

## *About this Product:*

Plate tectonics is a key standards-based topic taught in earth science classrooms throughout the United States. The purpose of this map is to help educators (teachers, museum tour guides, etc.) teach students about the forces that are responsible for earthquakes, mountains, volcanoes, and other natural phenomena. This product includes the latest version of the USGS map portion of the *This Dynamic Planet* poster. As the map alone has limited usefulness in allowing instructors, in both formal and informal learning environments, to convey the powerful ideas about how the Earth works, SCEC has developed an innovation that will allow this product to be used more easily and broadly by science educators.

One effective instructional method of teaching about plate tectonics is to cut the *This Dynamic Planet* poster into the individual tectonic plate pieces (e.g. Pacific plate, Caribbean plate, etc.), which may then be laminated for greater durability. Subsequently, the pieces can be used both as a world puzzle and to demonstrate the different types of boundaries that exist between each plate. Countless educators have shared their enthusiasm for this activity while also expressing interest in a simple guide that would allow them to carry out the process of cutting the USGS map quickly, easily, and accurately. After receiving this input, SCEC worked to reproduce the USGS map, creating a version that has outlines of the plate boundaries added to the back of the map to direct the process of cutting the plate pieces. Each piece is labeled with the name of its plate for easy identification.

## *Map Preparation:*

- 1.** Cut the plates out along all of the black lines on the back of the map. Some plates are in two pieces. When you are finished, you should have the following plates (19 separate pieces of the puzzle):

- 1-2 Antarctica Plate (two pieces)
- 3 Arabia Plate
- 4-5 Australia Plate (two pieces)
- 6 Caribbean Plate
- 7 Cocos Plate
- 8-9 Eurasia Plate (two pieces)
- 10 India Plate
- 11 Juan de Fuca Plate
- 12 Nazca Plate
- 13 North America Plate
- 14 Nubia Plate
- 15 Pacific Plate
- 16 Philippine Plate
- 17 Scotia Plate
- 18 Somalia Plate
- 19 South America Plate

- 2.** Laminate the 19 plate pieces and cut off excess laminating material. Do not cut too close or lamination will peel.

- 3.** A map legend is included at the end of this guide.

## Map Activity:

- 1.** Give one piece of the puzzle to each student or pair of students. Tell them that they will be responsible for their puzzle piece – placing it in the right position to form the world map and determining the piece's motion with respect to surrounding pieces.
- 2.** Have the students assemble the map (similar to putting together a jigsaw puzzle) on the floor or on a large table.
- 3.** Once the plates are assembled, have the students note the vectors on the plates. The numbers along the arrows indicate the plate's speed (in mm/y). Some plates have multiple vectors. This shows that different portions of the plate are moving at different speeds in slightly different directions.
- 4.** Find the highest and lowest plate velocities. Comment on these numbers; for example, 35 mm/y is equivalent to 35 km/million years (it is important for students to develop these math connections). 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?
- 5.** Have each student (or group) 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. To determine plate movement on a global scale, geologists use hotspots as reference points, such as the one underneath the Hawaiian Islands. Hotspots do not move as much as the plates above them. Modern techniques also include GPS and other tools to determine plate movement.
- 6.** 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. Tell them that as the plates move, they build up stress and that at a certain point the stress is released, causing an earthquake.
- 7.** You may also teach them how plate movement builds mountain ranges and volcanoes. Note that volcanoes and earthquake occurrences are accumulated along plate boundaries. Also, you can point out specific landmarks such as the Ring of Fire and mountain ranges such as the Himalayas.
- 8.** To discuss specific plate movement, here is further information:

Convergence: 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.

Divergence; for example: the Mid Atlantic Ridge (note Iceland on two sides of the ridge) or the East Pacific Rise.

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, 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.

9. 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.

### *Map Discussion:*

1. Explain why the Australian Continent has few earthquakes. However, note that there are very active earthquake zones near Australia.
2. 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)?
3. Compare the earthquake activity, volcanic activity and topography of the west and east coasts of South America. Why are these continental margins so different?
4. 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](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](http://gdcinfo.agg.emr.ca/app/app3_e.html).
5. What do you think is happening in East Africa, an area of volcanic and earthquake activity and distinctive topography?
6. Can you find areas representing different stages of continental separation (continental rifting, initial ocean crust formation, full ocean basins separating two continental areas)?
7. What direction do you think that the Scotia Plate is moving? How do you know?
8. What direction do you think the Juan de Fuca Plate is moving? How do you know?
9. 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) or a laser pointer 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 or laser pointer 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/y or cm/y)?

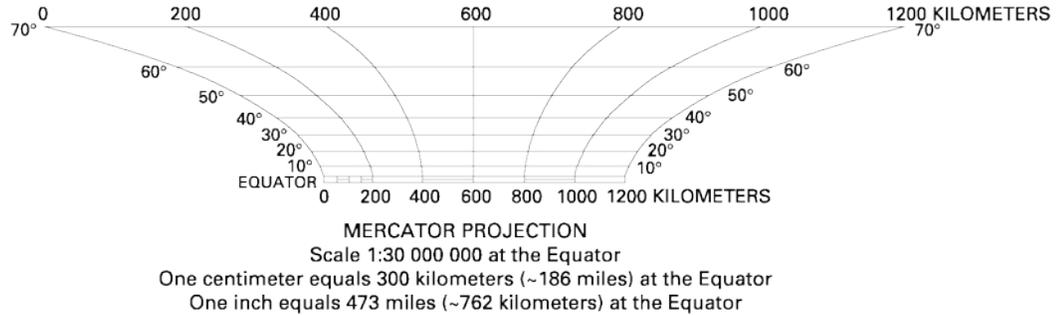
- 10.** The “This Dynamic Planet” map is a Mercator projection so the geographic features (plates, continents, etc.) are somewhat distorted, particularly in the high-latitude areas of the world. To examine this distortion and obtain a better visual image of what the plates look like, compare the outlines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

