Chapter 1
Alaska Plate Tectonics

Resources

- U.S. Geological Survey
  - Fuis, G.S., and Wald, L.A., 2003, Why do earthquakes occur in southern Alaska?: U.S. Geological Survey Fact Sheet 014-03, 4 p. (Also available at http://pubs.usgs.gov/fs/2003/fs014-03/alaska.html.)
  - Haeussler, P.J., and Plafker, G., 1995, Earthquakes in Alaska: U.S. Geological Survey Open-File Report, 95-624, 1 sheet. (Available at
    - PDF Poster http://geopubs.wr.usgs.gov/open-file/of95-624/of95-624L.pdf
    - PDF page-size http://geopubs.wr.usgs.gov/open-file/of95-624/of95-624.pdf
  - Kious, W.J., and Tilling, R.I., 1996, This dynamic Earth—The story of plate tectonics [online edition]: Reston, Va., U.S. Geological Survey website. (Available at http://pubs.usgs.gov/gip/dynamic/dynamic.html and
    - Some unanswered questions—What drives the plates?
    http://pubs.usgs.gov/gip/dynamic/unanswered.html#anchor19928310.)
  - Robertson, E.C., [n.d.], The interior of the Earth: Reston, Va., U.S. Geological Survey Generail Information Product. (Available at http://pubs.usgs.gov/gip/interior/.)
  - Shedlock, K.M., and Pakiser, L.C., 1994, Earthquakes: Reston, Va., U.S. Geological Survey General Information Product. (Available at http://pubs.usgs.gov/gip/earthq1/.)
  - Simkin, T., and others, 2006, This dynamic planet—World map of volcanoes, earthquakes, impact craters, and plate tectonics (3rd ed.): U.S. Geological Survey Geologic Investigations Map I-2800. (Available at http://www.minerals.si.edu/tdpmap/ and
    - Printable 8.5 x 11-inch pages http://www.minerals.si.edu/tdpmap/printable.htm.)
  - Winkler, G.R, 2000, A geologic guide to Wrangell-Saint Elias National Park and Preserve, Alaska—A tectonic collage of northbound terranes: U.S. Geological Survey Professional Paper 1616, p. 69–76. (Also available at
    - Website Introductory Page http://pubs.usgs.gov/pp/p1616/ and
    - PDF http://pubs.usgs.gov/pp/p1616/P1616.pdf [129 MB].)
  - U.S. Geological Survey, Earthquake Hazards Program
    - Wald, D., and Dewey, J.W., 2005, Did you feel it? —Citizens contribute to earthquake science: U.S. Geological Survey Fact Sheet 2005-3016, 4 p. (Also available at http://pubs.usgs.gov/fs/2005/3016/ and http://pubs.usgs.gov/fs/2005/3016/pdf/FS-2005-3016.pdf.)
    - Wald, D., Wald L., Dewey, J., Quitoriano, V., and Adams, E., 2001, Did you feel it?—Community-made earthquake shaking maps: U.S. Geological Survey Fact Sheet 030-01, 2 p. (Also available at http://pubs.usgs.gov/fs/fs030-01/ and http://pubs.usgs.gov/fs030-01/fs030-01.pdf.)

    - Wald, D., Wald, L., Woden, B., and Goltz, J., 2003, ShakeMap—A tool for earthquake response: U.S. Geological Survey Fact Sheet 87-03, 4 p. (Also available at http://pubs.usgs.gov/fs/fs-087-03/FS-087-03-508.pdf.)
    - U.S. Geological Survey, 2009, Earthquake Hazards program—Alaska Earthquake Information: U.S. Geological Survey website. (Available at http://earthquake.usgs.gov/earthquakes/states/index.php?regionID=3.)
- Alaska Earthquake Information Center (AEIC), 2010, Maps: Alaska Earthquake Information center website, accessed May 27, 2010, at
    - AEIC Maps http://www.aeic.alaska.edu/html_docs/maps.html and
    - AEIC Frequently Asked Questions http://www.aeic.alaska.edu/html_docs/faq.html.
- Lillie, R.J., 2005, Parks and plates—The geology of our National parks, monuments, and seashores: New York, W.W. Norton and Comdishy, 298 p.
    - Chapter 1: Plate tectonics, p. 5-21.
    - Chapter 5: Subduction zones, southern Alaska subduction zone, p. 119-120.
    - Chapter 11: Accreted terranes, Alaska—A glimpse of continental growth in action, p. 241-245.
- Nye, C.J., McGimsey, R.G., and Power, J., 1998, Volcanoes of Alaska: Alaska Division of Geological & Geophysical Surveys Information Circular 38, 1 sheet [2 sides], accessed May 27, 2010, at
    - Front http://www.dggs.dnr.state.ak.us/webpubs/dggs/ic/oversized/ic038ed1998_sh001.PDF and
    - Back http://www.dggs.dnr.state.ak.us/webpubs/dggs/ic/oversized/ic038ed1998_sh002.PDF

Activities

These activities include material associated with the concept of plate tectonics on a global scale and related plate boundaries using the depth and location of associated earthquakes. Through progression within the activities and from one activity to the next, these concepts will be locally applied to the types of plate boundaries and associated earthquakes and volcanic processes in Alaska. The materials included in these activities will serve as base upon which the associated concepts of subduction and volcanism will be built upon in subsequent chapters.

Activity I. Plate Tectonics Mapping
Activity II. Earthquake Mapping

Activity I. Plate Tectonics Mapping

An activity or discussion illustrating the layers of the Earth and the process of mantle convection would serve as an appropriate introduction prior to this activity. In addition to the resources listed above, an excellent exercise for convection can be found in B.A. Ford's Project Earth Science—Geology published by NSTA Press in 1996 (activity 6, p. 71-79).

Grade Level 6–11

Setting Classroom

Time 45–90 minutes

Vocabulary (see Glossary)
convergence, divergence, hot spot, subduction zone, tectonic plate, trench, velocity

Correlations to Alaska State Department of Education (2006) Performance Standards (Grade Level Expectations)
D1—Concepts of Earth Science

SD[6-11]	Students develop an understanding of the concepts, processes, theories, models, evidence, and systems of Earth and space science.
SD2[6-11]	Students develop an understanding of the origins, ongoing processes, and forces that shape the structure, composition, and physical history of the Earth.
SD2.2[7]	The student demonstrates an understanding of the forces that shape Earth by describing how the movement of the tectonic plates results in both slow changes (e.g., formation of mountains, ocean floors, and basins) and short-term events (e.g., volcanic eruptions, seismic waves, and earthquakes) on the surface.
SD2.2[9-11]	Students demonstrates an understanding of the forces that shape Earth by describing how the theory of Plate tectonics explains the dynamic nature of its surface

Overview
Plate boundaries have an overall effect on determining the landscape and dominant features local to a region, including volcanoes. In this activity, students will relate the physical features of Alaska's landscape with their associated tectonic plate boundaries, namely convergent zones.

Background
Alaska is home to an arc of volcanoes, which serves as one surface manifestation of the subduction zone formed by the convergence of the North American and Pacific Plates. Alaska's varying geologic features, such as faults, folds, and mountains are also associated with ongoing dynamic processes at depth associated with convergence.

Objectives
The students will be able to identify and define convergent, divergent, and transform tectonic plate boundaries. The students will be able to describe how the velocity and direction of movement of different plates affects the type of boundary present and will be able to cite examples of this relationship to various landscape features in Alaska.

