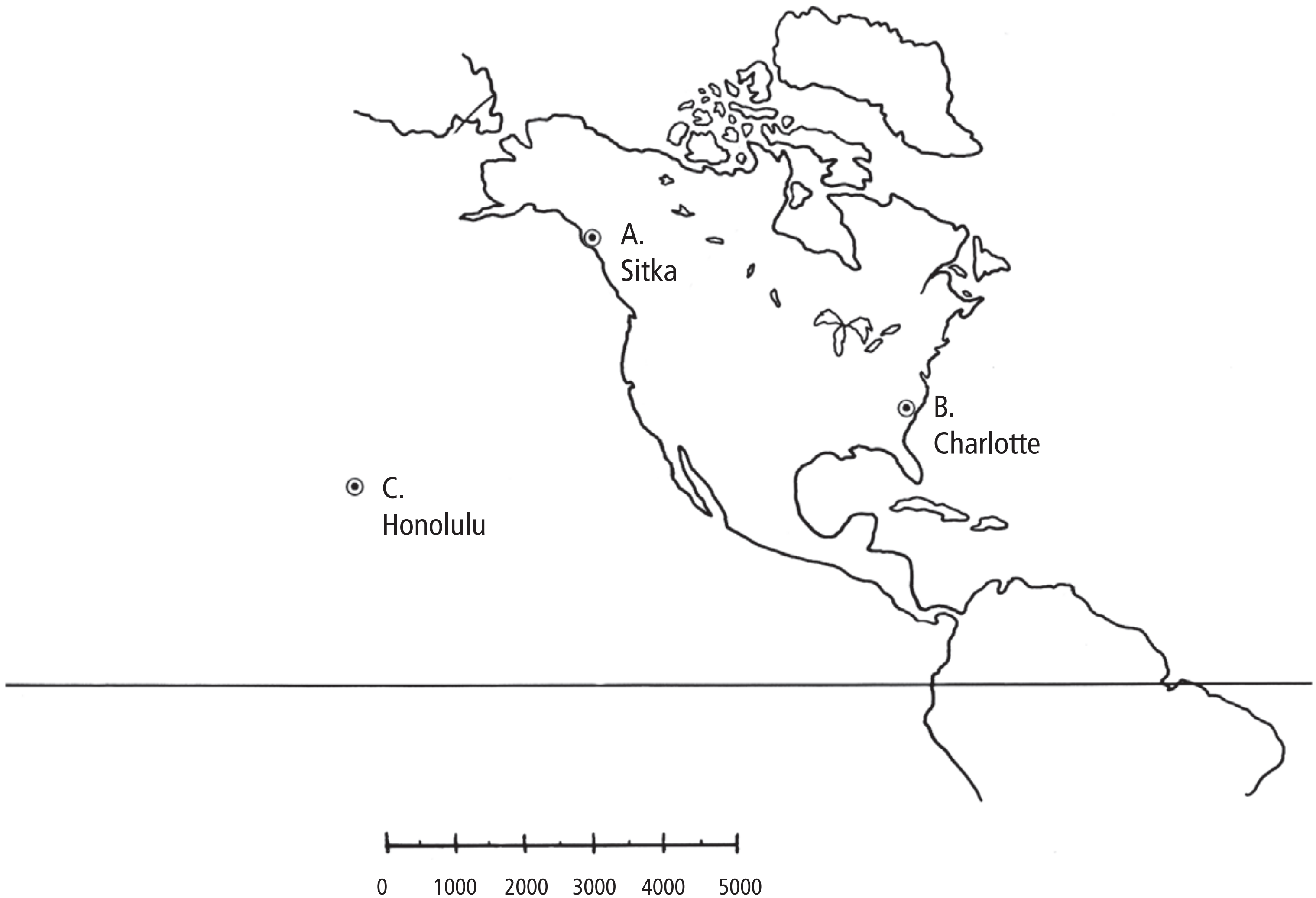
Seismic Station	Time of Arrival at Station		S-Wave Minus P-Wave	Distance to the Epicenter (km)
	Primary Wave (P-Wave)	Secondary Wave (S-Wave)		
A. ______________________	8:09	8:13		
B. ______________________				
C. ______________________				

© Smithsonian Institution

Student's Name ______________________ Date ____________ Class ________

Student Sheet 3.4: Locating the Epicenter of an Earthquake (page 2 of 2)

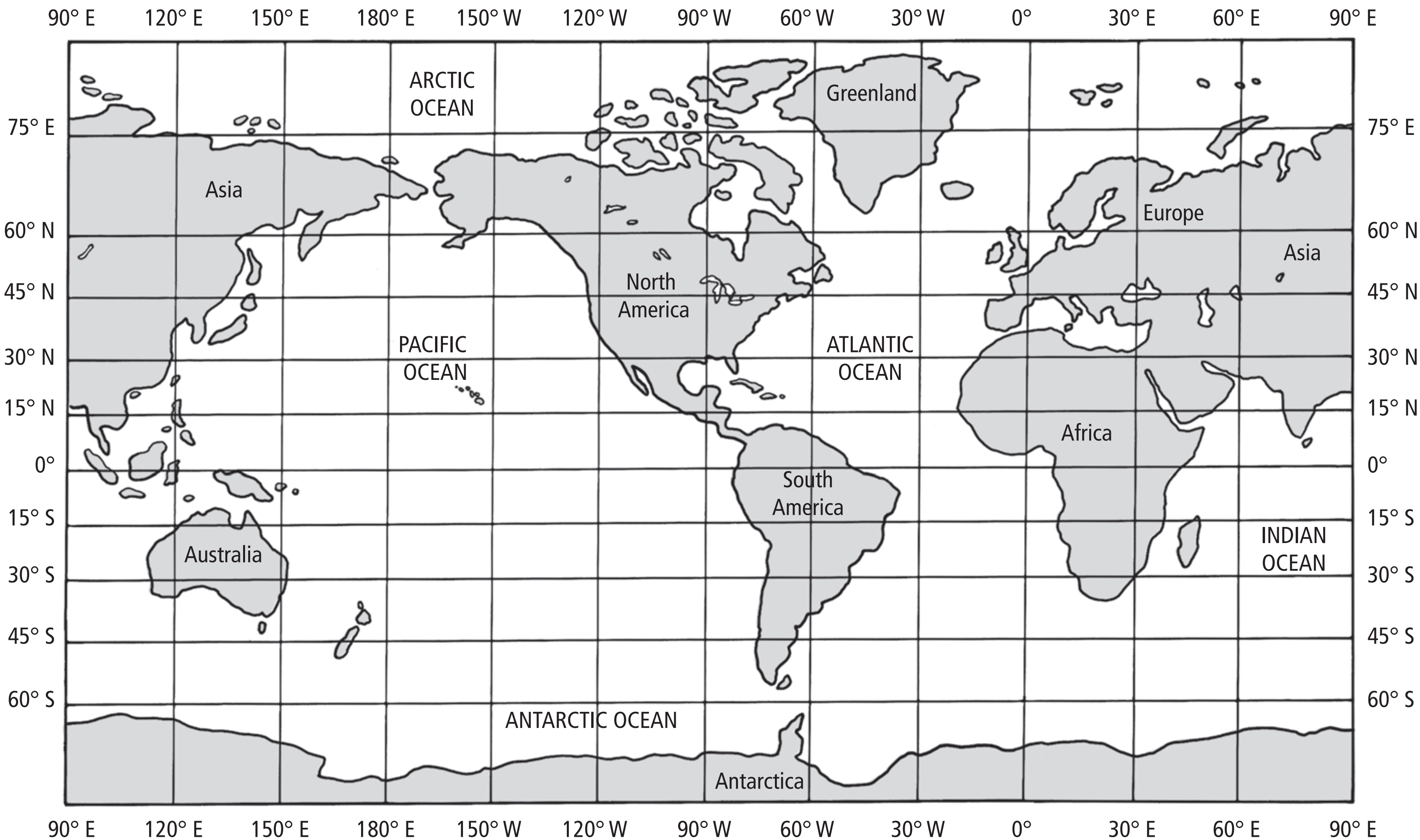
Directions: Follow the procedures in the Student Guide and use the map below to locate and mark the earthquake's epicenter.



© Smithsonian Institution

Student's Name ______________________ Date ____________ Class ________

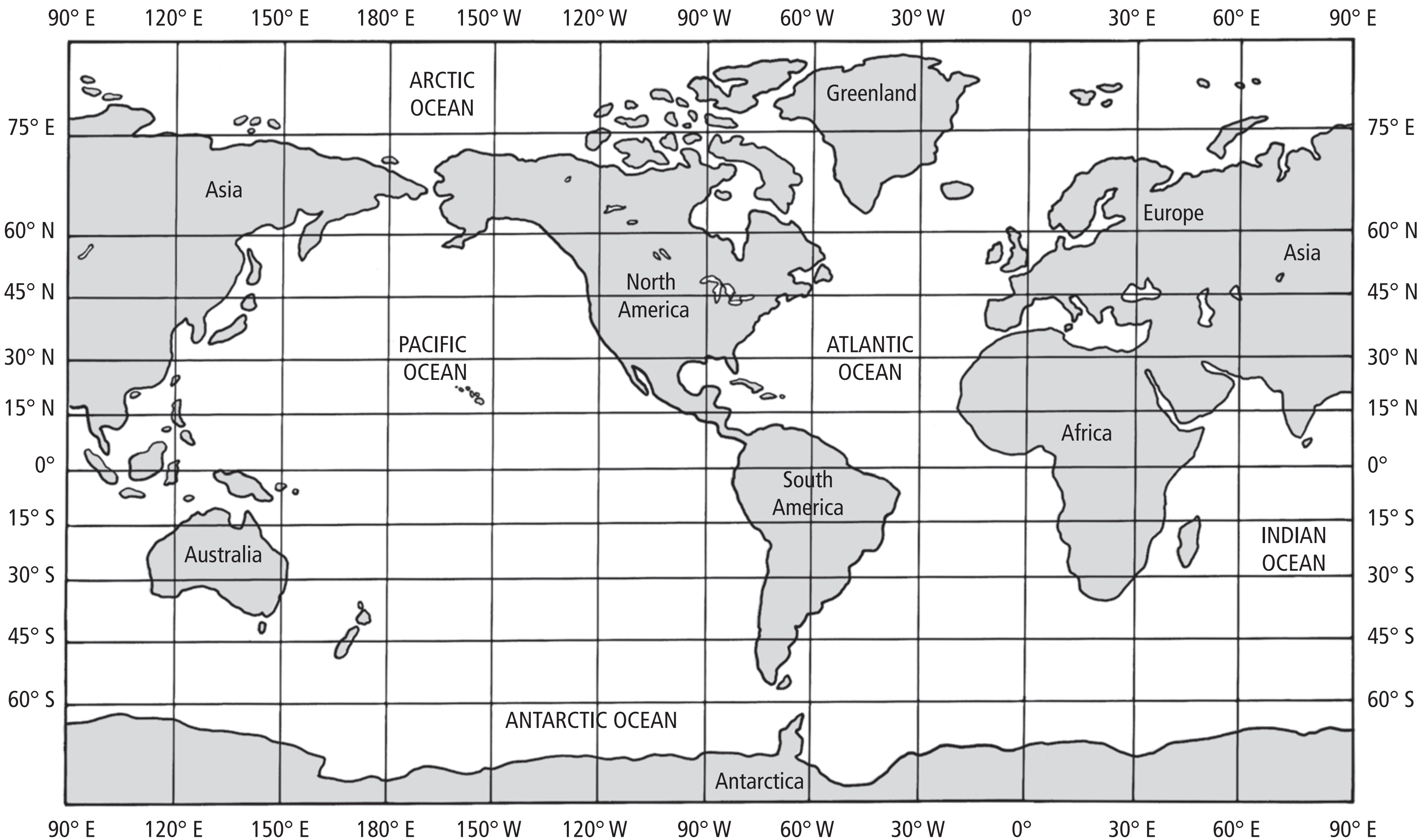
Student Sheet 4.GS: World Map



© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class ________

Student Sheet: 4.1: Plotting Earthquakes to Identify Patterns



© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class __________

Student Sheet 4.H: Plotting Earthquakes by Depth (page 1 of 2)

Background: You may remember that the focus of an earthquake is where the earthquake starts inside Earth. The depth of the earthquake tells you how far down inside Earth the earthquake originated. Some earthquakes originate very far inside Earth and are called deep-focus earthquakes, while others are shallower and are called shallow-focus earthquakes. Medium-focus earthquakes are neither on Earth's surface nor deep in Earth.

Directions: Use colored pens, pencils, or crayons to plot the earthquakes from Table 1 on the graph on the next page.

Table 1. Earthquake Data

Earthquake Focus*	Distance from Mainland (km)	Depth (km)
Blue	450	25
Blue	520	50
Red	50	650
Red	200	500
Green	320	300
Blue	450	90
Green	450	200
Blue	610	20
Blue	575	80
Green	375	250
Red	100	575
Blue	550	40
Green	425	275
Red	250	425
Green	500	125
Green	375	325
Blue	475	70
Green	310	350
Green	525	175

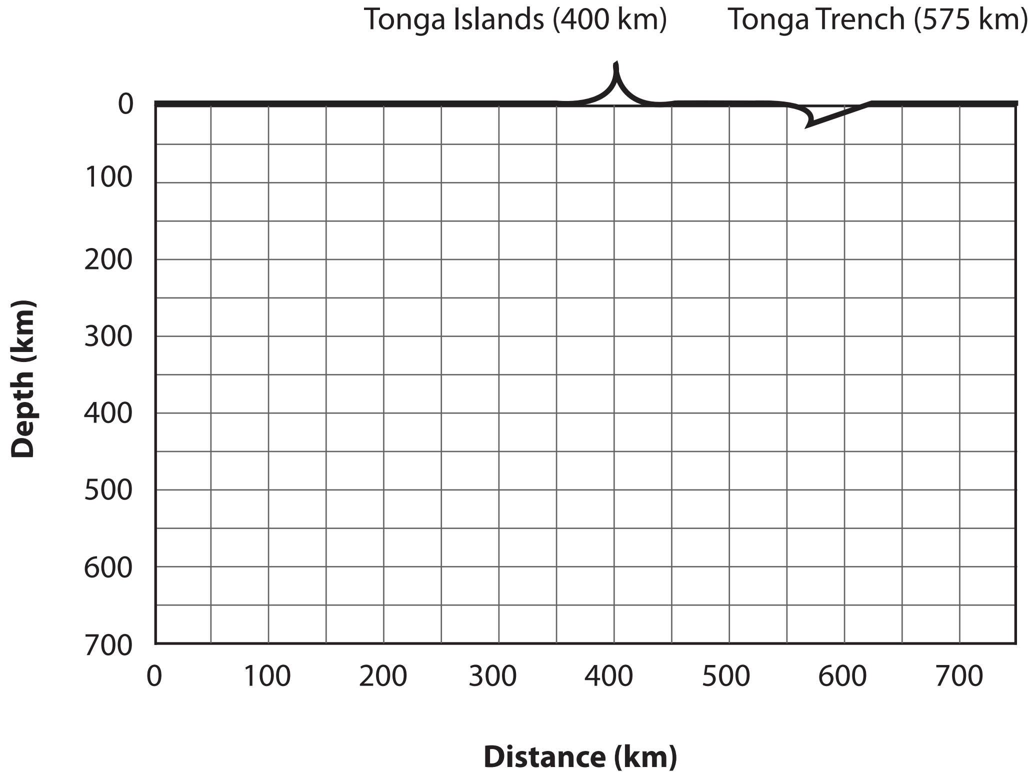
*Blue = shallow-focus earthquake
Green = medium-focus earthquake
Red = deep-focus earthquake

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class _________

Student Sheet 4.H: Plotting Earthquakes by Depth (page 2 of 2)

Plotting Earthquake Data



Directions: Write your answers to the following questions on a separate sheet of paper. Use complete sentences.

1. Use a ruler to draw a best-fit line for the earthquake data you graphed. Is there a pattern of earthquake activity occurring under the Tonga Trench? If so, what is it?
2. Think of the plate models you observed in class. What do you think is causing this line of earthquakes beneath the Tonga Trench?
3. What kind of plate boundary do you think is shown in this activity (divergent plate boundary, convergent plate boundary, or transform plate boundary)? Why do you think this?
4. Based on what you learned from this activity, how would you define a trench?
5. As an oceanic plate sinks into the mantle, it releases water that facilitates melting. What surface feature is the result of rising melt?

© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class __________

Student Sheet 4.5: Investigating Faults with Models

Title ____

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

Student Sheet 5.GS: Convection in the Mantle (page 1 of 2)

1. Add arrows to the illustration in Figure 1 to show the movement of the fluid in the jar. Add labels to indicate where the fluid is warmer and cooler. Under the illustration, write an explanation for the pattern of movement you see.

