

Plate Puzzle^o

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Objectives: Develop a better understanding of the Earth's plates and their distribution. Explore plate motions and the interactions of the plates along the plate boundaries. Before beginning this activity, students should have a basic knowledge of the Earth's plates, the lithosphere and asthenosphere, heat within the Earth, and the three types of plate boundaries – divergent, convergent and transform. Similar activities are contained in Tremor Troop (the FEMA/NSTA earthquake curriculum for grades K-6) on pages 43-44 and 56-60, and on Masters 13, 14a and 14b; and at: <http://quake.wr.usgs.gov/research/deformation/modeling/teaching/puzzle/>. Good activities to precede this lesson are the foam models of the lithosphere and the epicenter plotting activities. Good follow-up activities are: plate tectonics flip book, epicenter plotting using program SeisVolE, earthquake location, and thermal convection (<http://www.eas.purdue.edu/~braile>; these activities could also be performed before the Plate Puzzle lesson; in this case, the Plate Puzzle activity is an excellent authentic assessment tool).

Preparation:

1. Obtain an extra copy of the map "This Dynamic Planet" (you should have one copy hanging on the wall during the teaching of your Earth science unit). The map ("This Dynamic Planet," T. Simkin and others, 1994) is available from the U.S. Geological Survey, Box 25286, Denver, CO 80225, (303) 292-4693 (FAX) or (888) ASK-USGS, \$7 + \$5 shipping, <http://pubs.usgs.gov/pdf/planet.html> (Figures 1 and 2). A companion document, "This Dynamic Earth: The Story of Plate Tectonics," is also available from the USGS (\$6) and on the Internet at: <http://pubs.usgs.gov/publications/text/dynamic/html>.
2. With scissors, trim the white edges and the legend below the map from the map area. 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 map into pieces along the plate boundaries (Figure 3). Don't worry about the details of the boundaries, such as the many small transform faults along the mid-ocean ridges; just make a smooth cut approximately on the plate boundary. When you are finished, you should have the following plates (18 separate pieces of the puzzle):

African Plate

Antarctic Plate (cut into two pieces, for convenience, along the Antarctic peninsula just south of the southern tip of South America, see Figure 3)

Arabian Plate (includes Saudi Arabia)

Australian Plate (in two pieces because of the map edge at 100°E longitude)

Caribbean Plate

Cocos Plate (southwest of Middle America)

Eurasian Plate (in two pieces because of the map edge at 100°E longitude)

Indian Plate

Juan de Fuca Plate (west of Washington State)

Nazca Plate
North American Plate
Pacific Plate
Philippine Plate (west of Japan)
Scotia Plate (east of the southern tip of South America)
South American Plate

4. Find the light double arrows on most of the plates that indicate the directions of plate motion. Highlight these arrows with a red felt pen so that they are more visible. Write the velocity of the plate motion (the small black type number adjacent to the arrows) next to the red arrows using the felt pen so that the numbers are more visible. 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.
5. Laminate the 18 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.
6. For the discussion of the completed map in the procedure described below, it is convenient to have the students stand around the map and to use a laser pointer (or a meter stick or other pointer) to point out specific plates, plate boundaries, velocity vectors, or other features.

Procedure:

1. Give one piece of the puzzle (a plate or piece of a plate) to each student or pair 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 plate’s motion with respect to surrounding plates. Have the students 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 is the following. 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 the puzzle is to be put together in silence. After the puzzle is completed, the students can be asked about why they think the pieces are and why.
2. Note the arrows and velocities (in mm/yr) that indicate the motion of the plates. Some plates do not include arrows. Find the highest and lowest 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. What areas of the Earth are associated with the largest plate velocities?
3. Have each student (or pair of students) 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. After a brief time for discussion, ask a few students to explain what their plate’s motion is and how it is interacting with adjacent plates.
4. Find locations on the map that are associated with:
 - a. *convergence*; for example: the South American plate and the Nazca plate, the western Pacific, India and Asia. Note that convergence occurs when two plates are moving in almost opposite directions (for example, South America and Nazca), 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.
 - b. *divergence*; for example: the Mid Atlantic Ridge (note Iceland on two sides of the ridge) or the East Pacific Rise.
 - c. *transform* [this one is more difficult]; for example: the San Andreas fault in California, New Zealand (the Alpine fault), and the transform faults along the southern boundary of the Nazca plate.