Materials
- the map, *This Dynamic Planet* by T. Simkin and others, 2006—you can enlarge the version provided, or use a poster version of your own.
- scissors
- black felt, thick-tip pens or markers
- *Plate Tectonics Q & A* worksheet

Procedure
A. Teacher preparations before class
1. Study or prepare the map pieces on the page size map provided (*Dynamic Planet Map Pieces)* first before cutting the poster size map to use for the activity in the classroom. It is recommended to have an additional poster size version of the map available in the classroom for students to view and reference during, or only after, they do the activity. Two maps displayed in the classroom are preferred, because there is relevant material on both sides. Another option is to enlarge and use the *Dynamic Planet Map Pieces* on the page provided for the class to view after the activity is completed.

2. Use the poster size map, *This Dynamic Planet*. With scissors, trim off the white edges (leaving latitude and longitude degrees) and the legend below the map. Save the legend. Cut strips off the left and right sides of the map at 100°E longitude (some areas of the world are duplicated on both sides of the map).

3. Cut the poster size map into pieces along the plate boundaries. Make a smooth cut approximately on the plate boundary. You may use a simpler plate map to help you decide where the plates begin and end. Remember use the *Dynamic Planet Map Pieces* provided for guidance.

After cutting, you should have the following 17 pieces:

- __ 1. African Plate (includes Nubia and Somalia Plates)
- __ 2. - 3. Antarctic Plate (2 sections)
- __ 4. Arabian Plate
- __ 5. - 6. Australia Plate (2 sections)
- __ 7. Caribbean Plate
- __ 8. Cocos Plate
- __ 9. - 10. Eurasia Plate (2 sections)
- __ 11. Indian Plate
- __ 12. Nazca Plate
- __ 13. North American Plate
- __ 14. Pacific Plate
- __ 15. Philippine Plate
- __ 16. Scotia Plate
- __ 17. South American Plate

4. Find the arrows on most of the plates and the white numbers on many of the mid-ocean ridges that indicate the directions and velocities of plate motion. Write the velocity of the plate motion next to the arrows using a black felt marker or pen so that the numbers are bigger and more visible. The length of the arrows indicate the relative rate of plate motion (short arrows = slower velocities, long arrows = faster velocities). The velocities are given in mm/yr. If you are more familiar with plate motions given in cm/yr, you can write the velocities in cm/yr by "moving the decimal point." For example, for the Arabian Plate, the velocity is 26 mm/yr or 2.6 cm/yr. Still further, you may want to convert it into in/yr.

5. Laminate the 17 plate pieces and cut off excess laminating material. Also, laminate the legend (the strip cut off the bottom of the map) and save for reference (optional).

B. Students assemble the puzzle in class

1. Give one piece of the puzzle (a plate or piece of a plate) to each student or group of students. Tell them that they will be responsible for their plate – placing it in the right position to form the world map and determining the motion of the plate with respect to surrounding plates. Instruct your students to assemble the map (like putting together a jigsaw puzzle) on the floor or on a large table.

   An alternative procedure that works well and stimulates thinking and discovery:
   - Give a piece of the puzzle to each student (or team of students). Tell them that these are pieces of a puzzle and that it comes from a world map.
   - Their instructions are to put the puzzle together without talking. They can point to communicate, but they must put the puzzle together in silence.
   - After the puzzle is completed, the students can be asked about what they think the pieces are and why.

2. When the map puzzle is complete discuss with the class that the arrows and velocities (in mm/yr, cm/yr, or in/yr – which ever you chose) indicate direction and rate of the motion of the plates. Some plates do not include arrows. Find the highest (fastest) and lowest (slowest) plate velocities. Comment on the speed of the plates; for example, 35 mm/yr or 3.5 cm/yr is equivalent to 35 km/million years, so the plates are not moving very fast—about the speed that a person's fingernails grow. Identify areas of the Earth that are associated with the fastest plate velocities. (With older students, you may want to tie in the concept of rates and vectors.)

3. Encourage students to spend some time looking at their plate and determining what characteristics it may have. For instance, does the entire plate consist of a buoyant continent or a heavy oceanic basin, or portions of both? This is important for students to consider when determining the type of action the boundary of their plate may make. Generally, continental crust is more buoyant (less dense) than the mantle, and therefore resists subduction, however, after it cools, the oceanic crust is actually denser than the mantle, which makes for easier subduction. Pay particular attention to this during your discussion concerning convergent zones, subduction, and mountain building.

4. Direct each student (or group of students) to determine how their plate moves with respect to the surrounding plates. Students should discuss with each other and agree with each other or note their differing interpretations. Ask a few students to explain what their plate's motion is and how it is interacting with adjacent plates.

5. Discuss with your students the locations that are associated with the different types of plate boundaries. For each of these examples, move the appropriate plates a small amount in the direction of the arrows to see what the plate interactions will be. Question or comment on the features that are associated with the plate boundaries—earthquakes, mountain ranges, deep-sea trenches, volcanoes. For this and other parts of the activity, it is convenient for the class to stand around the map and to use a laser pointer or a meter stick (or a ski pole!) to point our individual plates or plate boundaries. The example summaries below are from:
    - Braile, Larry, and Braile, Sheryl, 2006, Plate puzzle: West Lafayette, Ind., Purdue University, Department of Earth and Atmospheric Sciences website. (Available at http://web.ics.purdue.edu/~braile/edumod/platepuzz/platepuzz.htm.)
    - Kious, W.J., and Tilling, R.I., 1996, This dynamic Earth—The story of plate tectonics [online edition]: Reston, Va., U.S. Geological Survey website. (Available at http://pubs.usgs.gov/gip/dynamic/dynamic.html.)

Plate Movements
Convergence: The South American Plate and the Nazca Plate, the western Pacific, Indian, and Eurasia (1) Plates. Note that convergence occurs when two plates are moving in almost directions toward each other (for example, South America Plate and Nazca Plate), or when two plates are moving in nearly the same direction but the plate that is "following" is moving faster (for example, the Pacific Plate and the Philippine Plate).

These two types of motions that result in convergence could be modeled with two parallel lines of students representing the edges of two plates. In the first type of convergence, the students face each other and walk slowly forward until collision. In the second type of convergence, the students face the same direction and walk slowly forward, with the second line of students walking faster until colliding with the first line.

Divergence: The Mid Atlantic Ridge. Point out that Iceland straddles two sides of the East Pacific Rise, thus is on two separate divergent plates, the North American and Eurasian Plates.

Transform: The San Andreas fault in California, the Alpine fault in New Zealand, and the transform faults along the southern boundary of the Nazca Plate.

Combination of movements: Sometimes the plate motions and interactions are more complicated. For example, for the North American and Pacific Plates, the Pacific Plate is moving approximately northwest and the North American Plate is moving approximately southwest. The combination of these motions and the irregularly shaped plate boundaries results in convergence along the Aleutian Islands, divergence at the Juan de Fuca Ridge and predominately transforms motions along the San Andreas Fault and within the Gulf of California.

Hot Spots: Note the Hawaiian Islands in the middle of the Pacific Plate. Although the islands are not near a plate boundary, they are very active seismically and volcanically. The ages of the volcanic rocks in the Hawaiian Islands, the chain of seamounts to the west-northwest, and the Emperor seamounts located farther west and north, all increase toward the west and north. These observations indicate that the Hawaiian Island chain is the track of a mantle hotspot, currently located beneath the southeastern part of the Island of Hawai`i (the "Big Island"). The volcanic islands and seamounts at the northern end of the Emperor Seamounts, near the Aleutian Trench, are more than 65 million years old. At the "bend" in the seamount chains, which connects the Emperor and Hawaiian chains, the volcanic rocks are about 42 million years old. At Kauai, the westernmost of the main Hawaiian Islands, the volcanic rocks are about 5 million years old. The Big Island (Hawai`i) is less than 1 million years old and eruptions are occurring today.

To model the hotspot, place the flashlight under the north end of the Emperor Seamount chain and cause the plate to move northwest and then west-northwest (at the “bend”) until the flashlight is at the current position of the hotspot under Hawai`i.