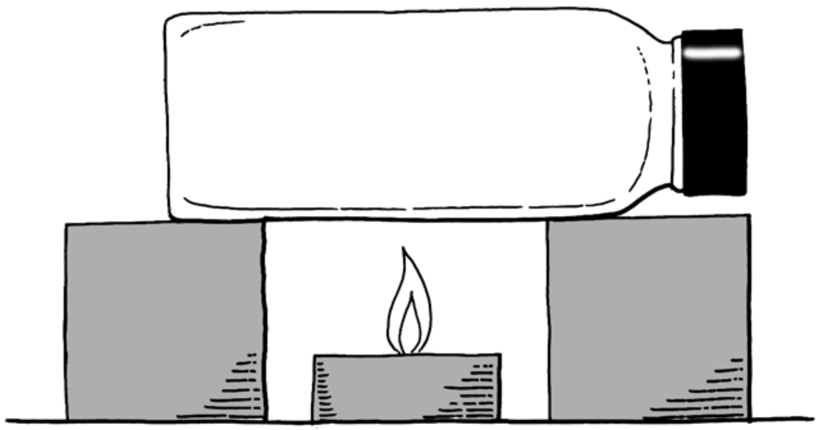


Figure 1
Jar model

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class _________

Student Sheet 5.GS: Convection in the Mantle (page 2 of 2)

2. Use the following terms to label the illustration shown in Figure 2:

convection cell   lower mantle   spreading ridge   trench   upper mantle

Under the illustration, write a description of what is happening in the convection cells, the cells' impact on the oceanic plates, and how you think it will change the appearance of the ocean floor in this area over time.

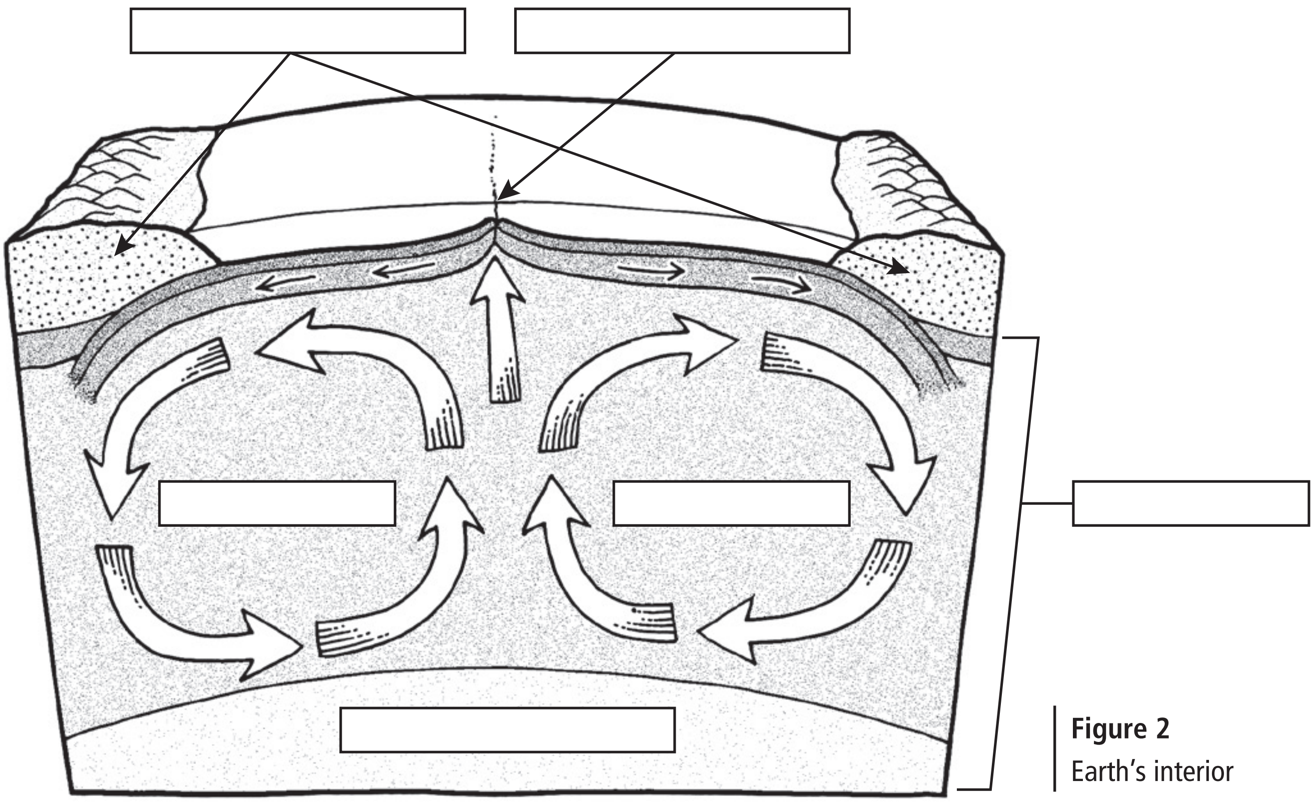


Figure 2
Earth's interior

____

____

____

____

____

____

____

____

© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class __________

Student Sheet 5.1: Plate Tectonics (page 1 of 3)

Simulation	Sketch Before Motion	Sketch After Motion
Plates: Continental and continental **Boundary**: Convergent		Time Elapsed: ___ Million Years
Plates: Continental and young (or old) oceanic **Boundary**: Convergent		Time Elapsed: ___ Million Years
Plates: Young oceanic and old oceanic **Boundary**: Convergent		Time Elapsed: ___ Million Years

© Smithsonian Institution

Student's Name ____ Date ______________ Class ___________

Student Sheet 5.1: Plate Tectonics (page 2 of 3)

Simulation	Sketch Before Motion	Sketch After Motion
Plates: Continental and continental **Boundary**: Divergent		Time Elapsed: ___ Million Years
Plates: Young oceanic and young oceanic **Boundary**: Divergent		Time Elapsed: ___ Million Years
Plates: Old oceanic and young oceanic **Boundary**: Divergent		Time Elapsed: ___ Million Years

© Smithsonian Institution

Student's Name ____ Date ______________ Class ___________

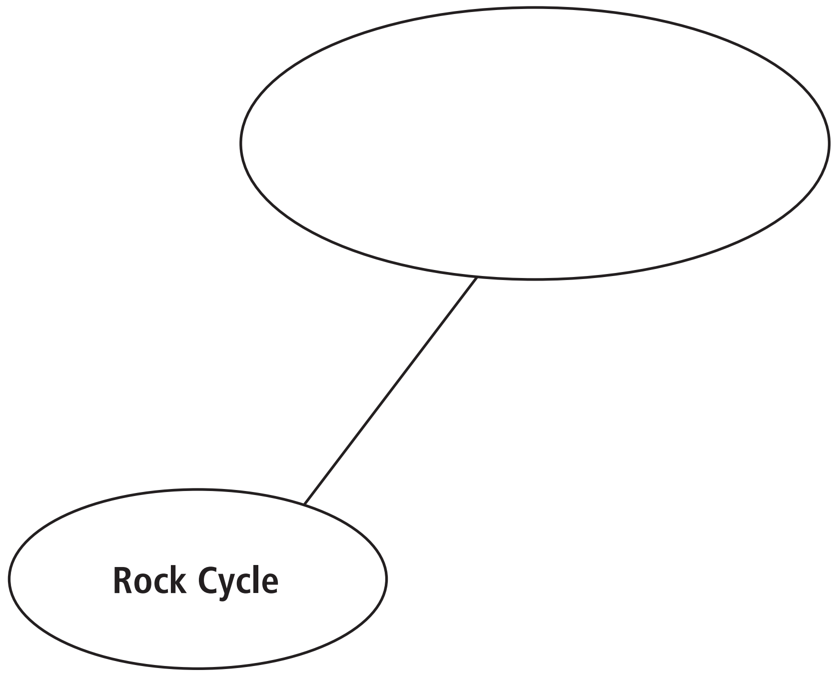
Student Sheet 5.1: Plate Tectonics (page 3 of 3)

Simulation	**Sketch Before Motion**	**Sketch After Motion**
Plates: Continental and continental **Boundary**: Transform		Time Elapsed: ___ Million Years
Plates: Young oceanic and young oceanic **Boundary**: Transform		Time Elapsed: ___ Million Years
Plates: Young oceanic and continental **Boundary**: Transform		Time Elapsed: ___ Million Years

© Smithsonian Institution

Student's Name ____ Date _____________ Class ___________

Student Sheet 5.2: Rock Cycle Concept Map



© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class __________

Student Sheet 5.3: Observing Rock Samples (page 1 of 2)

Directions: Use the table below to record data during your investigation.

Station	Sample	Colors of Minerals	Texture (Large-Grained, Small-Grained, or Glassy)	Other Observations
A	Basalt			
B	Calcareous tufa			
C	Conglomerate			
D	Gneiss			
E	Granite			
F	Limestone			
G	Marble			
H	Obsidian			

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

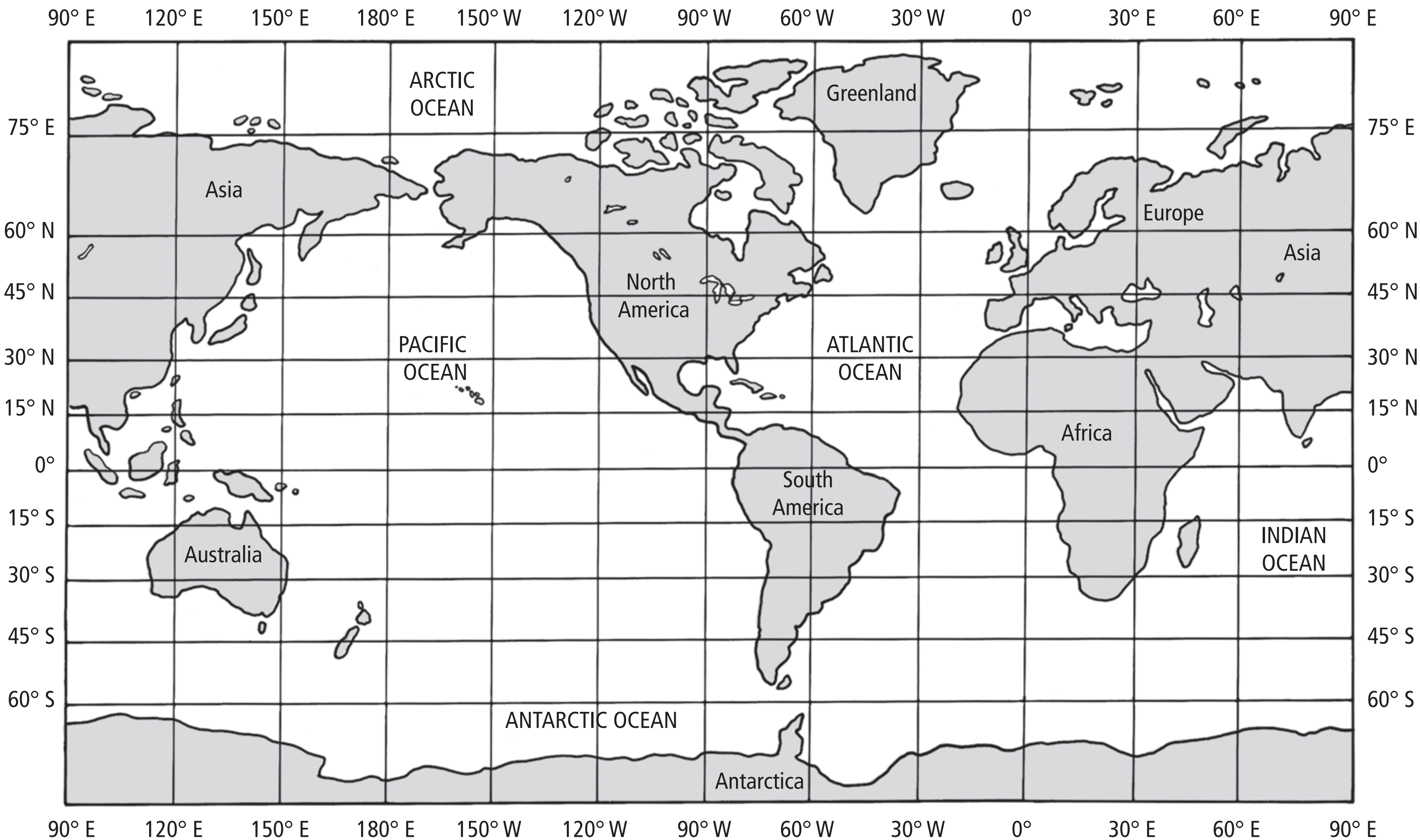
Student Sheet 5.3: Observing Rock Samples (page 2 of 2)

Station	Sample	Colors of Minerals	Texture (Large-Grained, Small-Grained, or Glassy)	Other Observations
I	Pumice			
J	Quartzite			
K	Rhyolite			
L	Sandstone			
M	Schist			
N	Scoria			
O	Shale			
P	Slate			

© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class ________

Student Sheet 6.GS: World Map



© Smithsonian Institution

Student's Name ____ Date ______________ Class ___________

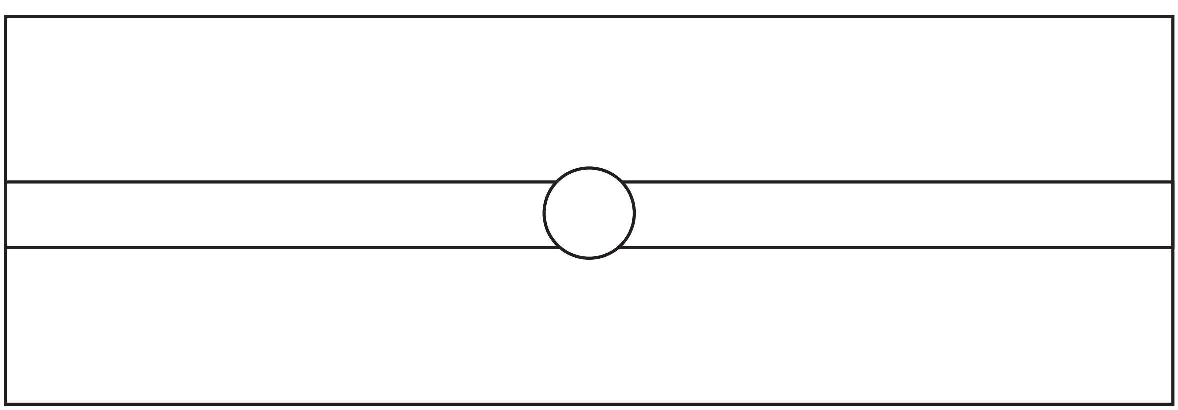
Student Sheet 7.3a: Investigation Observations

Directions: Use the table below to organize your observations and data.

Table 1. Record of Data and Observations from Individual Substances

Substance	General Observations (wind direction, straw position, amount used, etc.)	Distance Substance Traveled (cm)			Average Distance (cm)
		Trial 1	Trial 2	Trial 3	
Corn Kernel					
Cornmeal					
Cornstarch					

Directions: Draw your results from the investigation on the illustration below. If there is a wind source, draw and label an arrow to show the direction it is blowing. Show the trials by using different colors or labeling them (e.g., Cornmeal Trial #2).