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 while 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 transform motions along the San Andreas fault

and within the Gulf of California. Moving these two plates a small amount in the direction of the arrows (note that the Pacific plate moves faster) will illustrate the different interactions along these boundaries (collision in the Aleutians, “opening” of the ridge area at the Juan de Fuca plate, and transform or strike-slip faulting along the San Andreas fault system).

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 about 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 to point out individual plates or plate boundaries.

To better view the correlation of earthquake and volcanic activity along plate boundaries and to display the plate names and distribution, Figures 4 and 5 can be made into color or black and white transparencies. The transparency from Figure 5 can be overlain on the transparency from Figure 4 to show that the pattern of earthquake epicenters delineates the plates.

Examples of the plate boundaries and further information and illustrations of plate tectonics and continental drift can be found in the USGS publication "This Dynamic Earth" and in the video by T.A. Atwater (1988). These materials provide excellent color illustrations to supplement the Plate Puzzle activity.

5. Questions to generate discussion:

- a. Explain why the Australian continent has few earthquakes. However, note that there are very active earthquake zones near Australia.
- b. What is the cause of the Himalayan Mountains? Why is this zone of convergence unique on the Earth today (there are several examples of past continent-continent collisions)? You can explore the collision of the Indian plate with Asia using the plate tectonic flip book.
- c. Compare the earthquake activity, volcanic activity and topography of the west and east coasts of South America. Why are these continental margins so different?
- d. What happens when the plates move apart at the mid-ocean ridges? Note Iceland, an area of active volcanism, that is located along the Mid-Atlantic ridge. To further explore the mid-ocean ridges and other marine areas, you may wish to view a color map of ocean floor bathymetry at: http://www.ngdc.noaa.gov/mgg/announcements/images_predict.HTML, or a color map of the ages of the ocean crust at: http://gdcinfo.agg.emr.ca/app/app3_e.html.
- e. What do you think is happening in east Africa, an area of volcanic and earthquake activity and distinctive topography?
- f. Can you find areas representing different stages of continental separation (continental rifting, initial ocean crust formation, full ocean basins separating two continental areas)?
- g. What direction do you think that the Scotia plate is moving? How do you know?
- h. What direction do you think the Juan de Fuca plate is moving? How do you know?
- i. Note the Hawaiian Islands in the middle of the Pacific plate. Although the islands are not near a plate boundary, they are seismically and volcanically very active. The ages of the volcanic rocks in the Hawaiian Islands, the chain of seamounts to the west-northwest, and the Emperor seamounts located further 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 Hawaii (the “Big Island”). You can illustrate the formation of the Hawaiian Islands by movement of the Pacific lithospheric plate over the mantle hotspot using a small flashlight (a pen light works well) held directly to the bottom of the Pacific plate puzzle piece (the light will show through the paper). The volcanic islands and seamounts at the northern end of the Emperor seamounts, near the Aleutian trench, are over 65 million years old. At the “bend” in the seamount chains that 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 (Hawaii) 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 Hawaii. 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 Hawaii? Does the velocity measurement (near the arrow) agree with the velocity estimated from the volcanic ages (divide the distance in km from Hawaii to the “bend” by 42 million years, then convert to mm/yr or cm/yr)?

- j. The “This Dynamic Planet” map is a Mercator projection so the geographic features (plates, continents, etc.) are somewhat distorted, particularly in the high-latitude areas of the world. To examine this distortion and obtain a better visual image of what the plates look like, compare the outlines of the continents on the Mercator projection with the outlines on a globe.

References:

Atwater, Tanya, Continental Drift and Plate Tectonics Video, 20 minute videotape, 1988, (obtain from Rick Johnson, Instructional Consultation, UC-Santa Barbara, Santa Barbara, CA 93106, \$15, make check payable to "Regents of the University of California.")

National Science Teachers Association, *Tremor Troop – Earthquakes: A teacher's package for K-6 grades*, NSTA Publications, Washington, DC, 169 pp., 1990. (This book contains a reasonably complete curriculum for teaching earthquakes and related Earth science topics; FEMA 159, for free copy, write on school letterhead to: FEMA, PO Box 70274, Wash., DC 20024; FEMA 159, Revised Edition, August, 2000, available from FEMA Publication Warehouse, 1-800-480-2520).