For discussion:

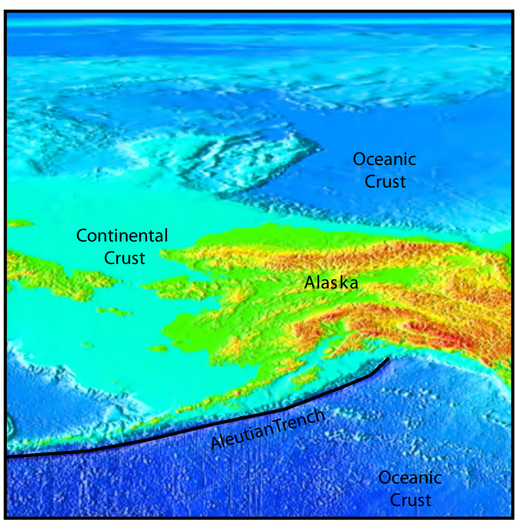
- What direction has the plate been moving (with respect to the mantle hotspot)?
- Where will the future volcanic chain of islands and seamounts be?
- How fast is the plate moving at Hawai`i?
- Does the velocity measurement (near the arrow) agree with the velocity estimated from the volcanic ages (divide the distance in km from Hawai`i to the “bend” by 42 million years, then convert to mm/yr or cm/yr)?

Note Mention to students that scientific understanding of ongoing and dynamic processes below the Earth’s surface is an ongoing process in itself. There has been research that indicates that the bend of the Hawaiian-Emperor hotspot track mentioned above may have been formed by a fast change in position of the Hawaiian hotspot (Tarduno and others, 2003)!

C. Exploring plate boundaries in Alaska

1. Convergence in the form of a subduction zone plays a major role in Alaskan volcanism. Be sure to stress the presence of a subduction zone along southern Alaska and note that it, like other convergent boundaries, experiences a great deal of volcanism due to the melting of rock above the subducting plates.

2. Point out that the map shows (and you can demonstrate by moving pieces) that the Pacific Plate is moving towards Alaska causing convergence and as it subducts it will melt and generate the volcanism witnessed in Alaska. You can also mention the existence of both continental and ocean crust playing key roles at this subduction zone as illustrated in the following figure provided by the Alaska Earthquake Information Center (AEIC).



3. Ask students if there are any other instances in the world where a convergent boundary is in an area of great volcanism. Emphasize the volcanism and subduction of Kamchatka, Russia, and Japan. Discuss and outline the "Ring of Fire."

4. Focus for a bit more on Alaska. According to the Alaska Earthquake Information Center website, Alaska is the most tectonically active region in the United States - experiencing more than half of all earthquakes recorded in North America annually. At the northwest corner of North America, Alaska is situated at the receiving end of the Pacific Plate, which slides laterally past southeast Alaska and collides directly with the North American Plate across southcentral Alaska and along the length of Aleutian Arc. The accumulation of tectonic stresses at depth along the plate boundaries and the translation of those stresses into the shallower crust of southern Alaska are the driving forces behind the high level of earthquake activity that occurs in the state.

5. You may wish to use additional maps to illustrate specific tectonic features in Alaska. Here are some resources:
   - Alaska Earthquake Information Center (AEIC), 2010, Maps: Alaska Earthquake Information center website, accessed May 27, 2010, at http://www.aeic.alaska.edu/html_docs/maps.html.
   - Haeussler, P.J., and Plafker, G., 1995, Earthquakes in Alaska: U.S. Geological Survey Open-File Report, 95-624, 1 sheet. (Also available at
     - PDF Poster http://geopubs.wr.usgs.gov/open-file/of95-624/of95-624L.pdf and
     - PDF page-size http://geopubs.wr.usgs.gov/open-file/of95-624/of95-624.pdf.)

   As illustrated on the USGS and AEIC Earthquakes in Alaska map, earthquake risk is high in much of the southern half of Alaska, but the risk is not the same everywhere. This map shows the overall geologic setting that produces earthquakes in Alaska. The Pacific Plate (darker blue) is sliding northwestward past southeastern Alaska and then dives beneath the North American Plate (light blue, green, and brown) in southern Alaska, the Alaska Peninsula, and the Aleutian Islands. Most earthquakes are produced where these two plates come into contact and slide past each other. Major earthquakes also occur throughout much of interior Alaska and result from a collision of a piece of crust with the southern border. A more detailed tectonic map of southern Alaska is on p. 70 of:
   - Winkler, G.R, 2000, A geologic guide to Wrangell–Saint Elias National Park and Preserve, Alaska—A tectonic collage of northbound terranes: U.S. Geological Survey Professional Paper 1616, 166 p. (Also available at http://pubs.usgs.gov/pp/p1616/P1616.pdf [129 MB].)

D. *Plate tectonics Q&A* worksheet

1. Direct the students to fill out the *Plate tectonics Q&A* worksheet or use the questions selectively to generate class discussion.

Extensions

1. Education Multimedia Isolation Visualization Center, 2008, Animation clips related to plate tectonics: Santa Barbara, Calif., University of California website, accessed June 1, 2010, at http://emvc.geol.ucsb.edu/downloads.php.

2. Incorporate discussion on the Denali Fault earthquake of 2002.
   Fuis, G.S., and Wald, L.A., 2003, Rupture in south-central Alaska—The Denali Fault earthquake of 2002, U.S. Geological Survey Fact Sheet 014-03, 4 p. (Also available at http://pubs.usgs.gov/fs/2003/fs014-03/index.html.)

Modified from

Braile, Larry, and Braile, Sheryl, 2006, Plate puzzle: West Lafayette, Ind., Purdue University, Department of Earth and Atmospheric Sciences, accessed June 1, 2010, at http://web.ics.purdue.edu/~braile/edumod/platepuzz/platepuzz.htm.

References Cited

Alaska Earthquake Information Center (AEIC), 2010, The tectonic setting of Alaska and how it causes earthquake in our state: Alaska Earthquake Information center website, accessed June 1, 2010, at http://www.aeic.alaska.edu/vltpage2.html.

Alaska State Department of Education and Early Development, 2006, Standards and grade level expectations, March 2006: State of Alaska website, accessed October 2009 at http://www.eed.state.ak.us/tls/assessment/GLEHome.html.

Simkin, T., and others, 2006, This dynamic planet—World map of volcanoes, earthquakes, impact craters, and plate tectonics: U.S. Geological Survey Geologic Investigations Map I-2800 1 sheet [2 sides]. (Also available at http://pubs.usgs.gov/imap/2800/.)

Tarduno, J.A., and others, 2003, The Emperor Seamounts—Southward motion of the Hawaiian hotspot plume in Earth's mantle: Science, v. 301, no. 5636, p. 1064-1069.

Glossary

Convergence–The act of two tectonic plates coming together, including subduction.

Divergence–The act of two tectonic plates moving away from each other.

Hot spot–An area where magma from deep within the mantle melts through the crust above it.

Subduction Zone–The zone of convergence of two tectonic plates, one of which usually overrides the subducting plate leading to localized volcanism.

Tectonic Plate–A segment of the Earth's crust that moves relative to other segments and is characterized by volcanic and seismic activity around its margins.

Trench–A long narrow valley on an ocean or sea floor that occurs where two plates converge or subduct.

Velocity–The time rate of change of position of a body in a specified direction.