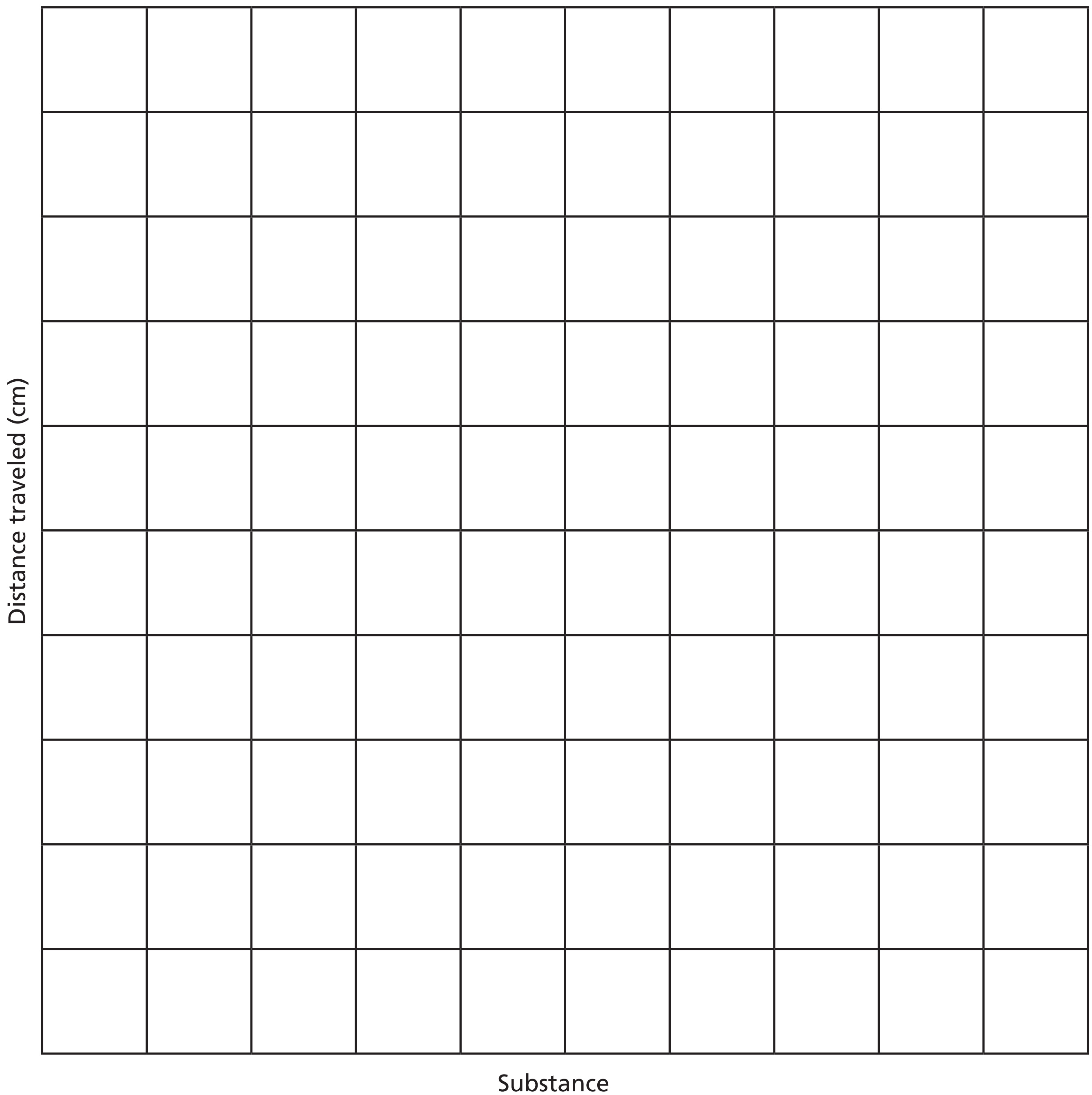
© Smithsonian Institution

Student's Name ____ Date ______________ Class ___________

Student Sheet 7.3b: Investigation Graph

Directions: Graph your results from Investigation 7.3.

Title:____

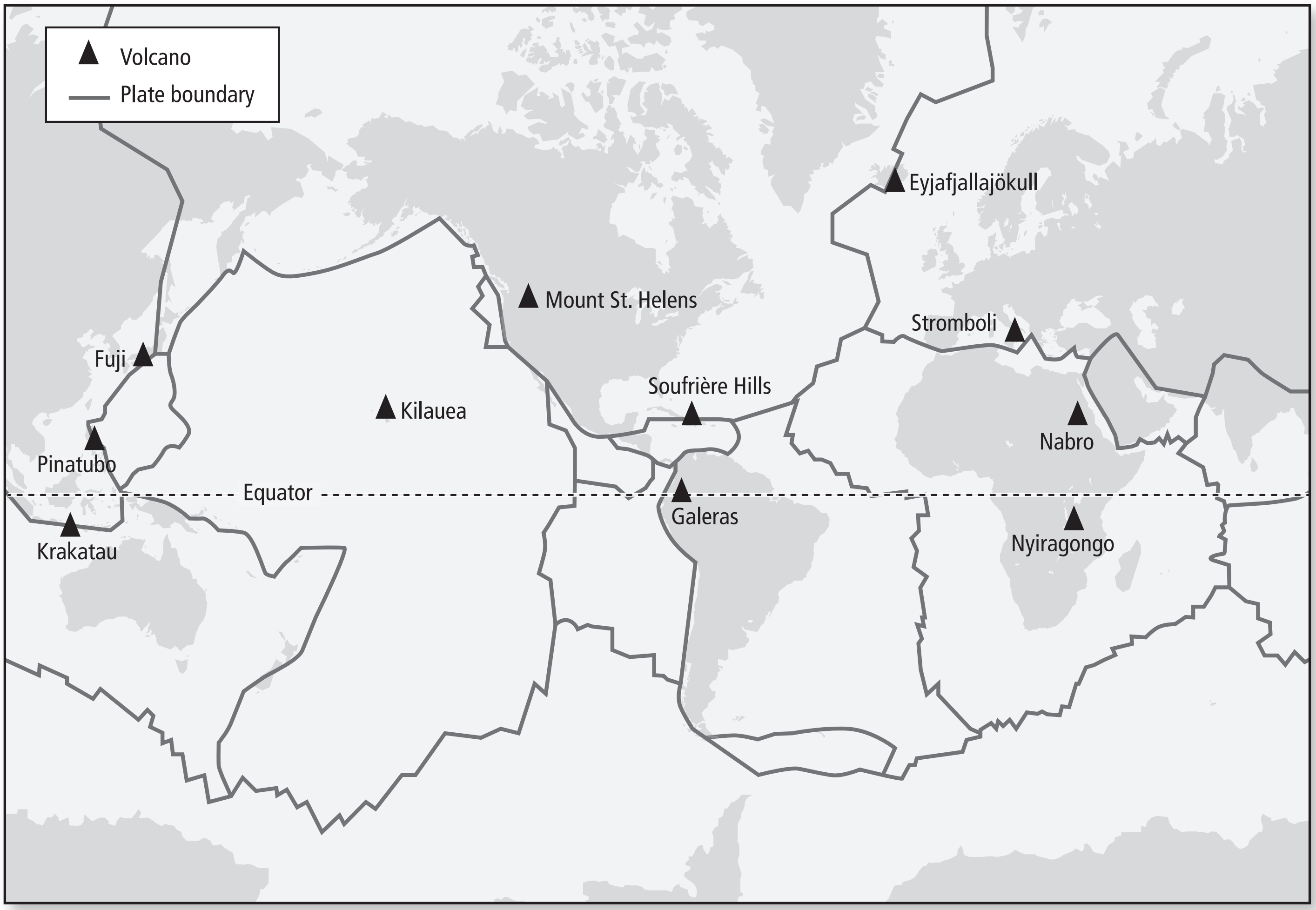


© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

Student Sheet 7.4a Map of Volcanoes and Plate Boundaries

Directions: Predict the Volcano Explosivity Index (VEI) for each labeled volcano and record in your science notebook.



© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

Student Sheet 7.4b: Volcano Explosivity Data Set

Directions: Using scientific reasoning, assign a Volcano Explosivity Index (VEI) to each volcano. Record your predictions in the table.

Volcano	Ejecta Volume	Plume Height	Eruption Frequency	Predicted VEI
Mount St. Helens	1–10 km^3	25–35 km	10s of years	
Stromboli	0.0001–0.001 km^3	0.1–1 km	Daily	
Fuji	1–10 km^3	25–35 km	10s of years	
Nyriagongo	0.0001–0.001 km^3	0.1–1 km	Daily	
Krakatau	10–100 km^3	> 30 km	100s of years	
Kilauea	< 0.0001 km^3	< 0.1 km	Daily	
Galeras	0.001–0.01 km^3	1–5 km	Weekly	
Nabro	0.01–0.1 km^3	3–15 km	Few months	
Pinatubo	10–100 km^3	> 30 km	100s of years	
Soufrière Hills	0.01–0.1 km^3	3–15 km	Few months	
Eyjafijallajökull	0.1–1 km^3	10–25 km	Yearly	

© Smithsonian Institution

Student's Name ______________________________ Date ____________ Class __________

Student Sheet: Credible Source Rubric

Directions: For each online source you use in your research, use the rubric to determine its credibility.

Criteria	3	2	1	Rating
Author	Author's name is easy to find. Author has previous knowledge and experience with the subject.	Author's name is not easy to find. Author may not have experience with the subject and uses common knowledge.	The author's name is unknown.	
Contact information	There is a clear and easy way to contact the author or organization responsible for the website.	It is difficult to find contact information for the author or organization responsible for the website.	There is no contact information available.	
Organization	This website is sponsored by a respectable, well-known organization. The sponsoring organization is clearly identified.	The website is sponsored by an organization that is not well known or is unrelated to the subject matter.	There is no clear sponsoring organization.	
Update frequency	The date of publication is clearly listed and the website is updated frequently.	The website has not been updated frequently and the article was published years ago.	There are no dates of publication or website updates.	
Factuality	The website is fact-based and appears to be free of opinion or bias.	The website appears factual, but the author has included some personal opinions.	The facts of this website are questionable and may be biased.	
Sources and citing	The author refers to and cites other sources to support the content.	The author refers to other sources, but does not provide citations or links.	The author does not provide the source of his or her information.	
Website purpose	The website exists to educate and inform.	The website exists to influence the audience to believe something.	The website exists to sell a product or for the author's personal gain.	

Is this website credible? Explain why or why not. ______________________________

____

____

____

____

© Smithsonian Institution

Source citation: ______________________________

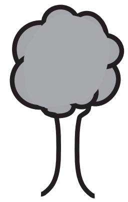
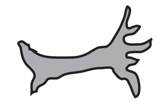
____

Student's Name ______________________ Date ____________ Class ________

Student Sheet 9.3: Radioactive Dating Game

Directions: Sketch the fossils shown in your simulation in the rock strata below. Beside each fossil, estimate its age. After you perform the simulation, record the correct results.

Age of Rock Layers

© Smithsonian Institution

Student's Name ____ Date _____________ Class __________

Student Sheet 9.4: Fossil Record

Directions: Create a fossil record of the organisms on your Fossil Record Card Set. Draw each fossil in the location in which it would most likely be discovered in rock strata based on emergence and extinction.

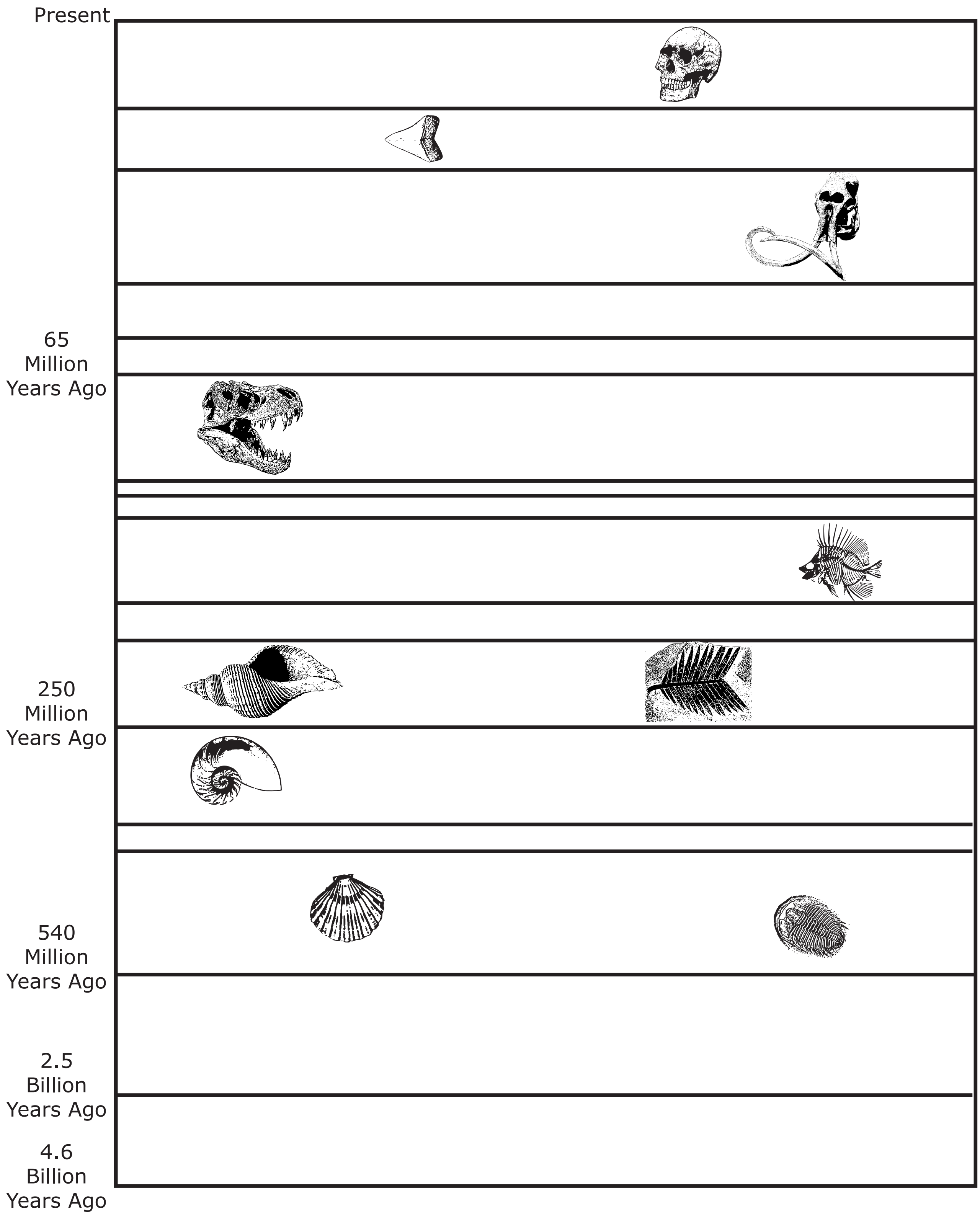
Years before present (millions)	
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	
390	
420	
450	
480	
510	
540	
570	
600	

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

Student Sheet 11.2a: Undisturbed Rock Strata

Directions: Designate a color for each era and color in the corresponding rock strata. With a different color, draw a line to represent the five mass extinctions.

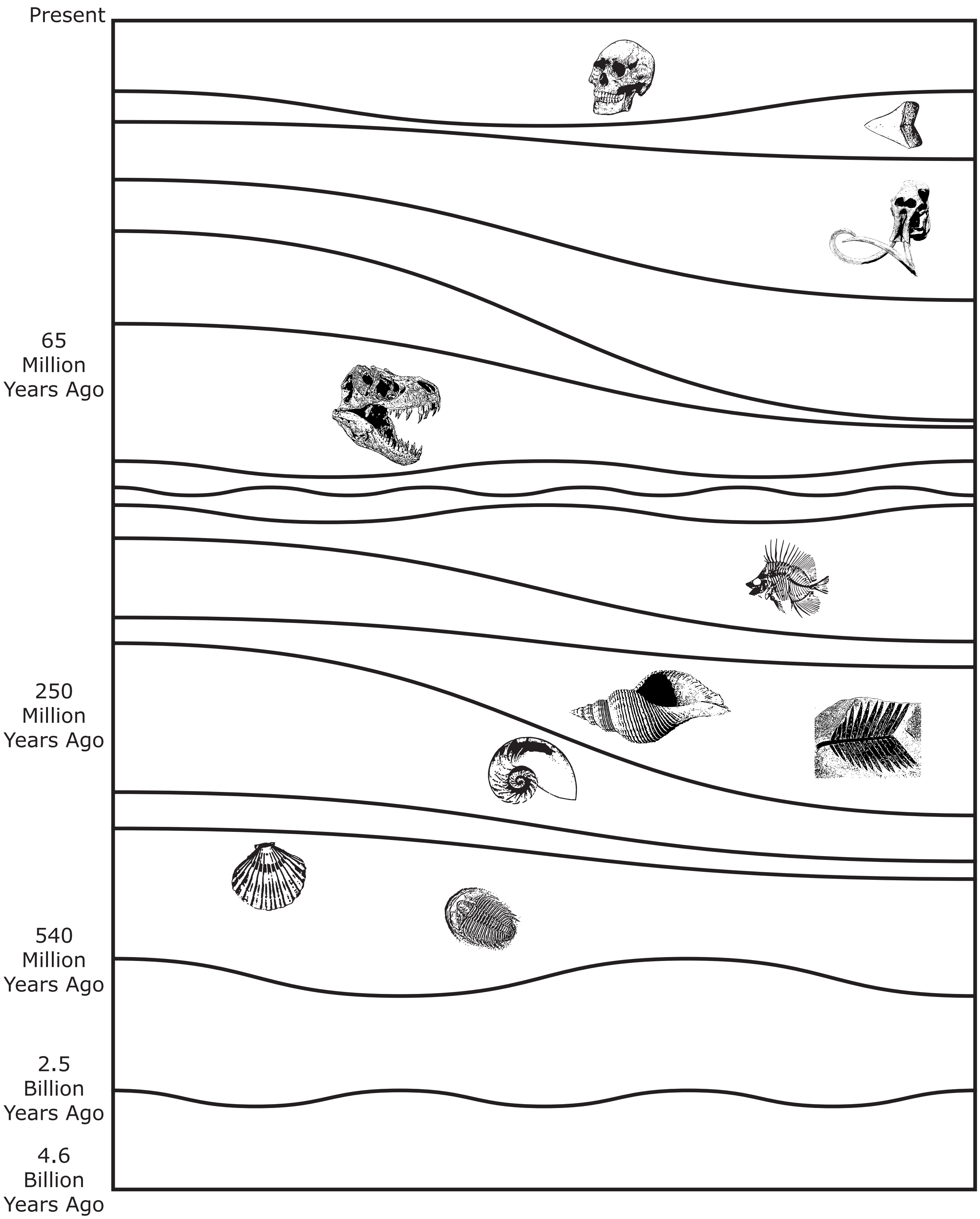


© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

Student Sheet 11.2b: Disturbed Rock Strata

Directions: Designate a color for each era and color in the corresponding rock strata. With a different color, draw a line to represent the five mass extinctions.