Simkin, T., J. D. Unger, R. I. Tilling, P. R. Vogt, and H. Spall, *This Dynamic Planet – World Map of Volcanoes, Earthquakes, Impact Craters, and Plate Tectonics*, Smithsonian institution and U.S. Geological Survey, 1994.

U.S. Geological Survey, *This Dynamic Earth: The Story of Plate Tectonics*, available from: U.S. Geol. Survey, Map Distribution, Federal Center, PO Box 25286, Denver, CO 80225, \$6, (888 ASK-USGS).



Figure 1. Reduced size image of 1994 "This Dynamic Planet" map (map size is 148 x 104 cm, including legend, 1:30,000,000 scale at the equator), compiled by Tom Simkin, John D. Unger, Robert I. Tilling, Peter R. Vogt, and Henry Spall. Cartography by James E. Queen, Will R. Stettner, and Paul Mathieux. This image, a full-size, color, digital image of the entire map, and the map legend are available on the Internet at: <http://www.pubs.usgs.gov/pdf/planet.html>.

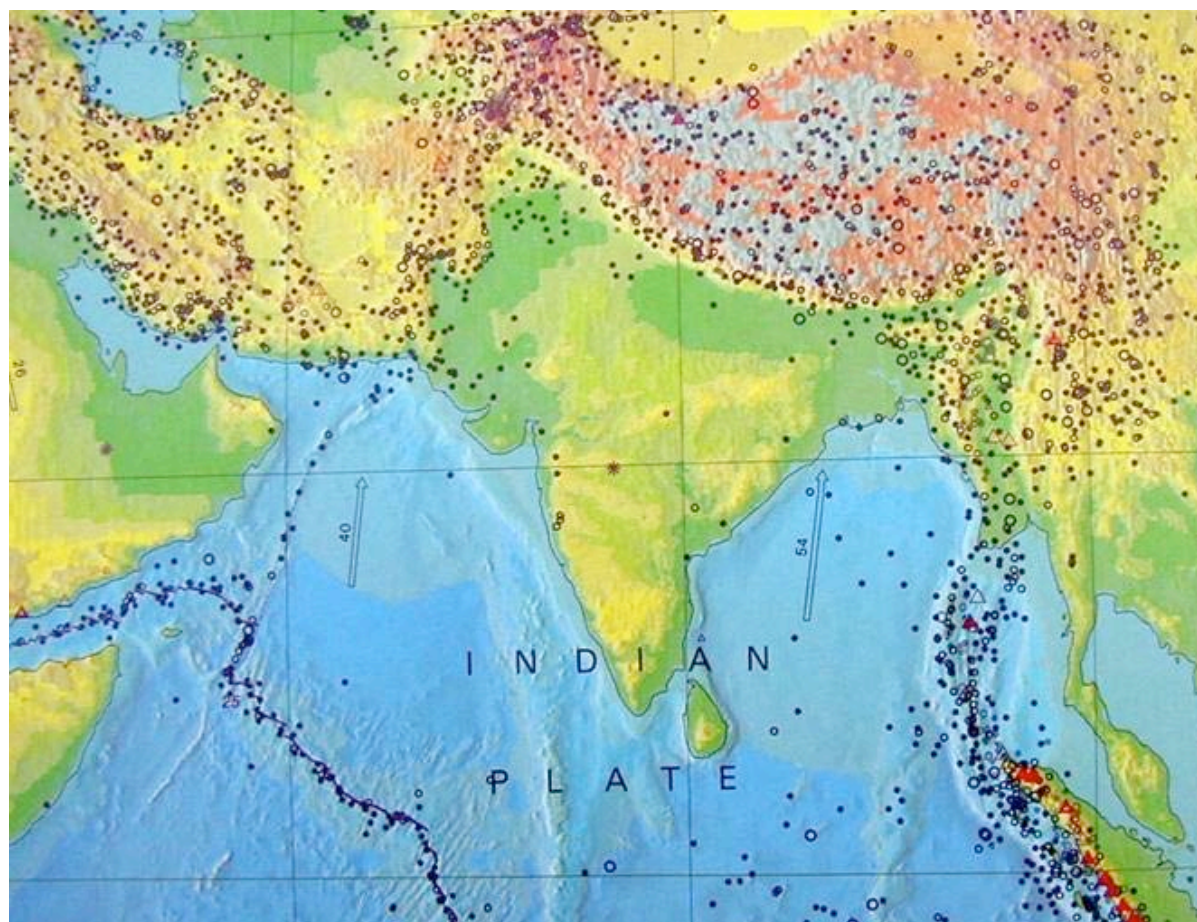


Figure 2. Example (Indian Plate and surrounding area) of the earthquake, topography, plate motion and geographic data shown on the "This Dynamic Planet" map. Dots are earthquake epicenters. Light double-line arrows indicate direction of plate motion. Numbers next to the arrows show plate velocity in mm/yr.