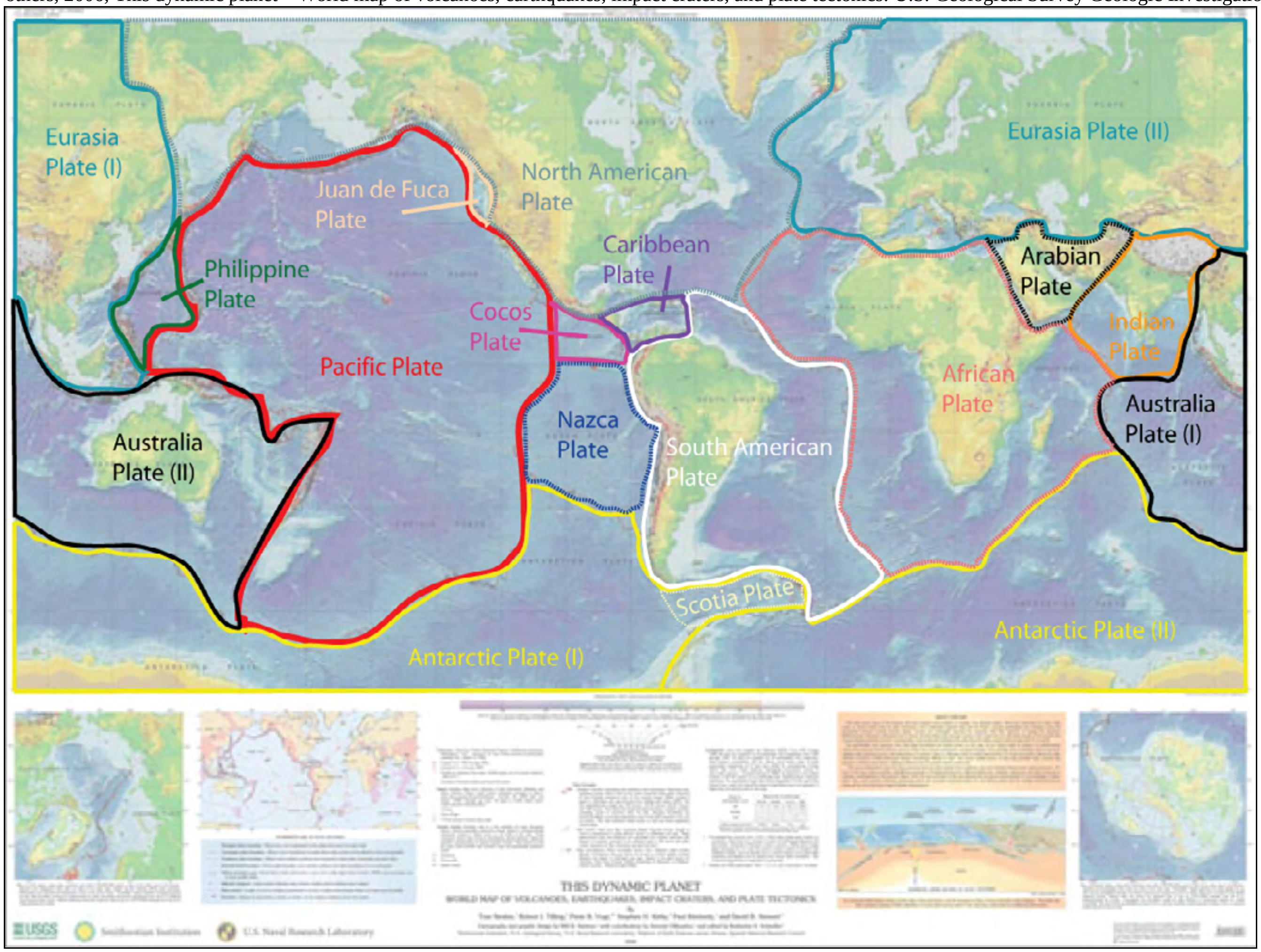
Sources of Glossary Definitions

Kious, W.J., and Tilling, R.I., 1996, This dynamic Earth—The story of plate tectonics [online edition]: Reston, Va., U.S. Geological Survey website. (Available at http://pubs.usgs.gov/gip/dynamic/dynamic.html.)

Stein, Jess, ed., 1982, The Random House College Dictionary Revised Edition: New York, Random House, Inc.

Dynamic Planet Map Pieces

Simkin, T., and others, 2006, This dynamic planet—World map of volcanoes, earthquakes, impact craters, and plate tectonics: U.S. Geological Survey Geologic Investigations Map I-2800.



Name ___________________________________ Date ______________ Period _____

Plate Tectonics Q&A

1. What type of boundary exists in southern Alaska between the Pacific and North American Plates?

2. Why is the boundary between the Pacific and North American Plates different in Alaska than it is in California? Why might that give us a clue as to why Alaska has so many volcanoes?

3. What happens when the plates move apart at the mid-ocean ridges? Note Iceland, an area of active volcanism, located along the Mid-Atlantic Ridge.

4. What direction do you think that the Pacific Plate is moving? How do you know?

5. How does the plate boundary between the Pacific and North American Plates account for or contribute to volcanism in Alaska? Draw a figure that shows this relationship.

6. Can all of the current and historical activity (last 250 years) at Alaska's volcanoes be accounted for due to subduction and the generation of the Aleutian Arc? Are there volcanoes in Alaska that do not lie on the Aleutian Arc? How might they have formed?

7. What is the cause of the Himalayan Mountains? Why is this zone of convergence unique on the Earth today? Are there Alaskan analogs to this kind of plate boundary?

Plate Tectonics Q&A Key

1. What type of boundary exists in Southern Alaska between the Pacific and North American Plates?

   Subduction, a combination of ocean-ocean and continental-oceanic collision/convergence

2. Why is the boundary between the Pacific and North American Plates different in Alaska than it is in California? Why might that give us a clue as to why Alaska has so many volcanoes?

   The direction of Pacific Plate movement is toward the northwest relative to the North American Plate. In Alaska, subduction is the dominant boundary process; however, along California's southern and central coast, the relative plate motion is transform, with the Pacific Plate scraping along the edge of the North American Plate. Without a subducting slab to contribute to the generation of molten material, there is no source for the production of volcanism. Subduction off the coast of northern California, Oregon, and Washington, is the primary source of magma for the Cascade volcanoes.

3. What happens when the plates move apart at the mid-ocean ridges? Note Iceland, an area of active volcanism, located along the Mid-Atlantic Ridge.

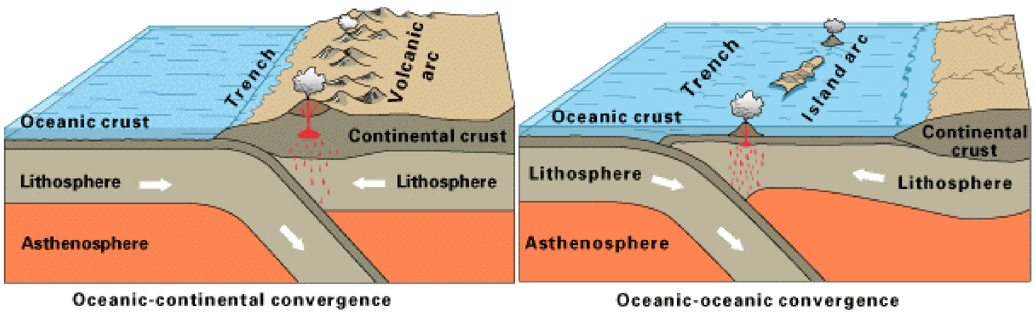
   Although the predominant plate motion is divergence, separate ridge segments are offset by transform faults. The Mid-Atlantic Ridge shows a number of great examples of divergence.