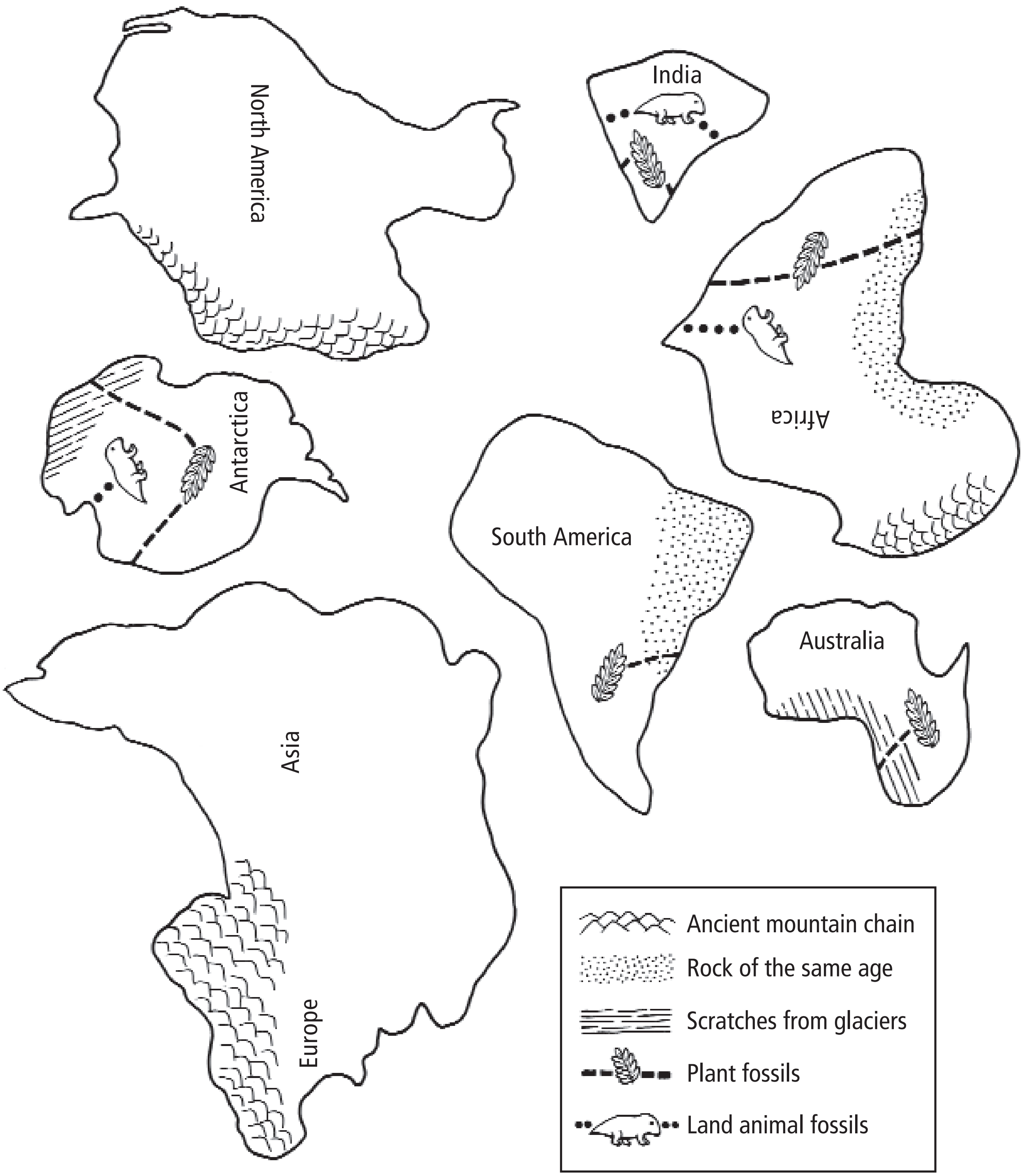


© Smithsonian Institution

Student's Name ________________________________ Date ____________ Class __________

Student Sheet 11.3: Putting the Pieces Together

Directions: Cut out the continents below. Use the legend to match the continents. On another sheet of paper, glue the continents into one large landmass.

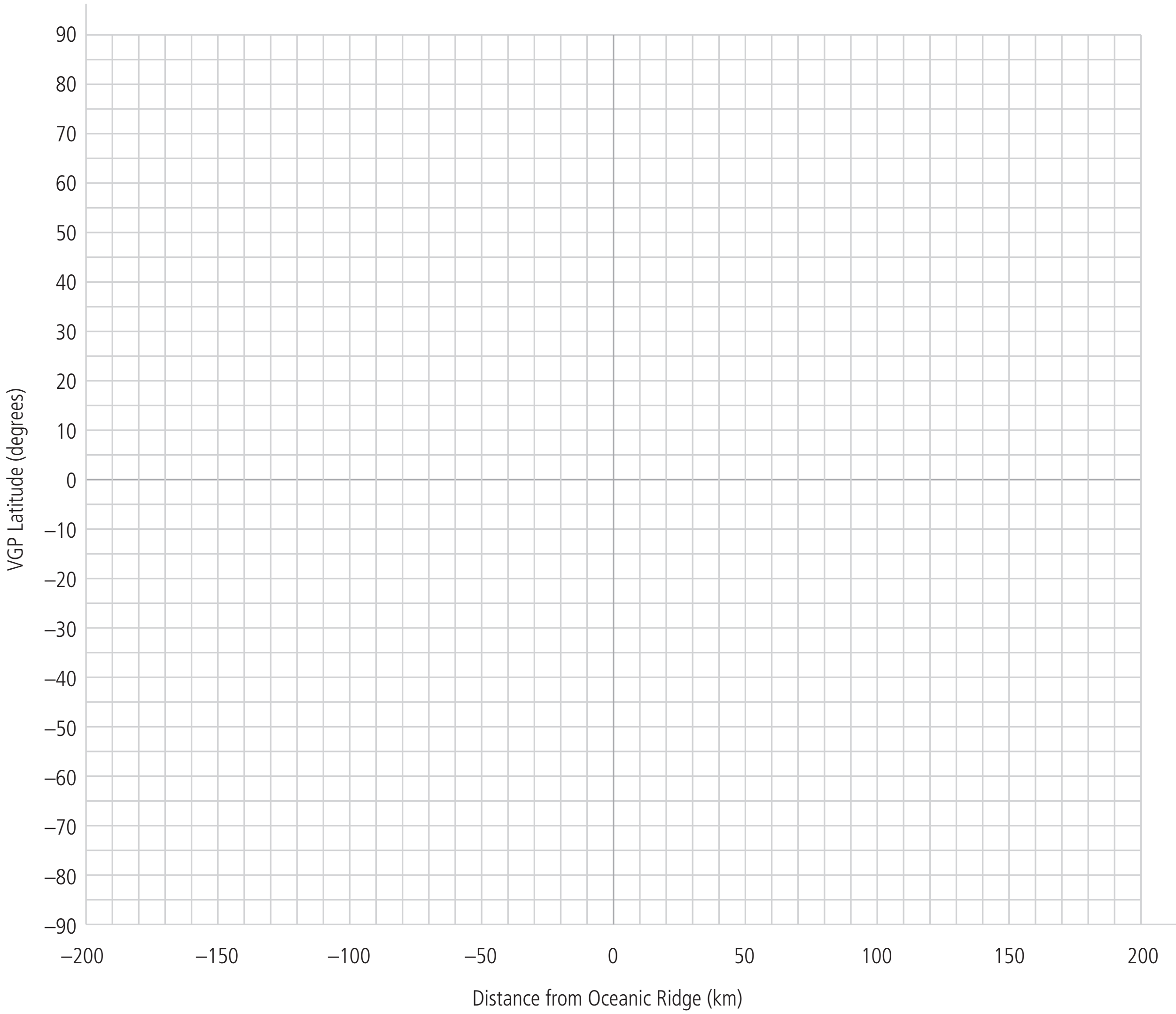


© Smithsonian Institution

Student's Name ______________________________ Date ______________ Class __________

Student Sheet 11.4: Mapping Magnetic Reversals

Directions: You are a scientist studying seafloor spreading. You measure the magnetism of rock samples in each direction of an oceanic ridge using virtual geomagnetic poles (VGP) of latitude. VGP of latitude ranges from 0° (the equator) to 90° (the poles) and is determined using a mathematical equation. Use the graph below and plot the data.



Distance from Oceanic Ridge (km)	VGP Latitude (degrees)
–163	88.9
–142	52.3
–130	–65.7
–115	–87.3
–98	68.5
–80	–84
–72	13
–59	85
–46	80.5
–27	44.4
–9	–81.5
3	–80
25	44
40	79.4
60	84.6
75	13.2
84	–84.6
100	70
112	–86.9
128	–65.1
137	50.2
165	89.1

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

Student Sheet 12.WA: *Earth's Dynamic Systems* Written Assessment Answer Sheet (page 1 of 4)

Multiple Choice

Directions: Circle the letter of your answer choice, and then clearly explain your reason for choosing it.

1. A B C D

2. A B C D

3. A B C D

© Smithsonian Institution

Student's Name ______________________ Date __________ Class __________

Student Sheet 12.WA: *Earth's Dynamic Systems* Written Assessment Answer Sheet (page 2 of 4)

4. A B C D

5. A B C D

Constructed Response

6.

© Smithsonian Institution

Student's Name ____ Date ____________ Class __________

Student Sheet 12.WA: *Earth's Dynamic Systems* Written Assessment Answer Sheet (page 3 of 4)

7. ____

8. ____

© Smithsonian Institution

Student's Name ______________________________ Date __________ Class ________

Student Sheet 12.WA: *Earth's Dynamic Systems* Written Assessment Answer Sheet (page 4 of 4)

9. ______________________________

10. ______________________________

© Smithsonian Institution

(Dates marked with an asterisk [*] indicate entries that appear in Student Guide Figure 1.8.)

August 30, 1909: Out collecting on the Stephen formation all day. Found many interesting fossils on the west slope of the ridge between Mounts Field and Wapta. Helena, Helen, Arthur, Stuart & Jack came up with remainder of outfit at 4 p.m.

August 31, 1909*: Out with Helena & Stuart collecting fossils from the Stephen formation. We found a remarkable group of phyllopod crustaceans. Took a large number of fine specimens to camp. [Sketches depict specimens now recognized as *Marrella*, *Waptia*, and *Naraoia*.]

September 1, 1909*: We continued collecting found a fine group of sponges on slope (in-situ) – Beautiful warm days. [Sketches depict specimens now recognized as *Vauxia* and *Hazelia*.]

September 2, 1909*: Working high up on the slope while Helena collected near the trail. Found that the large so called Leperditia like test is the shield of a phyllopod. Collected a large number of single [illegible] 1 1/2 in. to 2 in. long. Stuart, Helen, and Jack went to Field for mail, etc. [Sketch depicts specimen now recognized as *Canadaspis*.]

September 3, 1909*: Mist clouds, cold wind. Helena and Helen went to Field while Jack and Stuart took a [illegible] of camp outfits in an [illegible]. Out on the collecting ground but driven in by cold. Found a fine lot of phyllopod crustaceans & bro't in several slabs of rock to break up at home.

September 4, 1909: ...went after large slab of 'Phyllopod' rock 6:30 a.m. Camp outfit moved to Field & up on Mt. Stephen 1600 feet above hotel.

September 5, 1909: Out all day with Stuart, Helen & Mr. Rutten on fossil bed—We found a few good specimens including a new trilobite (2 in long). Bright, warm day.

September 6, 1909: Out on fossil beds—Stuart and Mr. Rutten climbed to top of Mt. Stephen—Helen with me—We found some fine trilobites. Fine day.

September 7, 1909: With Stuart & Mr. Rutten went up on fossil beds. Out from 7 a.m. to 6:30 p.m. Our last day in camp for 1909.

July 30, 1910: With Sidney went up to top of Mt. Field. Collected fossils and measured a portion of the section near the summit of the mountain.

August 1, 1910: All out collecting in the Burgess formation until 4 p.m. when a cold wind & rain drove us in to camp. Measured section of the Burgess formation 420 feet thick—Sidney with me. Stuart with his mother & Helen puttering about camp.

August 2, 1910: Out collecting with Helena, Stuart & Sidney. We found a fine lot of 'lace crabs' & various odds and ends of things. [Lace crabs refer to *Marrella*.]

August 3, 1910: Cloudy & threatening. Went out alone. Driven in at 3 p.m. by rain, hail & lightening. Sidney bro't horses but we were wet. Helena worked out a lot of phyllopod crustaceans from 'Lace Crab' layer.

continued

© Smithsonian Institution

August 9, 1910: Collecting all day from the 'lace Crab beds' which Stuart & I located in the morning. Obtained a fine lot of material…

August 25, 1910: With Sidney on the mountain quarrying rock. Found a fine lot of crustaceans. Helena at camp breaking out the fine fossils from the lace crab layer. Out on the mountain 7 a.m. to 5 p.m.—Stuart came up at 2 p.m.

August 26, 1910: Sidney & Stuart with me on the mountain all day. We quarried a lot of rock & incidentally found a lot of fossils. Helen assisted me all day. Helena working at camp. Air full of diffused smoke from forest fires.

August 27, 1910: Out with Stuart all day. A few rare finds & Helena found some good things. Sidney & Helen went to Field for dynamite and mail.

August 31, 1910: Light showers, fog—cold up to 10:30 a.m. Worked out a lot of fossils & at 11 a.m. went up on mountain with Sidney & Stuart. We got a lot of 'worm' rock up & bro't slabs down the mountain. Strong & cold west wind at night.

September 6, 1910: Cloudy & occasional sunshine & light snow squalls. Stuart & I worked at the fossil quarry all day & occasionally warmed up by making a small fire. Dragged down a lot of the 'lace crab' rock by rope over mud & snow to trail. Found a fine 'Sidney crab.'

September 14, 1910: The season has been a mixed up one. Very little geology, but big results in paleontology.

© Smithsonian Institution

Lesson Master 2.3a: Design Challenge Scoring Rubrics

Earthquake-Resistant Structure Rubric				
Criterion	**1. Beginning**	**2. Developing**	**3. Proficient**	**4. Exemplary**
Height	Group designed a structure, but it was not self-supporting.	Group designed a self-supporting structure with a height less than 20 cm.	Group designed a self-supporting structure with a height between 20 and 30 cm.	Group designed a self-supporting structure with a height greater than 30 cm.
Mass	Group designed a structure to support fewer than two bags of sand.	Group designed a structure to support two bags of sand.	Group designed a structure to support three bags of sand.	Group designed a structure to support four or more bags of sand.
Stability During Simulated Earthquake	Structure collapsed following magnitude 3.0 earthquake.	Structure withstood magnitude 3.0 earthquake but collapsed following magnitude 6.0 earthquake.	Structure withstood magnitude 3.0 and 6.0 earthquakes but collapsed following magnitude 9.0 earthquake.	Structure withstood magnitude 3.0, 6.0, and 9.0 earthquakes.

Grading Rubric				
Criterion	**1. Beginning**	**2. Developing**	**3. Proficient**	**4. Exemplary**
Written Instructions and Diagrams	Group did not present written instructions or diagrams pertaining to the design challenge.	Group presented either written instructions or diagrams that were unclear or incomplete but pertained to the design challenge.	Group presented either written instructions or diagrams that were clear and pertained to the design challenge.	Group presented written instructions and diagrams that were clear, detailed, and pertained to the design challenge.
Design Implementation	Group constructed a design that did not pertain to the design challenge.	Group constructed a design that somewhat pertained to the design challenge.	Group constructed a design that met the criteria of the design challenge.	Group constructed a design that exceeded the criteria of the design challenge.
Testing and Data Collection	Group did not test its design.	Group did not use appropriate procedures to test its design and did not collect relevant data.	Group used appropriate procedures to test its design but did not collect relevant data.	Group used appropriate procedures to test its design and collected relevant data.
Reflection and Presentation	Group presented methods and results in an incomplete and unclear manner and did not reflect on choices.	Group presented methods or results in an unclear manner or did not reflect on choices based on scientific principles.	Group presented methods or results adequately. Group reflected on choices based on scientific principles most of the time.	Group presented methods or results clearly and accurately. Group always reflected on choices based on scientific principles.

© Smithsonian Institution

Lesson Master 2.3b: Earthquake-Resistant Design Concepts (page 1 of 5)

Many teams of scientists and engineers work with local, state, and federal lawmakers to identify earthquake hazards and encourage the design and construction of structures to withstand them. An earthquake-resistant structure is expected to include a stable foundation, continuous load paths, adequate stiffness and strength, regularity, redundancy, ductility and toughness, and ruggedness. More information about each of these characteristics follows.