**Note:** To download a .pdf version of this user guide, print out replacements of the smallest and most commonly lost pieces, or access supplemental online resources, please visit

**[www.scec.org/education/plate\\_tectonics](http://www.scec.org/education/plate_tectonics)**

*This activity was produced by David Coss Y Leon, Gema Venegas, Benjamin Dansby, Grace Hwang, Christina Gotuaco, Robert de Groot, and Mark Benthien, Southern California Earthquake Center. It is based on The Plate Puzzle activity created by Professor of Earth Science Larry Braile at Purdue University. The map used was published as This Dynamic Planet by the United States Geological Survey (USGS). Aspects of the map have been altered for visual clarity e.g. colors, vectors, text.*

# MAP LEGEND



## Volcanoes

Data from Global Volcanism Program, Smithsonian Institution, Washington, D.C.; accessed at <http://www.volcano.si.edu/world/summary.cfm>, March 16, 2005

- ▲ *Erupted AD. 1900 through 2003*
- ▲ *Erupted AD. 1 through 1899*
- △ *Erupted in Holocene time (past 10,000 years), but no known eruptions since AD. 1*
- △ *Uncertain Holocene activity and fumarolic activity*

## Impact Craters

Data from University of New Brunswick, Planetary and Space Science Centre, Earth Impact Database; accessed at <http://www.unb.ca/passc/ImpactDatabase/>. October 23, 2003 (also see Grieve, 1998). Geologic age span: 50 years to 2,400 million years. Crater diameter indicated below

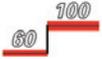
- \* *<10 km*
- \* *10 to 70 km*
- ☼ *>70 km (shown at actual map scale)*

## Notable Events

Numbers next to a few symbols - of many thousands shown - denote especially noteworthy events, keyed to correspondingly numbered entries in tables found on the back of the map. These numbered events have produced devastating natural disasters, advanced scientific understanding, or piqued popular interest. They remind us that the map's small symbols may represent large and geologically significant events

- 19** *Volcanoes*
- 9** *Earthquakes*
- 23** *Impact craters*

## Plate Tectonics



*Divergent (sea-floor spreading) and transform fault boundaries-Red lines mark spreading centers where most of the world's volcanism takes place; thickness of lines indicates divergence rate, in four velocity ranges. White number is speed in millimeters per year (mm/yr) from DeMets and others (1994). The four spreading-rate ranges are <30 mm/yr; 30-59 mm/yr; 60-90 mm/yr; and >90 mm/yr. Thin black line marks the plate boundary, whether sea-floor spreading center or transform fault. On land, divergent boundaries are commonly diffuse zones (see interpretive map to the left); therefore, most are not shown. The only transform faults shown on land are those separating named plates.*

← **9** *Plate motion - Data from Rice University Global Tectonics Group. Length of arrow is proportional to plate velocity, shown in millimeters per year. These approximate rates and directions are calculated from angular velocities with respect to hotspots, assumed to be relatively fixed in the mantle (see plate motion calculator at <http://tectonics.rice.edu/hs3.html>)*

## Earthquakes

Data from Engdahl and Villasenor (2002). From 1900 through 1963, the data are complete for all earthquakes  $\geq 6.5$  magnitude; from 1964 through 1999, the data are complete for all earthquakes  $\geq 5.0$  magnitude. Most location uncertainties <35 km. Eleven more recent major or great earthquakes (magnitude  $\geq 7.7$ ) have been added for completeness through 2004; data from USGS National Earthquake Information Center at <http://neic.usgs.gov/>, accessed January 4, 2005. An epicenter is the surface location of the first rupture on an earthquake fault. Symbols shown represent epicenters. For earthquakes larger than about magnitude 7.0, the size of the rupture zone, which can extend hundreds of kilometers from the epicenter, is larger than the symbols used on this map

Depth to earthquake, in km	Magnitude of earthquake			
	5.0-5.9	6.0-6.9	7.0-7.9	$\geq 8.0$
<60	•	●	○	⊙
60-300	◦	◐	◑	◒
>300	◑	◒	◓	◔
Global average occurrence <sup>1</sup>	1319/yr	134/yr	17/yr	1/yr

<sup>1</sup>Earthquakes of magnitude <5 (not shown on map) are much more frequent, with ~13,000/yr in the 4.0-4.9 range alone. Data from USGS National Earthquake Information Center.

○ *Earthquakes that occurred from 1750 to 1963 within stable plate interiors on continents - Data from AC. Johnston (Center for Earthquake Research and Information, University of Memphis, written commun., 2002). Even though these epicenters do not meet the precise location criteria of Engdahl and Villasenor (2002), they are plotted here to remind readers of the potentially hazardous earthquakes that are distant from known plate boundaries. Size of symbol proportional to earthquake magnitude*

◑ *Notable pre-1900 earthquakes*