4. What direction do you think that the Pacific Plate is moving? How do you know?

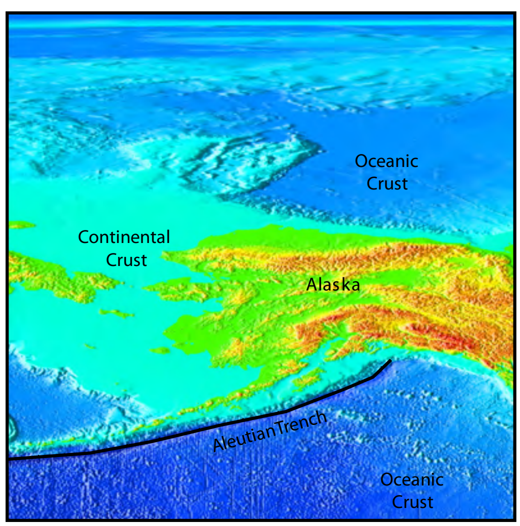
   The Pacific Plate is moving northwestward (white arrows point in that direction). In addition, the map shows a northwestward appearance of the Hawaiian Islands, which are produced as a mostly stationary hot spot form volcanic features on the overriding plate over time as it moves. Alternately, there is scientific discussion concerning the movement of the hotspot that may be associated with the current thinking concerning a change in direction of the movement of the Pacific Plate (see section in the activity on "hot spots").

5. How does the plate boundary between the Pacific and North American Plates account for or contribute to volcanism in Alaska? Draw one or more figures that illustrate these relations.

Subduction processes during plate convergence result in the formation of volcanoes. When the convergence is under the ocean, over millions of years, the erupted lava and volcanic debris pile up on the ocean floor until a submarine volcano rises above sea level to form an island volcano. Such volcanoes typically are strung out in chains called island arcs, such as the Aleutian Arc (and associated Aleutian Trench). As the name implies, volcanic island arcs, which closely parallel the trenches, generally are curved. The trenches are the key to understanding how island arcs such as the Marianas and the Aleutian Islands have formed and why they experience numerous strong earthquakes. Magmas that form island arcs are produced by the partial melting of the descending plate and (or) the overlying oceanic lithosphere. The descending plate also provides a source of stress as the two plates interact, leading to frequent moderate to strong earthquakes. Associated figures are provided below.



From Kious and Tilling, 1996 http://pubs.usgs.gov/gip/dynamic/understanding.html



From Alaska Earthquake Information Center

6. Can all of the current and historic activity (last 250 years) at Alaska's volcanoes be accounted for due to subduction and the generation of the Aleutian Arc? Are there volcanoes in Alaska that do not lie on the Aleutian Arc? How might they have formed?

   For the most part the process of subduction contributes to the historic activity of Alaska's volcanoes. This includes Mt. Wrangell and mud volcanoes near the difficult but accomplished subduction of the Yakutat block (or terrane) which was carried to the region on the Pacific Plate.

7. What is the cause of the Himalayan Mountains? Why is this zone of convergence unique on the Earth today? Are there Alaskan analogs to this kind of plate boundary?

   Continent to continent collision or convergence is the type of plate motion that continues to cause rise of the Himalayas. Rocks within the Indian and Asian continents are of similar rock density. Because the one plate does not subduct beneath the other, pressure of the colliding plates is relieved by upward thrusting, and formation of the Himalayas. Mt. Everest, in the Himalayas, is the world's tallest peak on land at 29,035 ft (~8,850 m) high. The same mechanism applies to the development of the St. Elias Range in Alaska. The St. Elias Range is rising rapidly today because of the collision of the Yakutat block (or terrane), which does not easily subduct and thus causes mountain building.

Activity II. Earthquake Mapping

Grade Level 6–11

Setting Classroom

Time 50 minutes

Vocabulary (see Glossary)
latitude, longitude, plate boundary, seismicity, subduction zone, tectonic

Correlations to Alaska State Department of Education (2006) Performance Standards (Grade Level Expectations)
D1—Concepts of Earth Science

SD[6-11] Students develop an understanding of the concepts, processes, theories, models, evidence, and systems of Earth and space science.

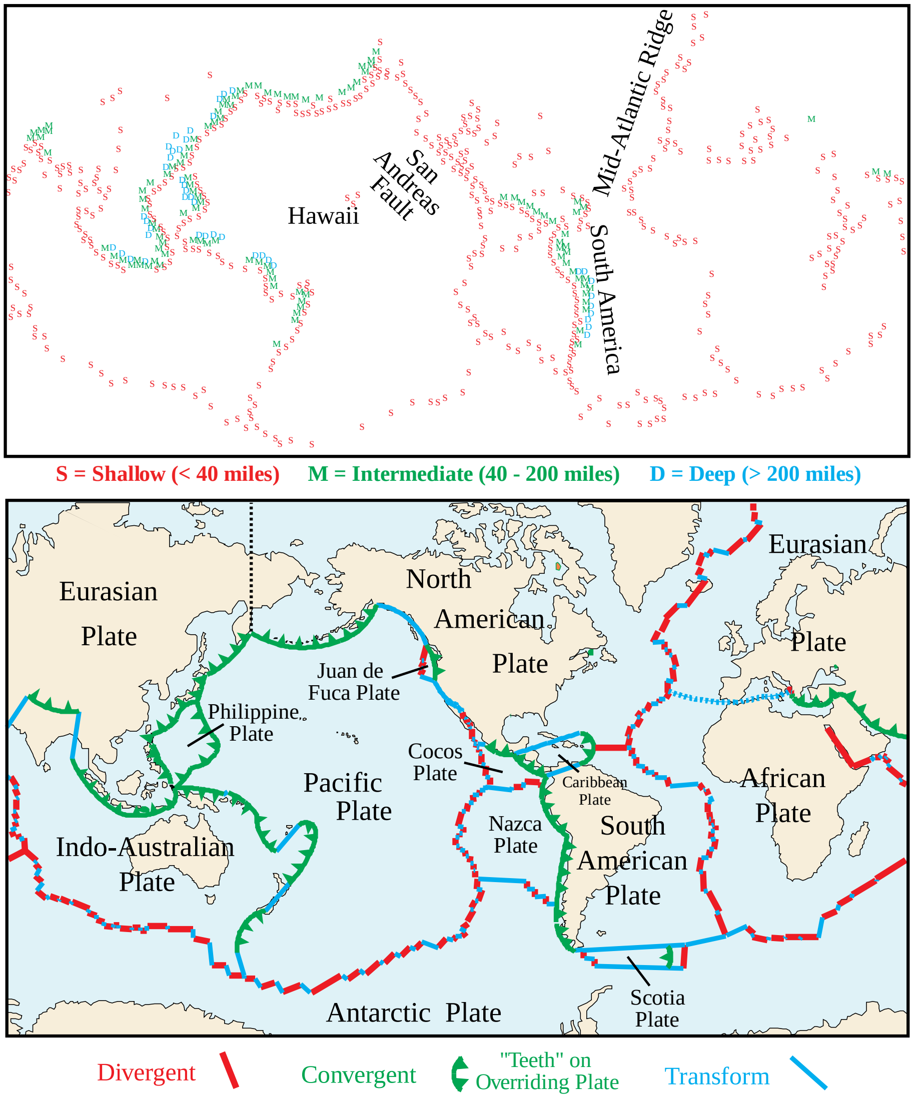
SD2[6-11] Students develop an understanding of the origins, ongoing processes, and forces that shape the structure, composition, and physical history of the Earth.

SD2.2[7] The student demonstrates an understanding of the forces that shape Earth by describing how the movement of the tectonic plates results in both slow changes (e.g., formation of mountains, ocean floors, and basins) and short –term events (e.g., volcanic eruptions, seismic waves, and earthquakes) on the surface.