Stable Foundations

At the bottom of a structure sits a foundation, which is in direct contact with the ground below. An earthquake-resistant structure has a foundation that:

- Supports the structure above it
- Minimizes movement and damage
- Anchors the structure
- Resists sliding and overturning (See Figure 1.)

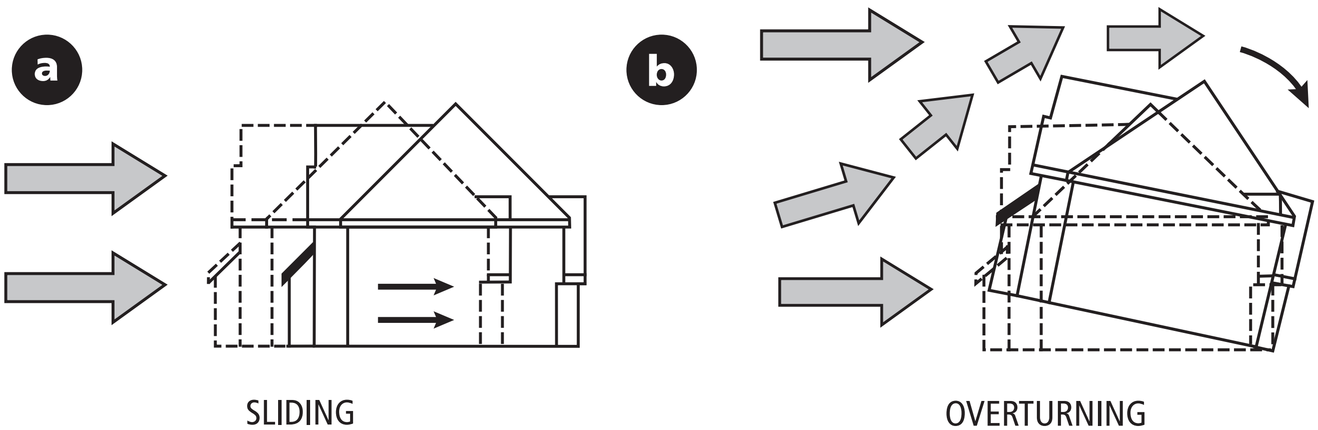


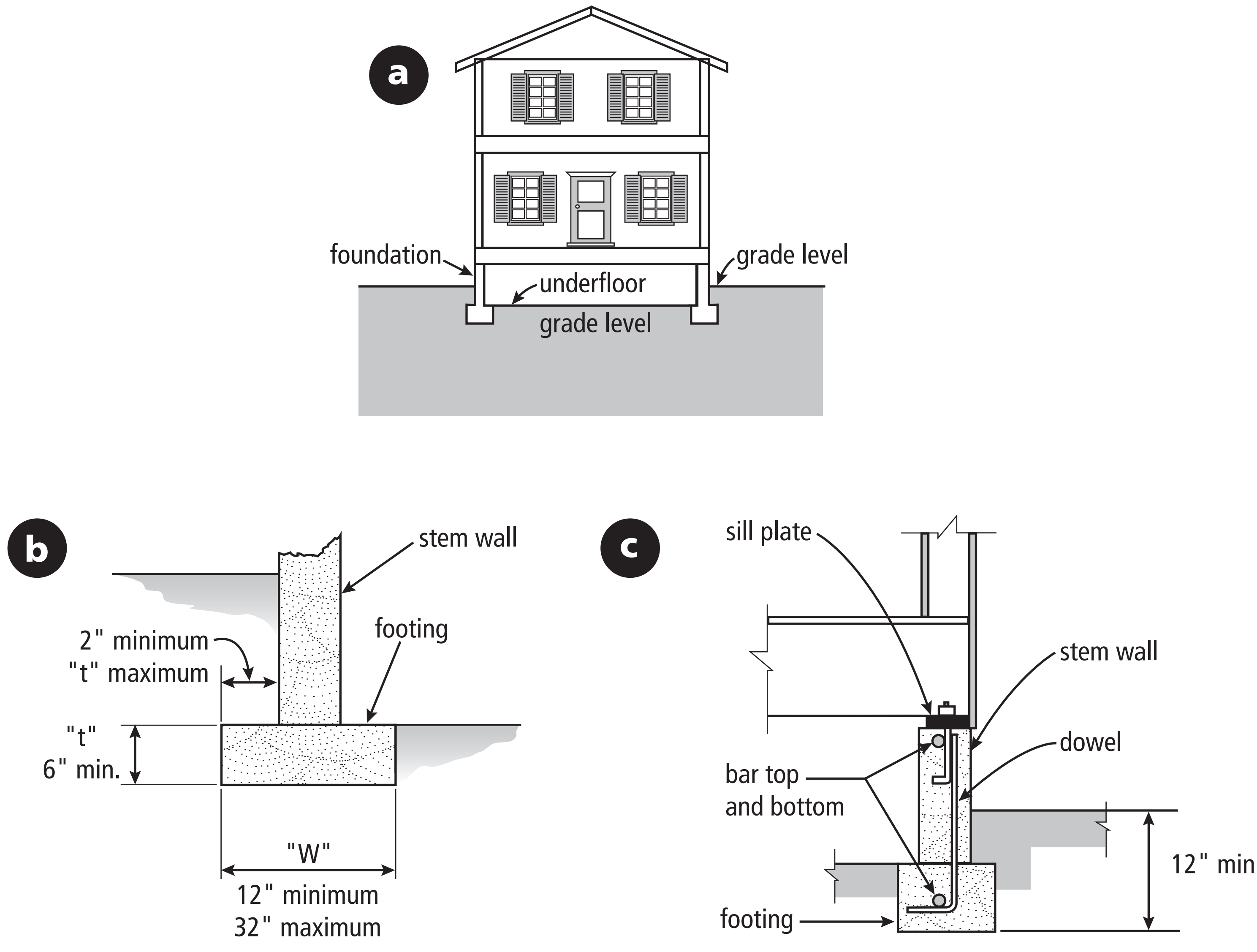
Figure 1

Foundations resist actions that cause sliding (a) and overturning (b).

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

© Smithsonian Institution

Foundations must also provide stability to the structure if the shape of the ground below the structure changes. Foundations commonly have a large continuous piece (called a slab) and may use T-shaped footings or thicker edges to anchor the house to the ground. (See Figure 2.)



Note: Reinforcing not shown.

Figure 2

Concrete is commonly used to construct foundations that include a stem wall and footing (a).
Recommendations for design and construction include guidelines for both dimensions (b) and reinforcement (c).

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

© Smithsonian Institution

Continuous Load Paths

The term "load path" is used to describe the transfer of energy through a structure (including walls, floors, and roof). When a structure is stable, a load applied to any part of the structure can be transferred down to the foundation and ground below. (See Figure 3.) If parts of the structure are not tied together as one system, the parts will move independently and can separate. If parts of the structure separate, it may partially or totally collapse. In an earthquake-resistant structure, all parts of the structure are tied together.

For example, a two-story structure transfers loads using:

- The roof–ceiling system and its connections to the second-story walls
- The second-story wall system and its connections to the floor–ceiling system
- The floor–ceiling system and its connections to the first-story wall system
- The first-story wall system and its connections to the foundation
- The foundation to the supporting soil

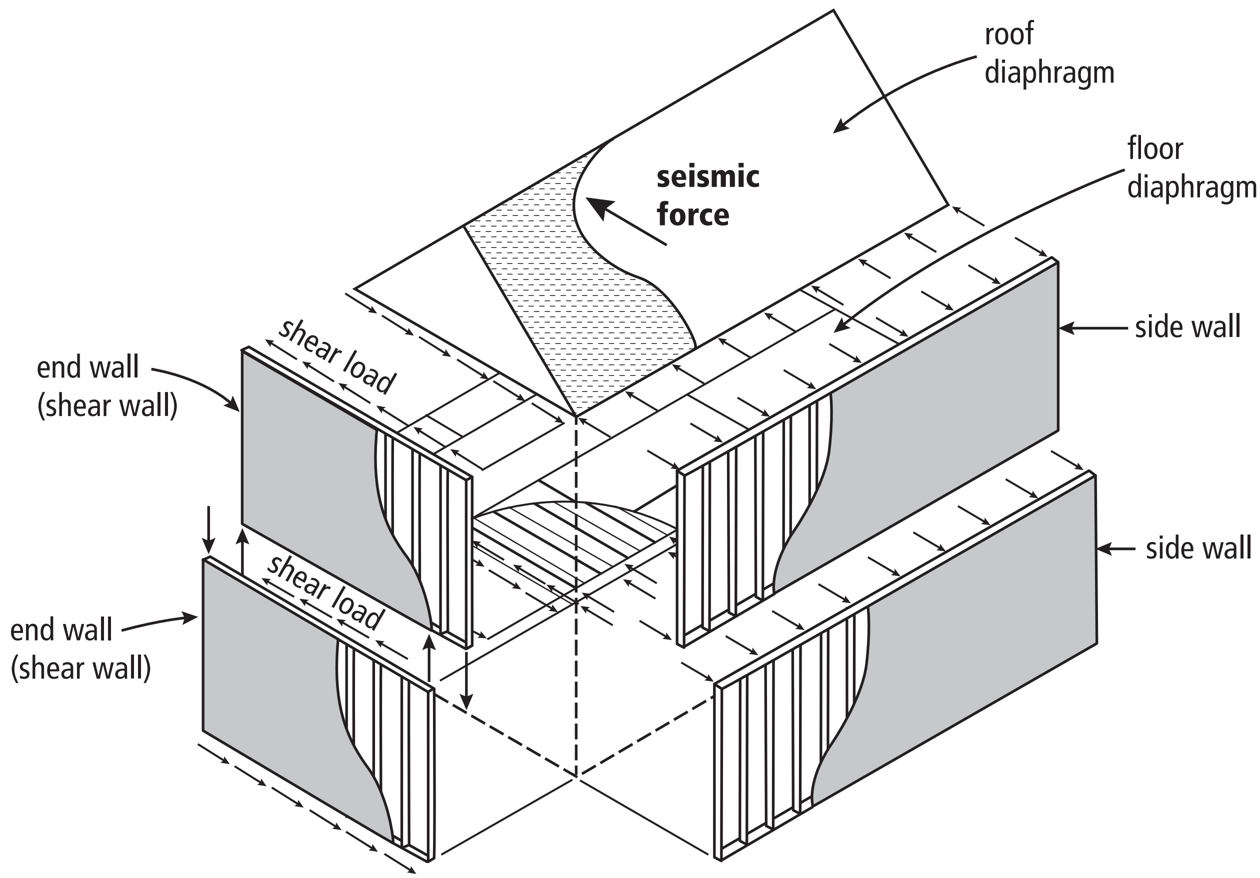


Figure 3

Adequate connection between systems ensures that a seismic force applied to any part of the structure can follow a continuous path through the building and into the foundation and ground below it.

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

© Smithsonian Institution

Adequate Stiffness and Strength

Strong earthquakes will result in both vertical and lateral seismic forces. Particularly damaging are lateral forces that move structures horizontally. (See Figure 4.) An earthquake-resistant structure features:

- Adequate strength in all roof–ceiling, floor, and wall systems
- Adequate stiffness to limit deformation
- Adequate connection between systems to ensure a continuous load path

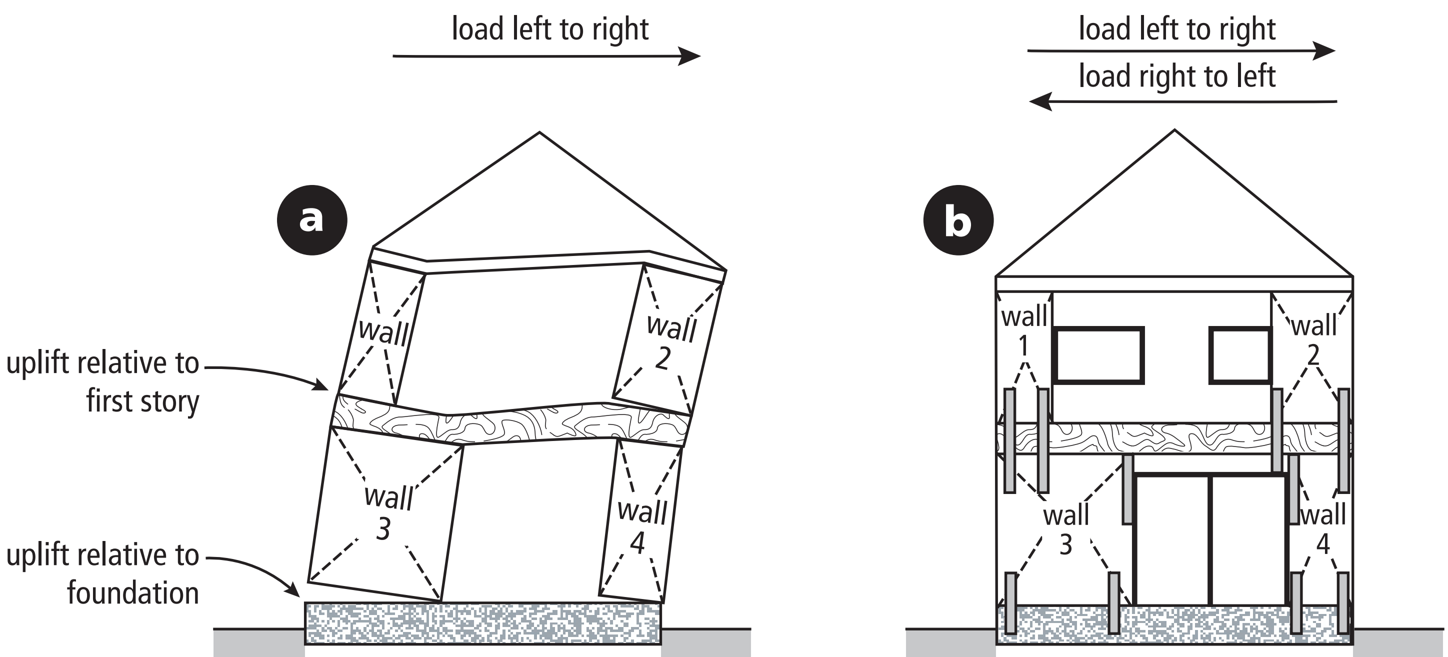


Figure 4

If a structure lacks adequate stiffness or strength, horizontal movement can cause instability (a). Adding hold-down straps helps connect walls on each story and helps resist overturning (b).

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

Regularity

A structure is "regular" if its parts are balanced in terms of mass, strength, and stiffness. A regular structure will respond to shaking in a uniform manner and dissipate energy evenly. An ideal earthquake-resistant structure has:

- A simple, rectangular shape
- Uniform and symmetric walls
- Even weight distribution
- Lower levels with longer bracing walls and upper levels with shorter bracing walls (See Figure 5.)

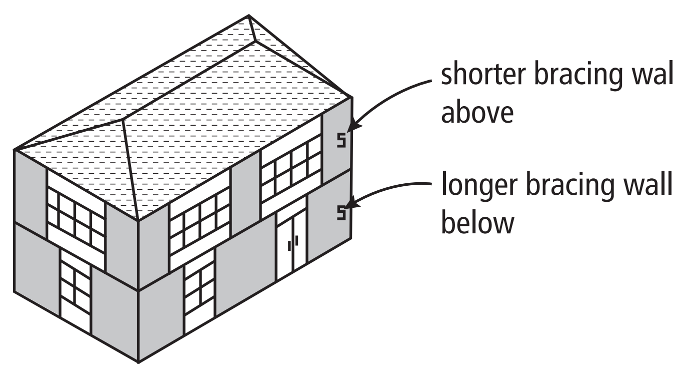


Figure 5

Placing bracing walls adjacent to each other reduces the need to transfer energy through roof and floor systems.

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

© Smithsonian Institution

Redundancy

Redundancy is when something is repeated over and over again. In earthquake-resistant structures, critical design elements may be repeated in multiple areas. If an earthquake seriously damages a critical element, others may be strong enough to support the structure. (See Figure 6.)