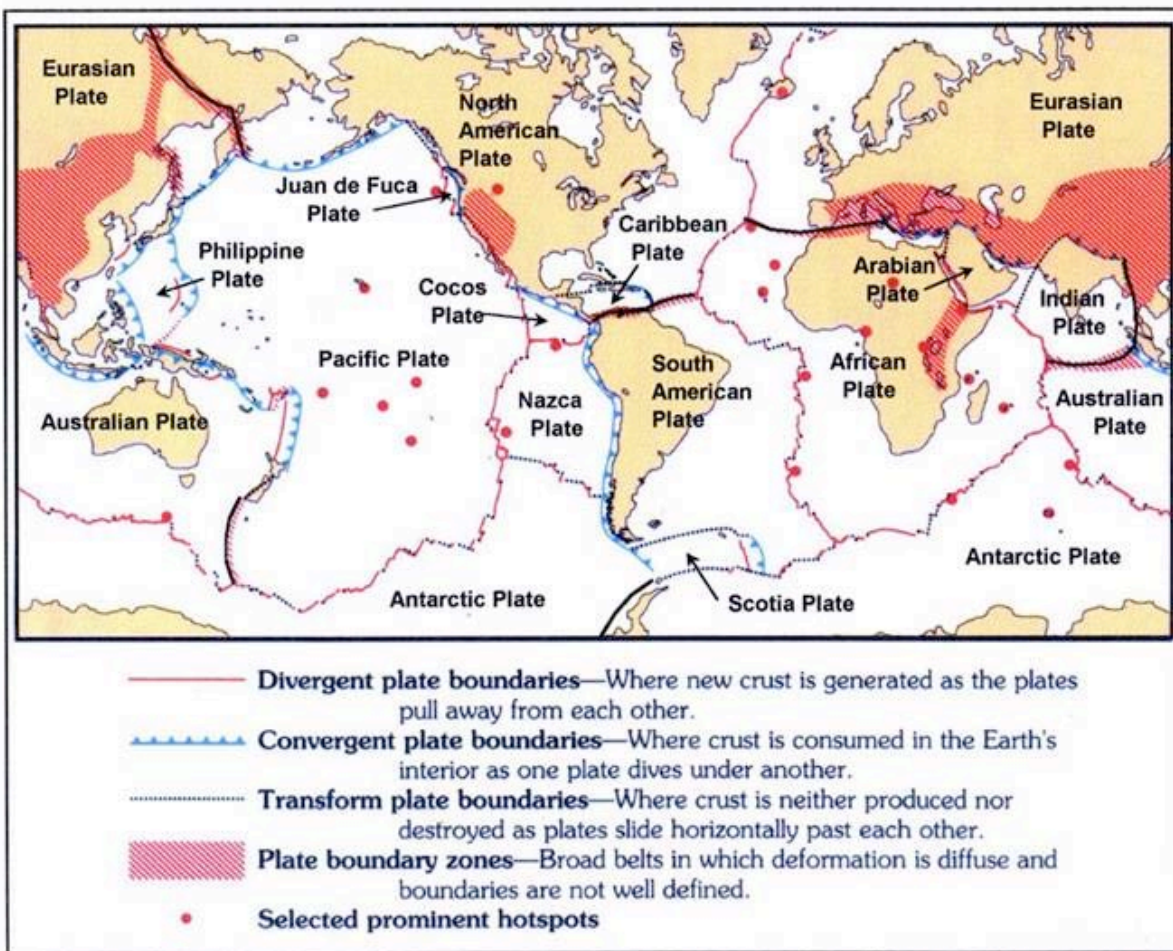


Figure 3. Map of plate boundaries and plate names. For the plate puzzle activity, cut along boundaries (divergent, convergent and transform boundaries) and along the "plate boundary zones" (diagonal shaded areas) that are marked with a bold line. Cut the Antarctic plate along the bold line to the southwest of the Scotia plate. The result will be 18 plates or pieces of plates. Because the map is a Mercator projection, the polar regions are not shown and the high-latitude regions are distorted.