SD2.2[9-11] Students demonstrate an understanding of the forces that shape Earth by describing how the theory of Plate tectonics explains the dynamic nature of its surface

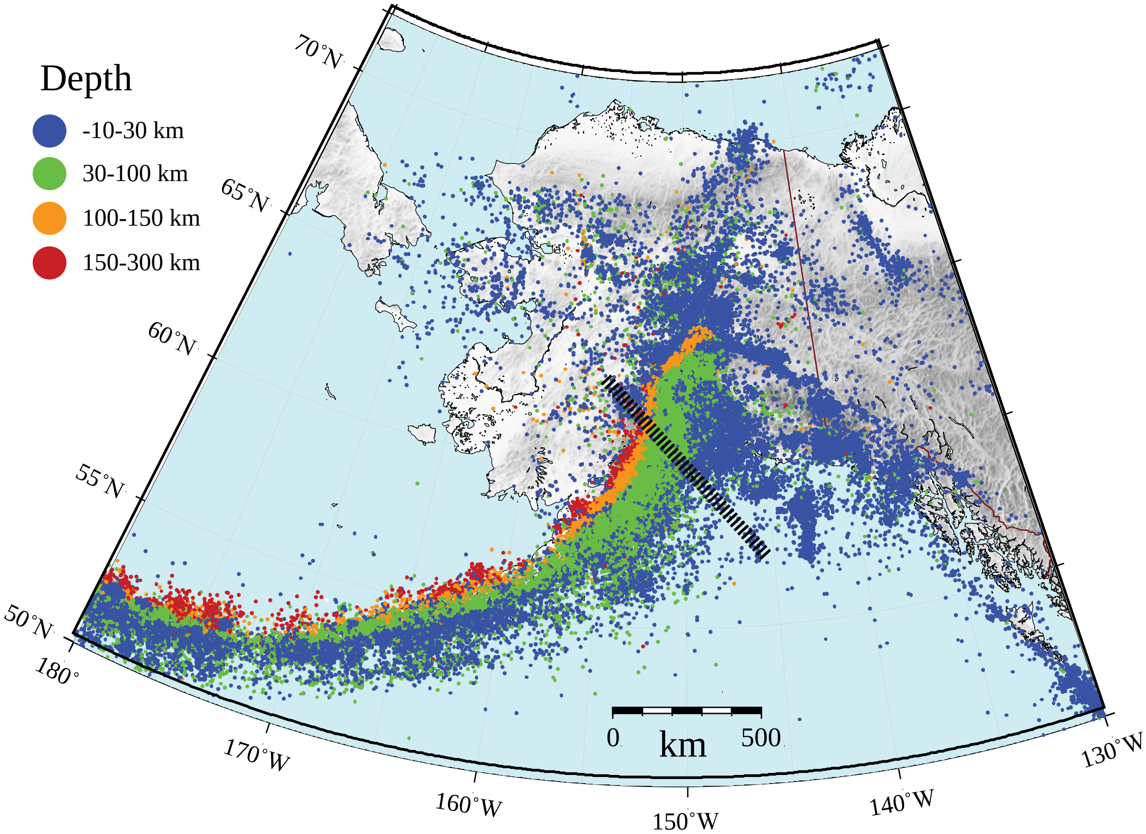
Overview
In addition to the observations of sea floor spreading stripes due to magnetic pole reversals, the history of determining the location of plate boundaries involves determining the location and depth of earthquakes. The location of earthquakes tends to correspond to the location of plate boundaries and the depth of earthquakes corresponds to the type of process occurring at the plate boundary. In this activity, students will build an interactive map of earthquakes to illustrate the relation between the location and depth of earthquake occurrences, and associated plate tectonic boundaries worldwide and specifically, in Alaska.

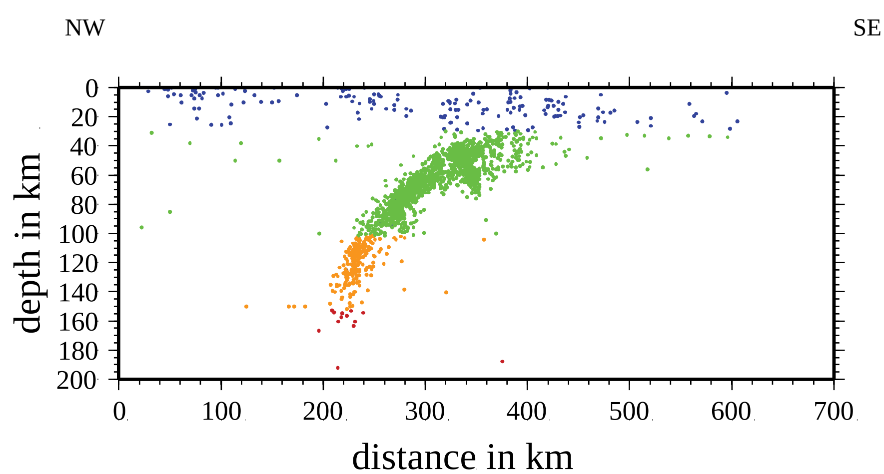
Background
Generally, the depth of an earthquake is related to the type of tectonic boundary in which it occurs. Relatively shallow earthquakes occur at divergent and transform boundaries and hotspots. Closely spaced earthquakes with a range of depths that deepen in the direction of plate movement can reflect a subducting plate at a convergent boundary. Plotting the location and depth of earthquakes in a latitude and longitude area can illustrate a rough outline of the plate boundaries of the Earth and the type of plate boundary in which they occur. You can see this relation using the following figures modified from Lillie, 2005.



Modified from Lillie, 2005

The subducting part of the Pacific Plate generates a significant number of earthquakes. As the Pacific Plate deepens under the North American Plate, the depth of earthquakes generated by this subduction also deepens. The depth where the crust is no longer brittle enough to produce earthquakes is the maximum depth where earthquakes can be used to identify a subducting plate. The Pacific Plate is subducting under the North American Plate at an angle that shallows westward, so the region of earthquakes associated with the subducting plate also shallows westward. This phenomenon in Alaska can be illustrated by using the next set of figures from the Alaska Earthquake Information Center.





The above figures show earthquakes in Alaska greater than or equal to M2 (magnitude 2) recorded between 1970 and 2008. The cross section above is taken across the subduction zone in south-central Alaska and is represented by the dashed line in the top figure. The colors of earthquake locations represent the depth of the earthquakes as noted on the map. Figure modified courtesy of Lea Burris, Alaska Earthquake Information Center (AEIC).

Objective
The students will be able to illustrate the connection between plate boundaries, tectonic activity, and the depth and location of earthquakes (also known as seismic events) with an emphasis in Alaska.

Materials

- provided continent outline maps (world and Alaska)
- blank, transparent overhead sheets (transparencies)
- fine tipped markers that will work on overheads (transparencies)
- clear tape
- overhead projector and screen or wall on which to project
- Incorporated Research Institutions for Seismology (IRIS) list of global earthquakes from last 30 days available at http://www.iris.edu/seismon/last30.html
- Alaska Earthquake Information Center (AEIC) list of Alaskan earthquakes for a few days previous available at http://Earthquake.usgs.gov/eqcenter/recenteqsus/Maps/special/Alaska.php

Procedure

A. Building an illustrative tectonic map of the world

1. To build an illustrative tectonic map of the world, instruct each group of students to plot a different set of earthquakes from the IRIS list of global earthquakes from the last 30 days, which have been downloaded or provided.

2. Direct students to lay an overhead sheet carefully over the world map given using the lines of latitude and longitude for guidance.

3. Further, instruct students to align the two sheets carefully and then clip or tape together so they will not move.

4. Assign each group some of the earthquakes and a few volcanoes to map on their sheet. For this part of the exercise, students plot shallowest earthquakes and a single color should be used by all groups to identify that these are the shallowest earthquakes plotted. Many sources are available online for location maps of volcanoes. One source is the:
    - Smithsonian Institution [n.d.], Global volcanism program—Find a Volcano by Region: Smithsonian Institution web page, accessed June 1, 2010, at http://www.volcano.si.edu/world/find_regions.cfm.