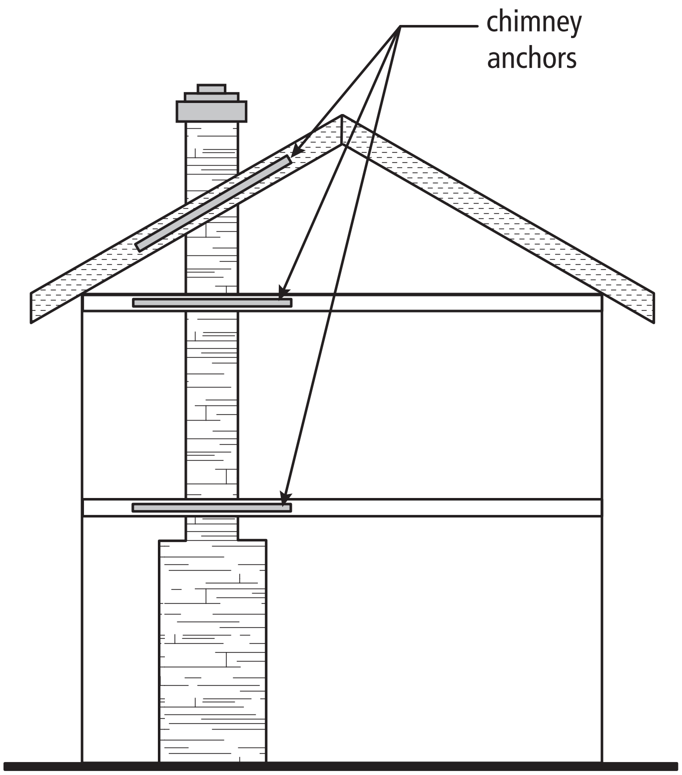


Figure 6

Steel straps are used to anchor a chimney at multiple locations. If one anchor point fails during an earthquake, others may remain intact and hold the chimney in place.

CREDIT: Adapted from Building Seismic Safety Council. *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. June 2006. (FEMA 232)

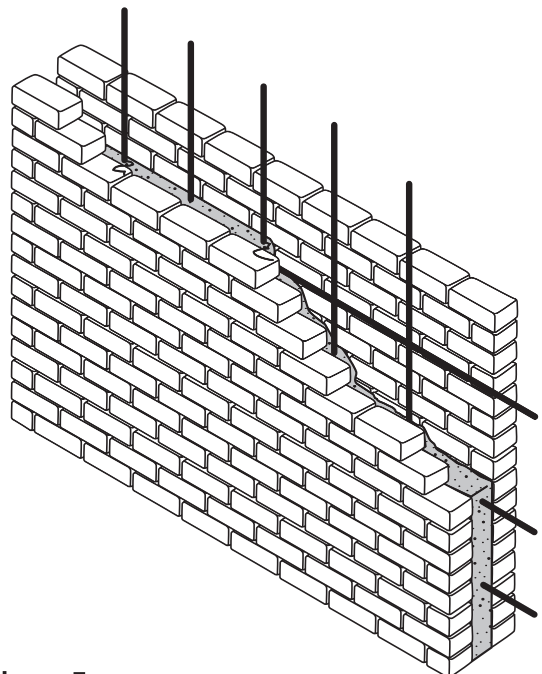


Figure 7

Brick walls can contain steel reinforcing bars. The addition of steel improves both ductility and toughness. Unreinforced brick walls are brittle. During a strong earthquake, unreinforced brick is subject to cracking and collapse.

CREDIT: Adapted from Applied Technology Council. *Unreinforced Masonry Buildings and Earthquakes: Developing Successful Risk Reduction Programs*. October 2009. (FEMA P-774).

Ductility and Toughness

Ductility describes the ability of something to deform without fracturing. Both ductility and toughness allow structures to sustain damage without collapse. Construction materials like wood, bricks, concrete, or steel all have unique properties. An earthquake-resistant design combines these materials in a way that carefully uses one material to protect others from damage. (See Figure 7.)

Ruggedness

Ruggedness describes the ability of a nonstructural building component to remain functional after strong shaking associated with an earthquake. Nonstructural components include architectural features (e.g., ceilings, stairs); mechanical devices (e.g., emergency generators, elevators); electrical components (e.g., transformers, lighting); plumbing (e.g., pipes, fixtures); and fire-suppression systems. The ruggedness of nonstructural components can be tested using real earthquakes or by simulating an earthquake using a shake table.

© Smithsonian Institution

Lesson Master 3.2a: Testing Direction

Procedure

1. Pull the paper strip very slowly through the paper frame. Do not shake the table at all. Is the pen marking the paper? If not, readjust your pen. If it did mark the paper, label your paper strip "Control—No Vibrations." Do not tear off the paper yet.

2. As one person slowly pulls the paper through the frame, have a second person do the following:

   a. Pound on the front of the table parallel to the seismograph's arm. Write "Parallel" on the paper. (See Figure 1.)

   b. Pound on the side of the table perpendicular to the seismograph's arm. Write "Perpendicular" on the paper. (See Figure 2.)

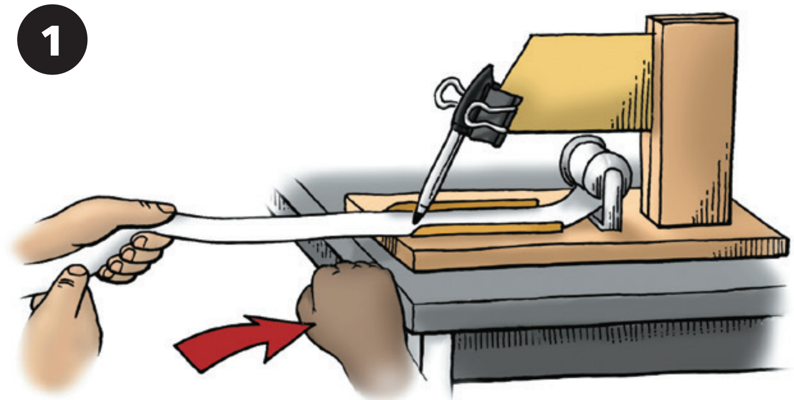
   c. Pound on the surface of the table. Write "Surface" on the paper. (See Figure 3.)

3. Tear the paper strip off the seismograph.

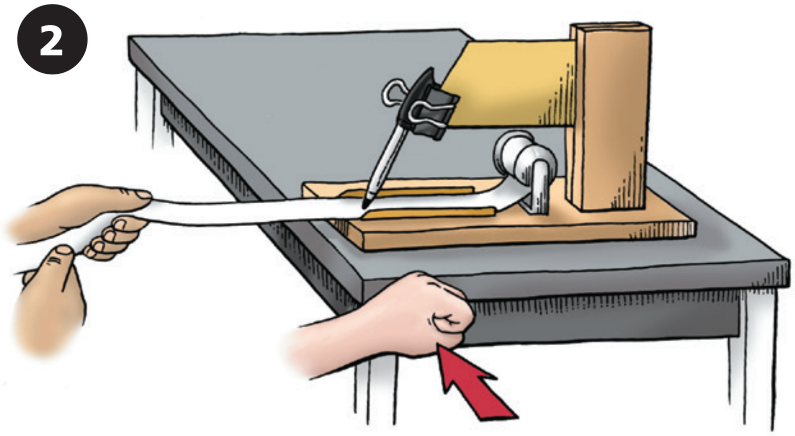
4. Use the paper strip as evidence to support your conclusions as you answer this question: What happened when you changed the direction of your pounding?

5. Roll up the strip and secure it with a paper clip. Write your variable and your group's number on the roll.

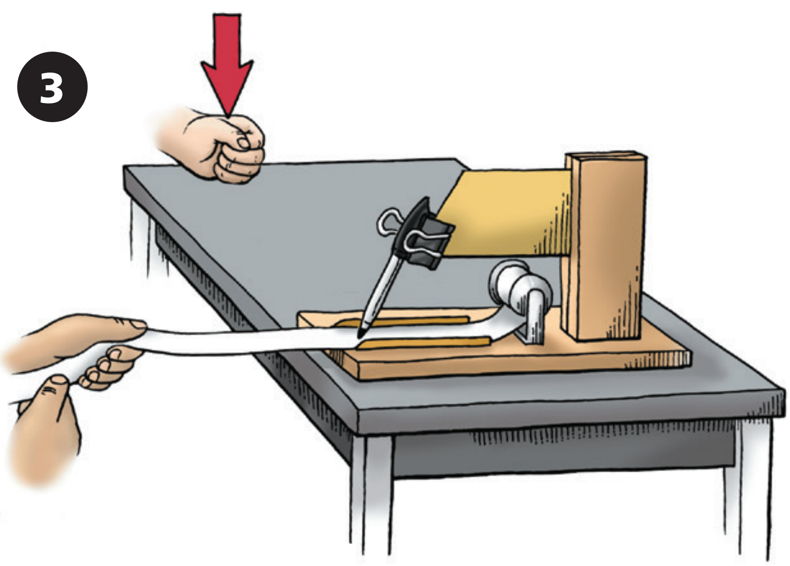
1



2



3

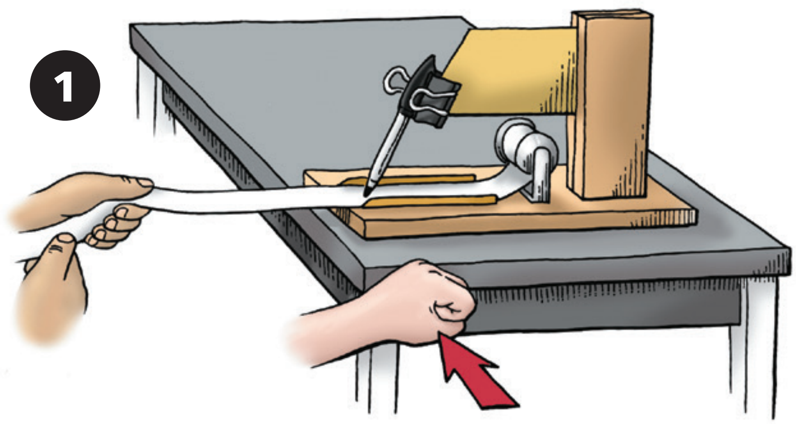


© Smithsonian Institution

Lesson Master 3.2b: Testing Distance

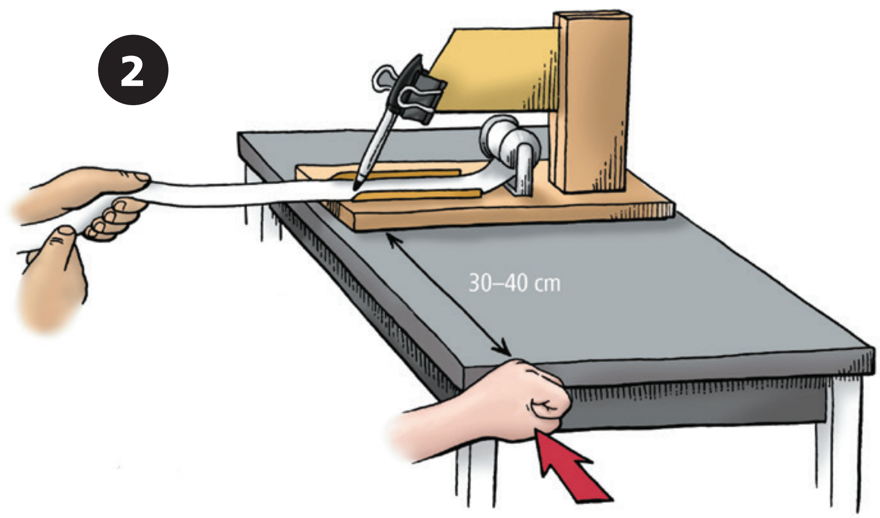
Procedure

1. Pull the paper strip very slowly through the paper frame. Do not shake the table at all. Is the pen marking the paper? If not, readjust your pen. If it did mark the paper, label your paper strip "Control—No Vibrations." Do not tear off the paper yet.



2. Test the variable of distance. With each test, change the distance of your seismograph is from the pounding, but keep the direction of your pounding constant. For example, do the following:
   - **a.** Pound close to the seismograph. Pound the side of the table that is perpendicular to the seismograph's arm (see Figure 1), while your partner pulls the paper through the frame. Measure the distance. Label the paper—for example, "Close to the seismograph—10 cm."
   - **b.** Move the seismograph far from your hand, approximately 30 to 40 cm. (See Figure 2.) Measure the distance. Remember to pound in the same way and from the same direction as you did when you pounded close to the model. Label the marks on your paper.

   Note: If you are using a copier box or plastic box, your distances may be less than 30 cm.



3. Tear the paper strip off the seismograph.
4. Use the paper strip as evidence to support your conclusions as you answer this question: What happened when you changed the distance of pounding from the seismograph?
5. Roll up the strip and secure it with a paper clip. Write your variable and your group's number on the roll.

© Smithsonian Institution

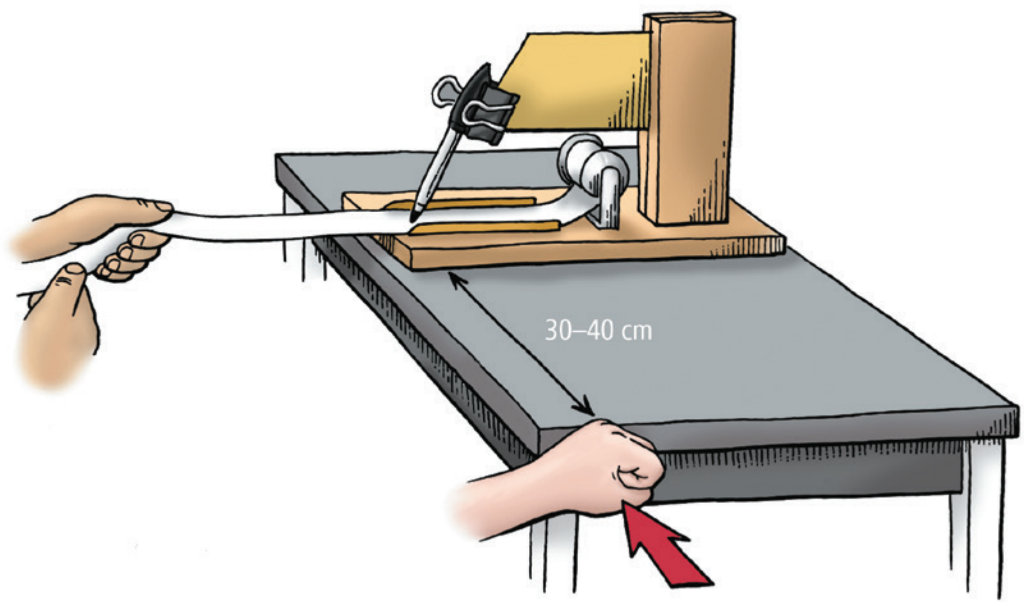
Lesson Master 3.2c: Testing Force

Procedure

1. Pull the paper strip very slowly through the paper frame. Do not shake the table at all. Is the pen marking the paper? If not, readjust your pen. If it did mark the paper, label your paper strip "Control—No Force." Do not tear off the paper yet.

2. Now, test the variable of force. Remember to keep the distance and the direction constant. Do the following:

   a. Very gently, pound the side of the table close to and perpendicular to the seismograph's arm. Pull the paper through as you pound gently. Mark your paper strip "Small Force."



   b. Pound much harder this time. Make sure you pound from the same direction so that you are only changing one variable at a time. Mark your paper strip "Large Force."

   c. If you have found a way to quantify the force of your pounding, record this data.

3. Tear the paper strip off the seismograph.

4. Use the paper strip as evidence to support your conclusions as you answer this question: What happened when you changed the force of the pounding? (If you quantified your pounding, answer this question: What is the relationship between the amount of force of the pounding and the strength of the "earthquake"?)