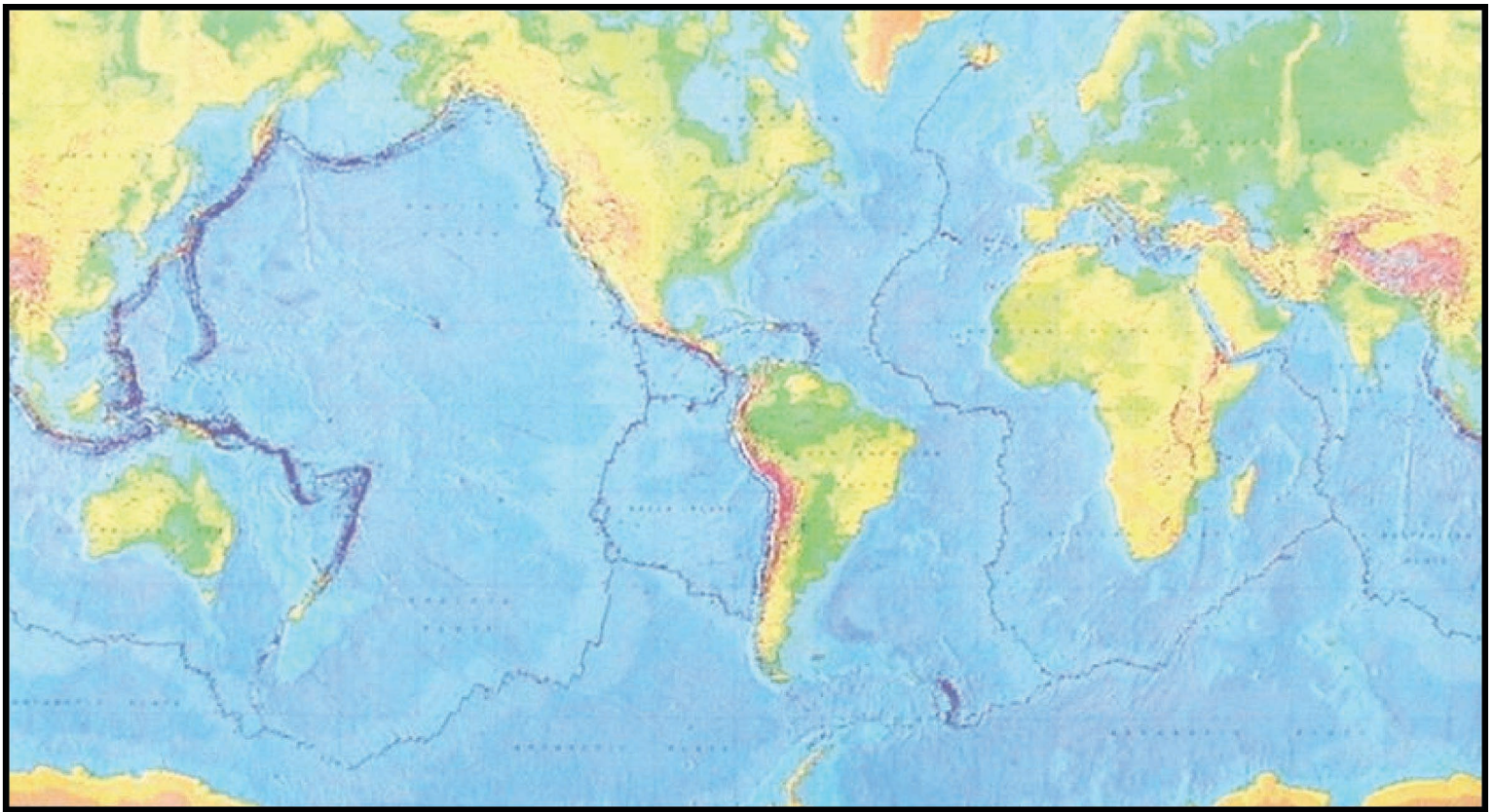


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This Dynamic Planet map from Simkin and others, 1994,

<http://pubs.usgs.gov/pdf/planet.html>

Figure 4. This Dynamic Planet map (Simkin et al., 1994) for transparency (base map for Figure 5 overlay).