5. After the groups have finished this exercise, instruct the students to layer the mapped overhead sheets (making sure that the orientation is the same for each layer) on top of each other in a single pile on one desk and view from above. Students also can be instructed to pile overhead sheets on top of the overhead projector for display on a screen or wall) and watch as the plotted earthquakes begin to outline the plate boundaries (as seen in the figure in the Background section).

6. If a rough outline of the plate boundaries cannot be seen, assign the students an additional set of deeper earthquakes to plot in another color and stack up their results again. Repeat until the outlines of the plates are apparent.

B. Building an illustrative tectonic map of Alaska

1. To build an illustrative tectonic map of Alaska given, instruct each group of students to plot a different set of earthquakes from the list downloaded or provided.

2. Direct the students to lay an overhead sheet carefully over the map of Alaska and use the lines of latitude and longitude as guides.

3. Further, instruct students to align the two sheets carefully and then clip or tape together so they will not move.

4. Assign each group some of the earthquakes and a few volcanoes to map on their sheet. It is best if you assign earthquakes in depth ranges to different groups of students. For instance a shallow set, an intermediate set, and a deep set. The students should plot these sets with a different color representing each set. Many online sources are available for location maps of volcanoes. Sources include:
   - Alaska Volcano Observatory, [n.d.], Regional map of Alaskan volcanoes: Alaska Volcano Observatory webpage. (Available at http://www.avo.alaska.edu/volcanoes/.)
   - Nye, C.J., McGimsey, R.G., and Power, J., 1998, Volcanoes of Alaska: Alaska Division of Geological and Geophysical Surveys Information Circular 38, 1 sheet [2 sides], accessed May 27, 2010, at
     - PDF Front http://www.dggs.dnr.state.ak.us/webpubs/dggs/ic/oversized/ic038ed1998_sh001.PDF and
     - PDF Back http://www.dggs.dnr.state.ak.us/webpubs/dggs/ic/oversized/ic038ed1998_sh002.PDF
   - Schaefer, J., and Nye, C.J., 2002, Historically active volcanoes of the Aleutian Arc: Alaska Division of Geological and Geophysical Surveys Miscellaneous Publication MP 0123, 1 sheet, accessed June 1, 2010, at http://www.avo.alaska.edu/pdfs/mp123.pdf.
   - Smithsonian Institution, [n.d.], Global volcanism program—Volcanoes of Alaska map: Smithsonian Institution web page, accessed June 1, 2010, at http://www.volcano.si.edu/world/region.cfm?rnum=11.

5. After the groups have finished, instruct the students to layer the mapped overhead sheets (making sure that the orientation is the same for each layer) on top of each other in a single pile on one desk and view from above. Students also can be instructed to pile sheets on top of the overhead projector for display on a screen or wall) and watch as the plotted earthquakes begin to outline the subduction zone at this convergent plate boundary.

6. The compilation of the plots should illustrate a progression of shallow to deep earthquakes at the Pacific Plate and North American Plate subduction zone.

7. If a rough outline of the subduction zone cannot be seen, assign the students an additional set of deeper earthquakes to plot in another color and stack up their results again. Repeat until the outlines of the subduction zone is apparent.

C. Discussion

1. Conduct a class discussion about why earthquakes occur along tectonic plate boundaries, worldwide, and in Alaska.

2. Use the figures from the Background section (available in the companion digital presentation) to illustrate the coherence with which thousands of plotted earthquakes image the plate boundaries worldwide and the subduction zone of southern Alaska.

3. Elaborate on the Pacific Plate and North American Plate subduction zone cross section including the angle of subduction and its relation to earthquake depth. You may ask students to draw or describe an additional cross section west of the cross section shown in the figure.

Extensions

1. Have students plot earthquakes from the same general location vs. depth and summarize the connections between earthquake depth and plate boundary type.

2. Saltus, R.W., and Barnett, A., 2000, Eastern Aleutian volcanic arc digital model–ver. 1.0: U.S. Geological Survey Open-File Report 00-365. (Available at http://pubs.usgs.gov/of/2000/ofr-00-0365/report.htm.)

3. UNAVCO, 2010, Jules Verne Voyager Jr. Map Tool: UNAVCO web page, accessed June 1, 2010, at http://jules.unavco.org/VoyagerJr/Earth.

4. Van Wagner, Lois, 1991, The great continental drift mystery: Yale—New Haven Teachers Institute, Global Change, Volume VI, accessed May 27, 2010 at http://www.yale.edu/ynhti/curriculum/units/1991/6/91.06.05.x.html.

References Cited

Alaska Earthquake Information Center (AEIC), 2010, Patterns of regional seismicity and major earthquakes: Alaska Earthquake Information center website, accessed May 27, 2010, at http://www.aeic.alaska.edu/vltpage3.html.

Alaska State Department of Education and Early Development, 2006, Standards and grade level expectations, March 2006: State of Alaska website, accessed October 2009 at http://www.eed.state.ak.us/tls/assessment/GLEHome.html.

Lillie, R.J., 2005, Parks and plates—The geology of our National parks, monuments and seashores: New York, W.W. Norton and Comdishy, 298 p.

- Chapter 1: Plate tectonics, p. 5–21; figure 1.1, p. 6; figure 1.9, p. 10.
- Chapter 5: Subduction zones, southern Alaska subduction zone, p. 119-120.
- Chapter 11: Accreted terranes, Alaska: A glimpse of continental growth in action, p. 241-245.

Modified from

Atwater, Tanya, 2008, World tectonics map exercise—World earthquake and volcanoes map exercise: Santa Barbara, University of California website, accessed June 1, 2010, at http://emvc.geol.ucsb.edu/download/worldtectonicsmap.php.

Driedger, C.L., Doherty, Anne, and Dixon, Cheryll, 2005, Living with a volcano in your backyard—An educator's guide with emphasis on Mount Rainier: U.S. Geological Survey General Interest Product 19; produced in cooperation with the National Park Service, available at

- Chapter 1: What the past tells us—Surrounded by volcanoes: http://vulcan.wr.usgs.gov/Outreach/Publications/GIP19/framework.html and
- http://vulcan.wr.usgs.gov/Outreach/Publications/GIP19/chapter_one_surrounded_by_volcanoes.pdf (6.9 MB)

Glossary

Latitude–The angular distance of a point on the earth's surface north or south or the equator, measured along a meridian.

Longitude–The angular distance between the meridian of a given place and the prime meridian of Greenwich, England, measured east or west to a maximum value of 180 degrees.

Plate boundary–An area on the margins of tectonic plates where seismic, volcanic, and tectonic activity takes place because of the relative motion of the plates.

Seismicity–The distribution and frequency of seismic events such as earthquakes or fault movement.