5. Roll up the strip and secure it with a paper clip. Write your variable and your group's number on the roll.

© Smithsonian Institution

Lesson Master 3.3: Horizontal and Vertical Seismographs (page 1 of 2)

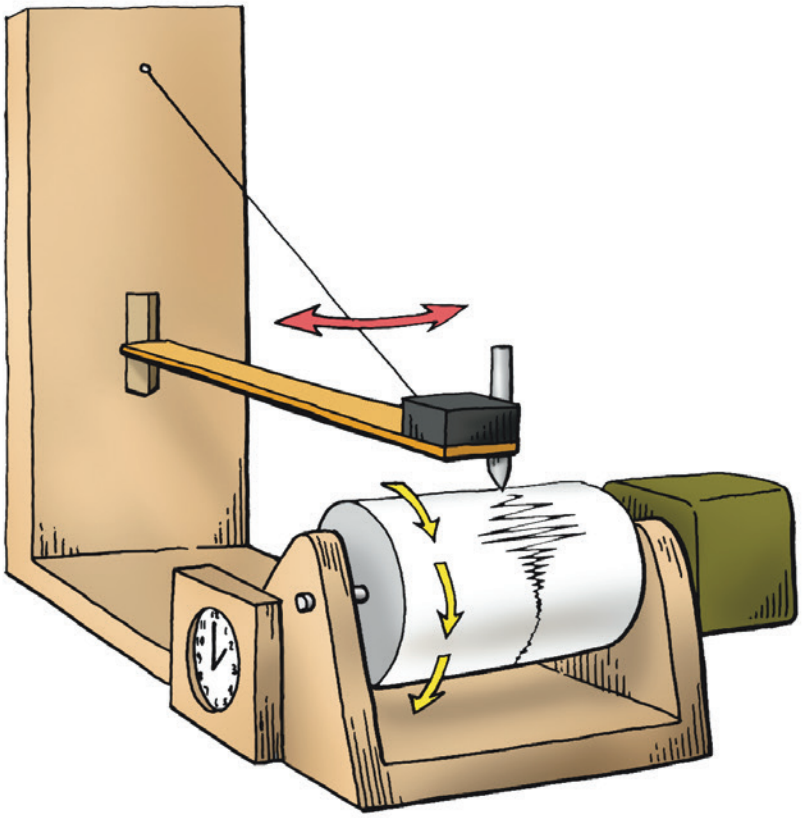


Figure 1
Horizontal seismograph

© Smithsonian Institution

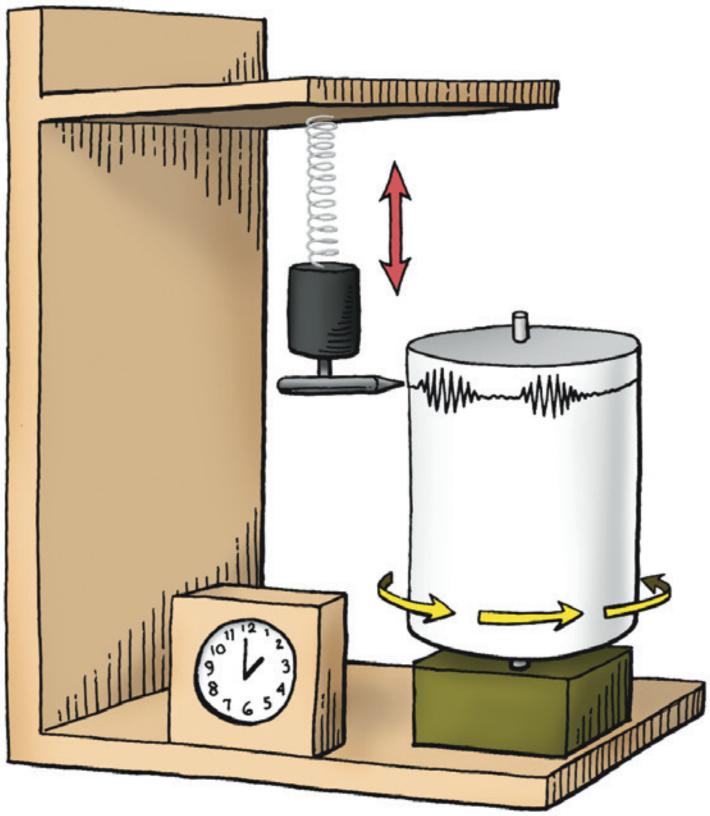
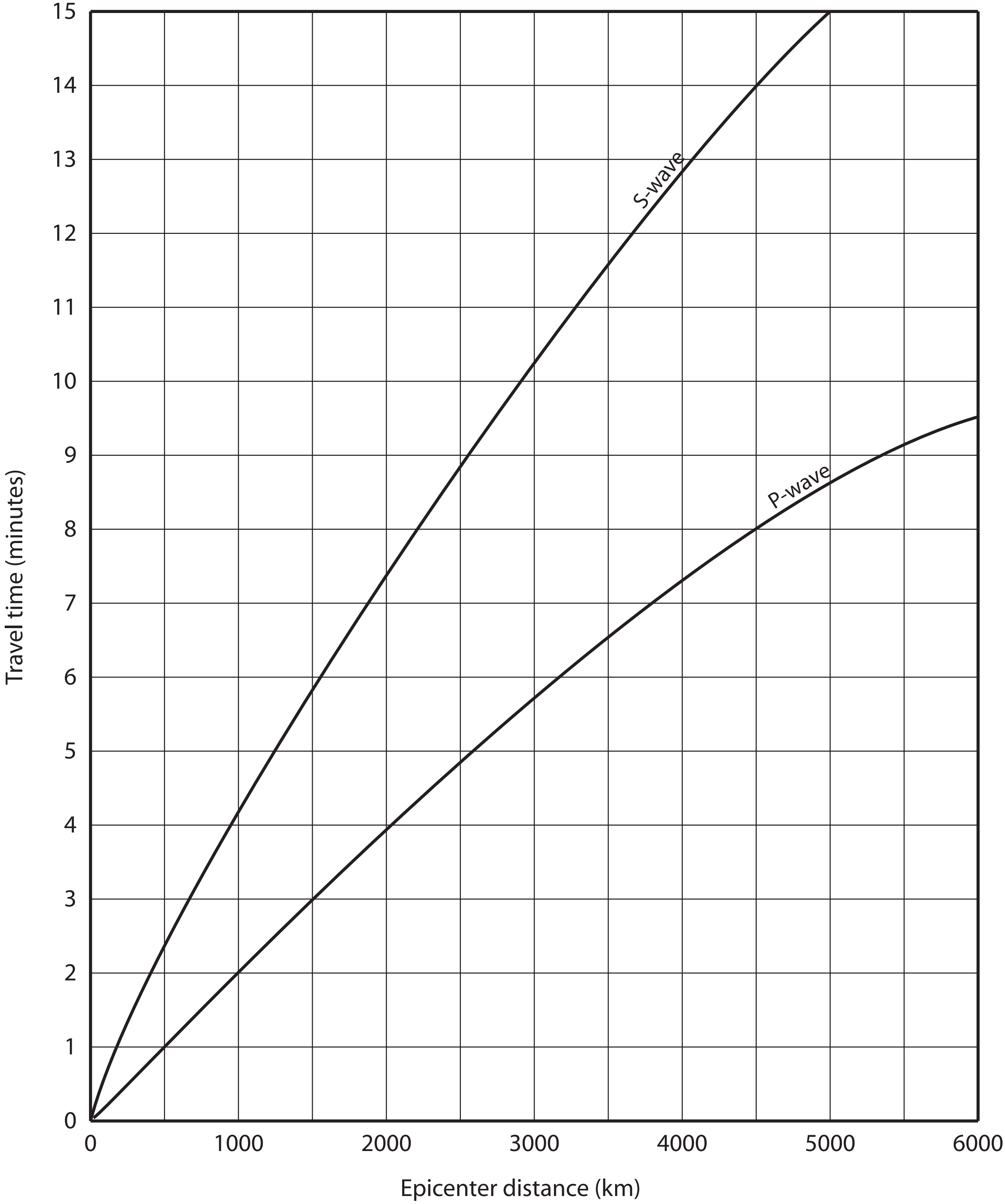


Figure 2
Vertical seismograph

© Smithsonian Institution

Lesson Master 3.4: Time–Distance Graph

Directions: During your investigation, you will use the graph below to analyze data about P- and S-waves to determine the distance between a seismograph station and the epicenter of an earthquake.



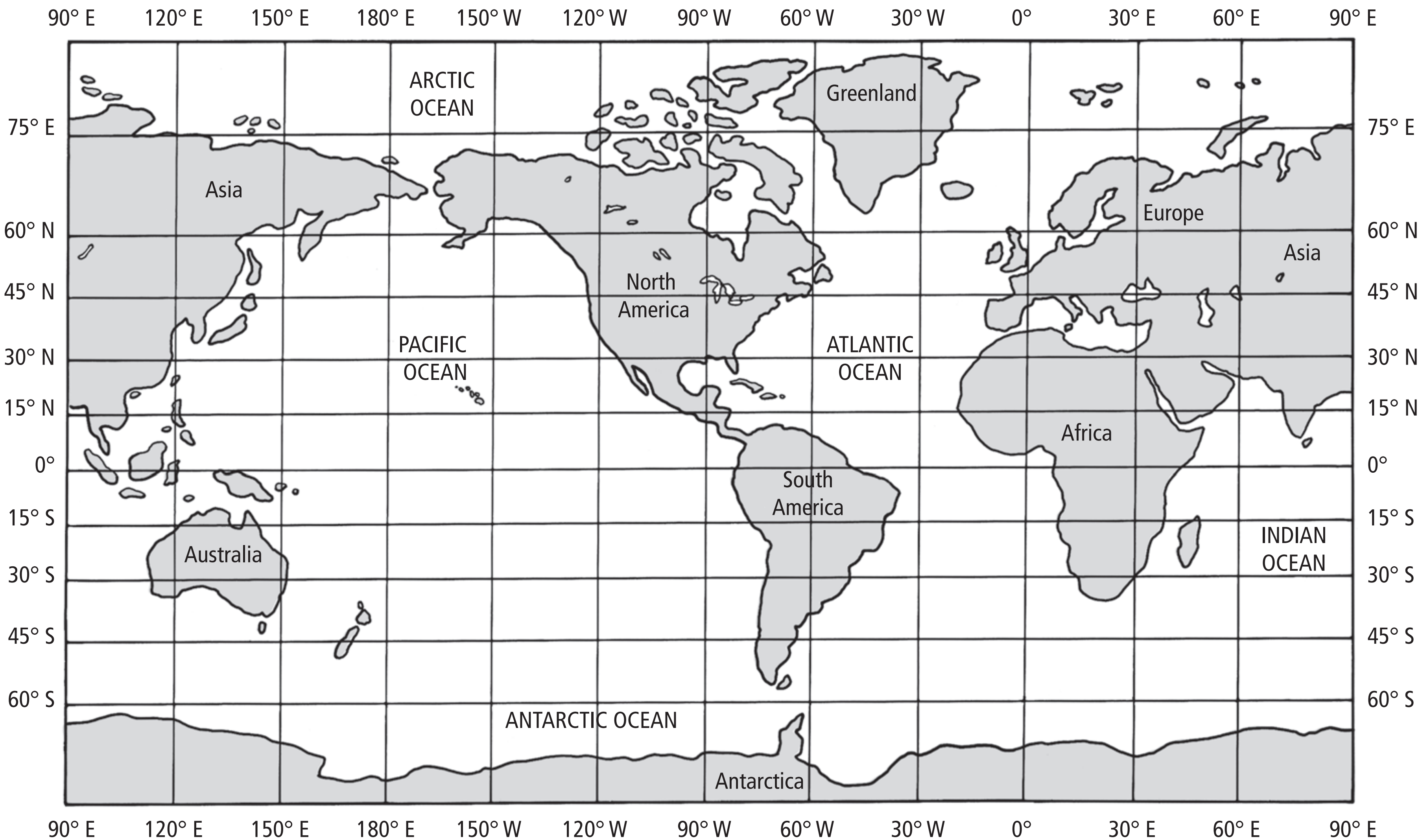
© Smithsonian Institution

Lesson Master 4.1a: Seismic Activity

Earthquake Number	Date	Latitude	Longitude	Depth (km)	Magnitude (mb)	Location
1	9/26/16	28 N	129 E	40	6.0	Between Taiwan and Japan
2	9/23/16	7 N	127 E	65	6.3	Off coast of Philippines
3	9/12/16	36 N	129 E	13	5.4	South Korea
4	9/3/16	40 N	126 W	29	5.6	California
5	8/24/16	43 N	13 E	3.3	5.6	Italy
6	8/28/16	0 N	18 W	10	7.1	North of Ascension Island
7	7/25/16	3 S	148 E	14	6.4	New Guinea
8	7/11/16	1 N	80 W	21	6.3	Ecuador
9	6/10/16	13 N	87 W	10	6.1	Nicaragua
10	5/31/16	26 N	123 E	246	6.4	Taiwan
11	4/29/16	10 N	104 W	10	6.6	East Pacific Rise
12	4/14/16	33 N	131 E	9	6.2	Japan
13	4/3/16	14 S	167 E	26	6.9	Vanuatu
14	6/21/16	22 N	45 W	10	6.1	Northern Mid-Atlantic Ridge
15	2/14/16	43 S	173 E	8	5.8	New Zealand
16	1/30/16	54 N	158 E	177	7.2	Russia
17	1/24/16	60 N	153 W	129	7.1	Alaska
18	1/21/16	19 N	107 W	10	6.6	Off west coast of Mexico
19	1/3/16	25 N	94 E	55	6.7	India
20	1/1/16	51 S	139 E	10	6.3	Off south coast of Australia
21	9/18/15	15 N	46 W	10	6.0	Northern Mid-Atlantic Ridge
22	12/17/15	16 N	84 W	85	6.6	Mexico
23	11/27/15	25 S	71 W	34	6.2	Chile
24	11/18/15	9 S	158 E	13	6.8	Solomon Islands
25	11/11/15	30 S	72 W	12	6.9	Chile
26	10/26/15	37 N	70 E	231	7.5	Afghanistan
27	10/19/15	14 N	121 E	106	5.8	Philippines
28	9/21/15	35 S	17 W	10	7.0	Southern Mid-Atlantic Ridge
29	9/16/15	32 S	72 W	23	8.3	Chile
30	9/7/15	33 S	178 W	17	6.3	New Zealand
31	7/27/15	3 S	139 E	48	7.0	Indonesia
32	7/18/15	10 S	165 E	11	7.0	Solomon Islands
33	7/3/15	38 N	78 E	20	6.4	China
34	6/20/15	36 S	74 W	11	6.4	Chile
35	4/25/15	28 N	85 E	8	7.8	Nepal
36	3/29/15	5 S	153 E	41	7.5	New Guinea
37	5/24/15	17 S	14 W	10	6.3	Southern Mid-Atlantic Ridge
38	2/16/15	40 N	143 E	23	6.7	Japan
39	2/2/15	33 S	67 W	172	6.3	Argentina
40	1/7/15	6 N	83 W	8	6.5	Off south coast of Panama

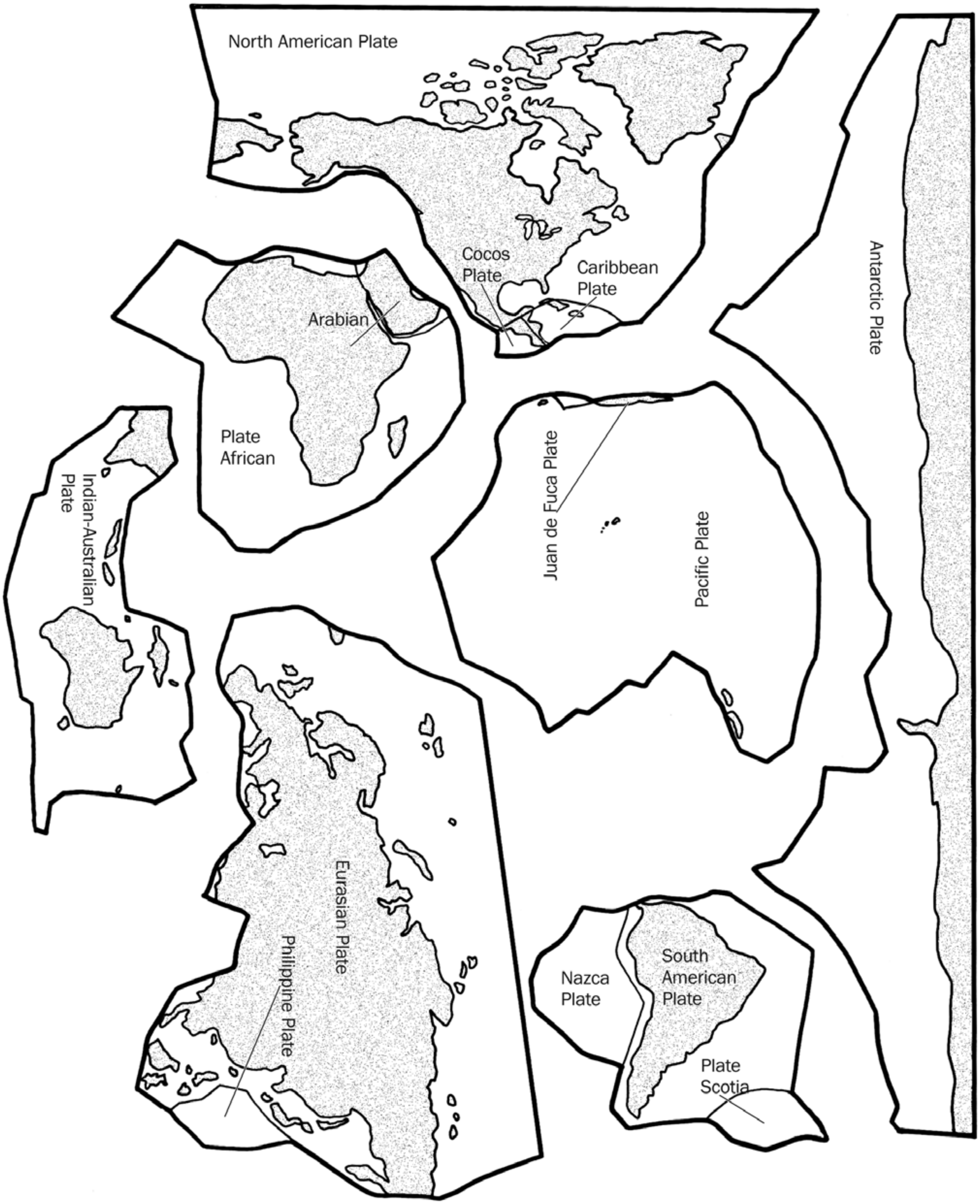
© Smithsonian Institution

Lesson Master 4.1b: World Map



Lesson Master 4.H: Making a Plate Model

Directions: Use scissors to cut out the lithospheric plates on this page. Then use the plate boundaries to put the plates back together like a puzzle.



© Smithsonian Institution

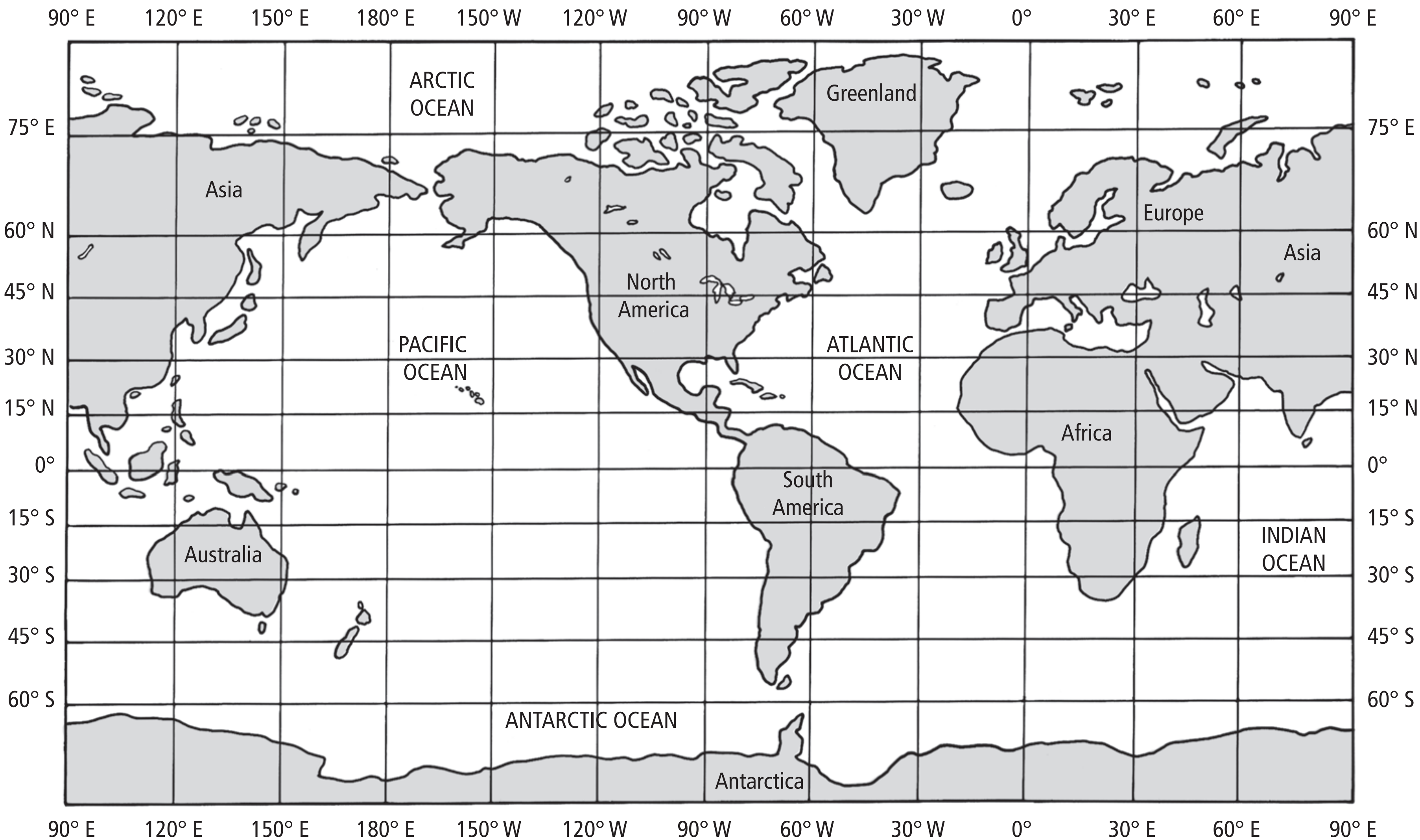
Lesson Master 5.R: Rock Information

Directions: Use information in the table to classify rock samples by type (sedimentary, metamorphic, or igneous).

Card	Sample	Mineral Composition	Formation
A	Basalt	Plagioclase Pyroxene Olivine Amphibole	Forms when lava from volcanic eruptions cools quickly and hardens
B	Calcareous tufa	Calcite Silica	Forms when solids containing calcium carbonate are removed from springs or groundwater
C	Conglomerate	Quartz Feldspar Rock fragments	Forms from small pieces of other rocks that become pressed together at the bottom of a lake or an ocean
D	Gneiss	Quartz Feldspar Hornblende Mica	Forms when shale and granite are heated and pressed together
E	Granite	Quartz Feldspar Mica	Forms when molten rock cools slowly in Earth's crust
F	Limestone	Calcite Dolomite	Forms from accumulation of plant and animal remains at the bottom of the ocean
G	Marble	Calcite Dolomite	Forms when limestone (or other carbonate rock) is put under pressure or heated
H	Obsidian	Quartz Feldspar Mica	Forms when lava erupts from a volcano and cools very quickly
I	Pumice	Feldspar Quartz Mica	Forms when lava erupts from a volcano and gases bubble out as the rock cools
J	Quartzite	Quartz	Forms when sandstone is put under pressure or heated
K	Rhyolite	Feldspar Quartz Mica	Forms when molten rock cools quickly in Earth's crust
L	Sandstone	Quartz Calcite Hematite	Forms when sand is compacted and cemented together
M	Schist	Mica Chlorite Quartz Talc Hornblende	Forms when shale or limestone is put under pressure or heated
N	Scoria	Feldspar Augite Hornblende	Forms as a crust on lava or is ejected from volcanoes
O	Shale	Clays Mica Chlorite	Forms when clay, silt, or mud is compacted and cemented together
P	Slate	Clays Mica Chlorite	Forms when shale is put under pressure or heated

© Smithsonian Institution

Lesson Master 6.1a: Plotting Volcanic and Seismic Activity



Lesson Master 6.1b: Volcanic Activity

Volcano Number	Latitude	Longitude
1	41° N	122° W
2	41° N	14° W
3	13° N	124° E
4	25° S	69° W
5	0° S	78° W
6	16° S	72° W
7	57° N	158° W
8	38° N	15° E
9	6° S	130° E
10	35° N	138° E
11	63° N	19° W
12	46° N	122° W
13	38° N	131° E
14	37° N	138° W
15	0°	126° E
16	71° N	8° W
17	2° S	121° E
18	33° N	127° E
19	1° N	125° E
20	8° S	118° E

© Smithsonian Institution

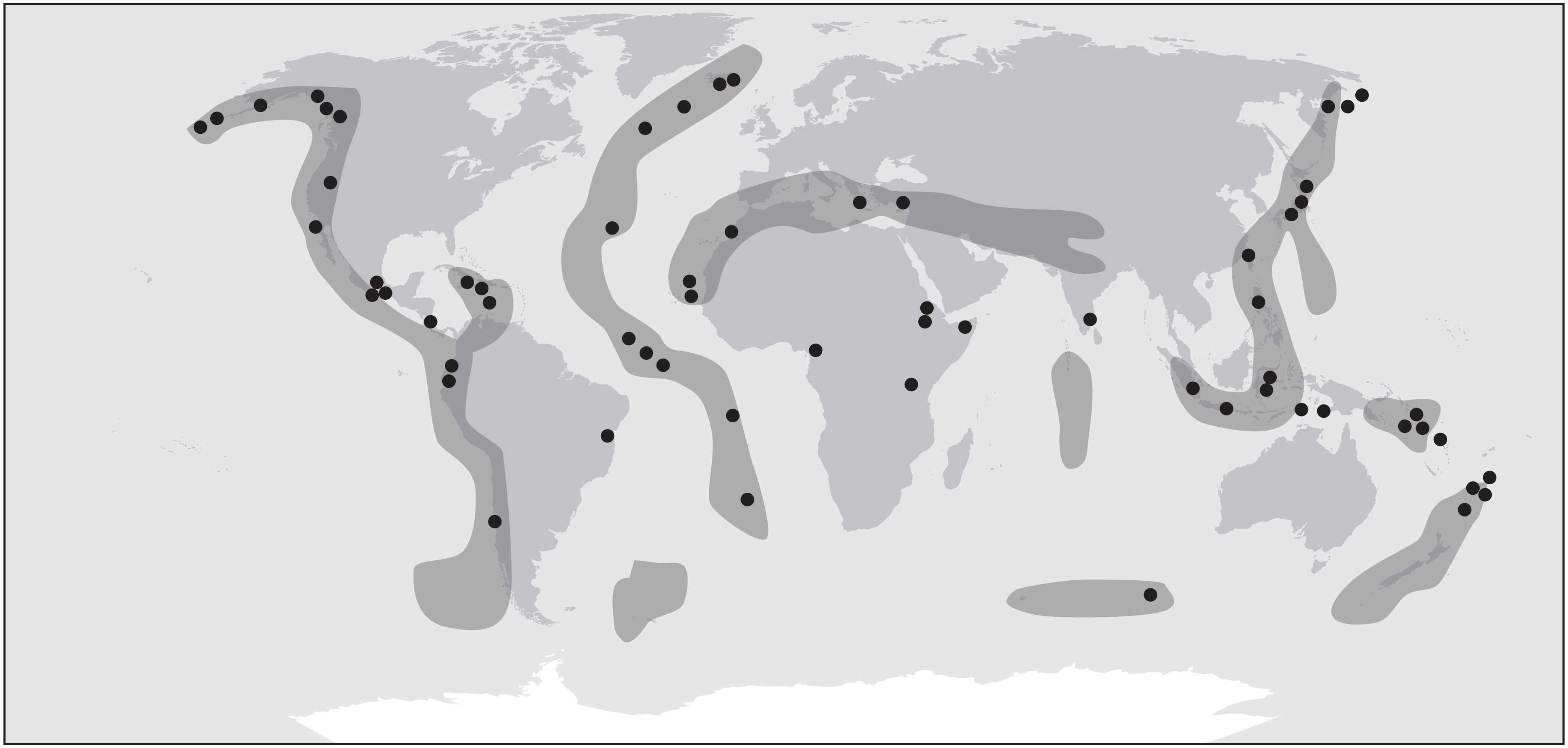
Lesson Master 6.1c: Seismic Activity

Earthquake Number	Latitude	Longitude
1	28° N	129° E
2	7° N	127° E
3	36° N	129° E
4	40° N	126° W
5	43° N	13° E
6	1° N	80° W
7	26° N	120° E
8	33° N	133° E
9	6.3° S	130° E
10	19° N	107° W
11	25° S	21° W
12	64° N	21° W
13	14° N	121° E
14	32° S	72° W
15	3° S	139° E
16	36° S	74° W
17	40° N	143° E
18	5° N	83° W
19	61° N	148° W
20	43° N	13° W

© Smithsonian Institution

Lesson Master 10.1a: Map of Geodynamic Regions

Directions: Tape your transparency on top of this sheet and plot the locations of copper deposits. The shaded portions represent the location of earthquakes, while the black dots represent volcanoes.



Lesson Master 10.1b: Copper Deposit Data

Directions: The points on this map represent locations of copper deposits on Earth. Use this data to mark your transparency. Then, compare the locations of the copper deposits to areas of seismic and volcanic activity.

Lesson Master 12.PAa: Geodynamic Event Preparedness Scoring Rubric (page 1 of 3)

Part A. Conducting the Research				
Criterion	**1. Beginning**	**2. Developing**	**3. Proficient**	**4. Exemplary**
Number of Sources	Student found fewer than three sources of information about events in their assigned region.	Student found three resources of information about events in their assigned region.	Student found four sources of information about events in their assigned region.	Student found more than four sources of information about events in their assigned region.
Quality of Sources	None of student's resources were from reputable sources.	Few of student's resources were from reputable sources.	Most of student's resources were from reputable sources.	All of student's resources were from reputable sources.
Location	The group did not describe patterns in the locations of geodynamic events relative to geographic or geologic features.	The group partially described patterns in the locations of geodynamic events relative to geographic or geologic features.	The group described patterns in the locations of geodynamic events relative to geographic or geologic features.	The group thoroughly described patterns in the locations of geodynamic events relative to geographic or geologic features.
Frequency	The group did not describe the frequency of geodynamic events.	The group partially described the frequency of geodynamic events.	The group described the frequency of geodynamic events.	The group thoroughly described the frequency of geodynamic events.
Types of Damage and Environmental Effects	The group did not describe the types of damage and environmental effects caused by geodynamic events.	The group described the types of damage **or** environmental effects caused by geodynamic events, but not both.	The group described both the types of damage and environmental effects caused by geodynamic events.	The group thoroughly described both the types of damage and environmental effects caused by geodynamic events.
Phenomena	The group did not describe phenomena observed before or after geodynamic events.	The group partially described phenomena observed before or after geodynamic events.	The group described phenomena observed before or after geodynamic events.	The group thoroughly described phenomena observed before or after geodynamic events.
Events	The group did not record data about significant events.	The group recorded data about one significant event.	The group recorded data about two significant events.	The group recorded detailed data about two significant events.

© Smithsonian Institution

Lesson Master 12.PAa: Geodynamic Event Preparedness Scoring Rubric (page 2 of 3)

Part B. Proposals for Geodynamic Event Preparedness				
Criterion	**1. Beginning**	**2. Developing**	**3. Proficient**	**4. Exemplary**
Event Forecast	The group did not forecast a likely geodynamic event within their region.	The group forecast a likely geodynamic event in their region but did not describe its location **or** probability.	The group forecast a likely geodynamic event in their region and described its location **or** probability.	The group forecast a likely geodynamic event in their region and described its location **and** probability.
Event Description	The group did not describe the severity, damage, or phenomena associated with the forecasted event.	The group described one of the following associated with the forecasted event: severity, damage, or phenomena.	The group described two of the following associated with the forecasted event: severity, damage, or phenomena.	The group described the severity, damage, and phenomena associated with the forecasted event.
Individual Proposal	Individual student did not prepare a proposal for geodynamic event preparedness.	Individual student prepared a proposal for geodynamic event preparedness, but did not support their argument with evidence.	Individual student prepared a proposal for geodynamic event preparedness and supported their argument with evidence from their research **or** investigations.	Individual student prepared a proposal for geodynamic event preparedness and supported their argument with evidence from their research **and** investigations.
Group Proposal	The group did not provide a proposal for geodynamic event preparedness.	The group provided a proposal for geodynamic event preparedness, but did not explain how it will mitigate the effects of future geodynamic effects.	The group provided a proposal for geodynamic event preparedness and explained how it will mitigate the effects of future geodynamic effects.	The group provided a proposal for geodynamic event preparedness and explained how it will mitigate the effects of future geodynamic effects **in their assigned region**.

© Smithsonian Institution

Lesson Master 12.PAa: Geodynamic Event Preparedness Scoring Rubric (page 3 of 3)

Part C. Presenting Research and Proposals to the Class				
Criterion	**1. Beginning**	**2. Developing**	**3. Proficient**	**4. Exemplary**
Visual Aid Design	Visual aid was designed so that the necessary information cannot be obtained and understood without a presentation.	Visual aid was designed so that some of the necessary information can be obtained and understood without a presentation.	Visual aid was designed so that most of the necessary information can be obtained and understood without a presentation.	Visual aid was designed so that the necessary information can be obtained and fully understood without a presentation.
Visual Aid Layout	Layout was not relevant for the presentation of information.	Layout was relevant for the presentation of information.	Layout was relevant and partially effective for the presentation of information.	Layout was relevant and effective for the presentation of information.
Visual Aid Images	Images were not present or were not relevant and not captioned appropriately.	Images were not relevant but were captioned appropriately.	Images were relevant but were not captioned appropriately.	Images were relevant and captioned appropriately.
Presentation	Presentation was not informative.	Presentation was disorganized but informative.	Presentation was fairly organized and informative.	Presentation was well organized and informative.
Citations	Student cited no sources appropriately.	Student cited few sources appropriately.	Student cited most sources appropriately.	Student cited all sources appropriately.

© Smithsonian Institution

Lesson Master 12.PAb: Geographic Region Assignments

Directions: Cut along the dotted lines to create region assignment slips. If you choose, remove the region where your school is located. Fold each slip in half and place them all in a plastic tray from the kit (or similar container) for students to obtain their geographic region assignment at random.

Alaska

Pacific Northwest

(States: Oregon, Washington)

Northern California

(North of 35° 47′ 28″ N)

Southern California

(South of 35° 47′ 28″ N)

Hawaiian Islands

Rocky Mountain Basin and Range

(States: Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming)

Great Plains

(States: Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Texas, Wisconsin)

Central

(States: Alabama, Arkansas, Illinois, Indiana, Kentucky, Louisiana, Mississippi, Missouri, Tennessee)

Northeast

(States: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont)

Southeast

(States: Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia)

© Smithsonian Institution