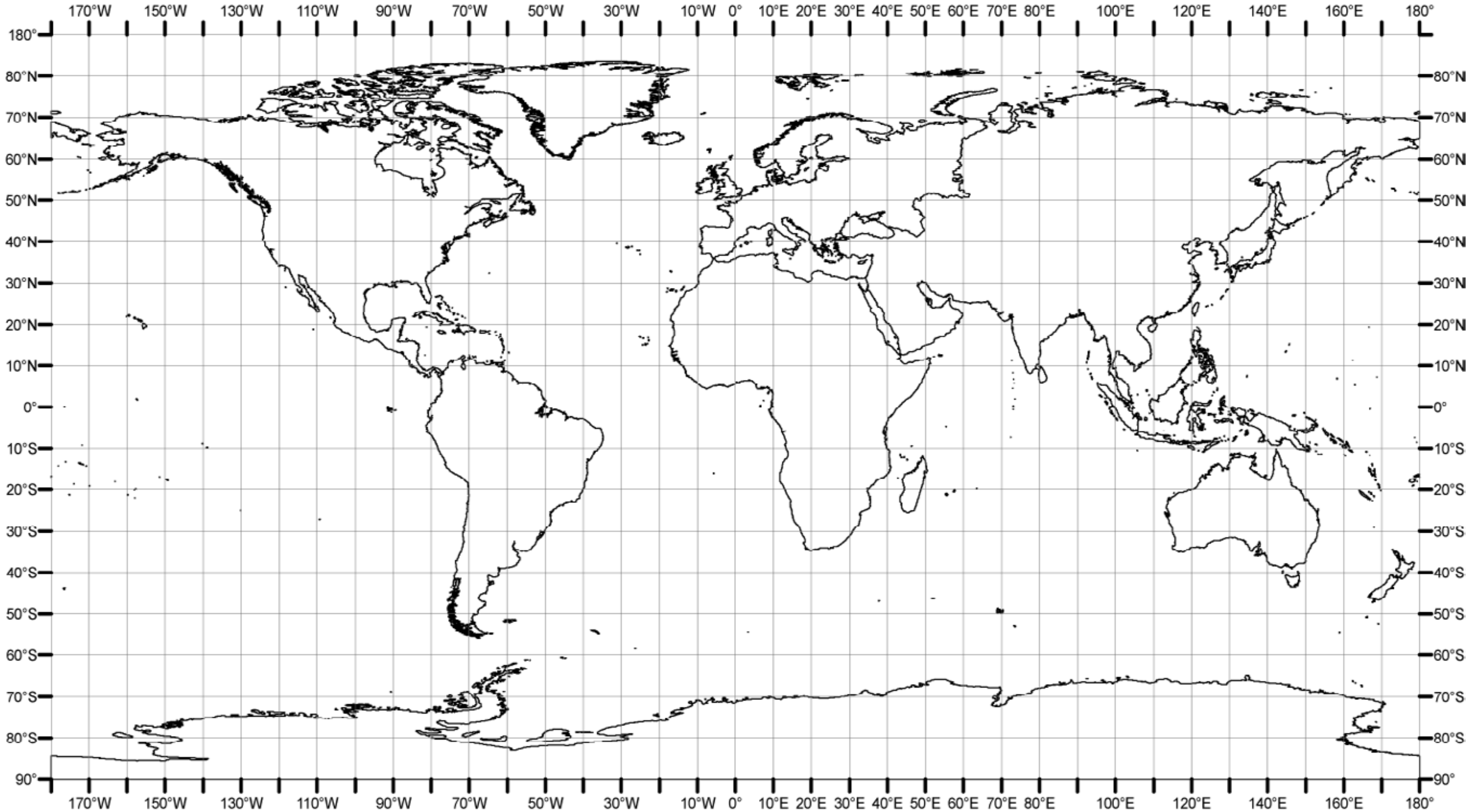
Subduction Zone–The zone of convergence of two tectonic plates, one of which usually overrides the subducting plate.

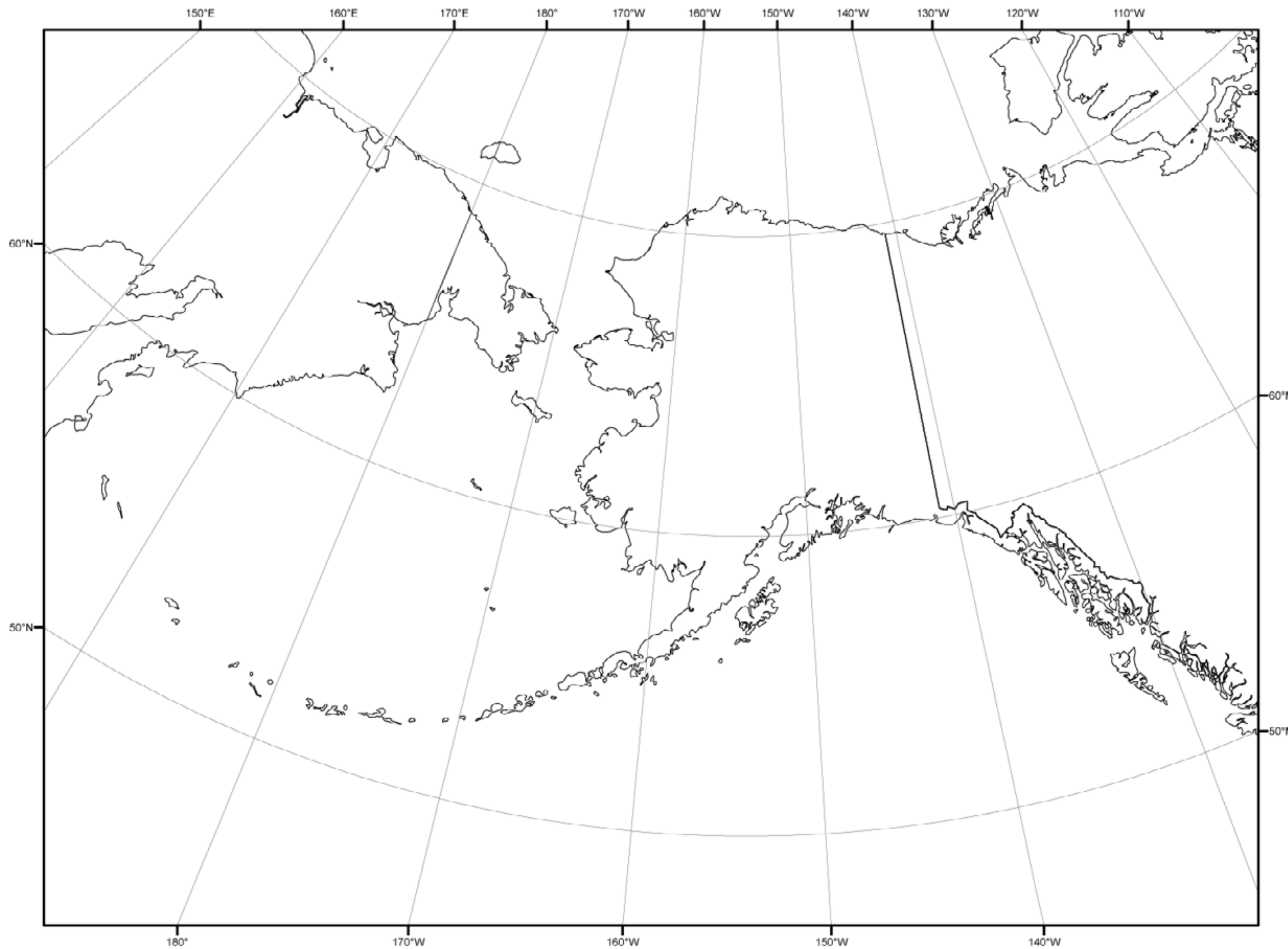
Tectonic–Refers to earthquakes generated by faulting rather than by volcanic activity. Latitude: an imaginary line joining points on Earth's surface that are all of equal distance north or south of the equator.

Sources of Glossary Definitions

Bates, R.K., and Jackson, J.A., eds., 1987, Glossary of Geology (3rd ed.): Falls Church, Va., American Geological Institute, 571 p.

Kious, W.J., and Tilling, R.I., 1996. This dynamic Earth—The story of plate tectonics: U.S. Geological Survey General Information Product. (Also available at http://pubs.usgs.gov/gip/dynamic/dynamic.html.)


170°W 150°W 130°W 110°W 90°W 70°W 50°W 30°W 10°W 0° 10°E 20°E 30°E 40°E 50°E 60°E 70°E 80°E 100°E 120°E 140°E 160°E 180°
180°
80°N
70°N
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S
70°S
80°S
90°


150°E
160°E
170°E
180°
170°W
160°W
150°W
140°W
130°W
120°W
110°W
60°N
50°N
180°
170°W
160°W
150°W
140°W