THIS DYNAMIC PLANET:
A TEACHING COMPANION

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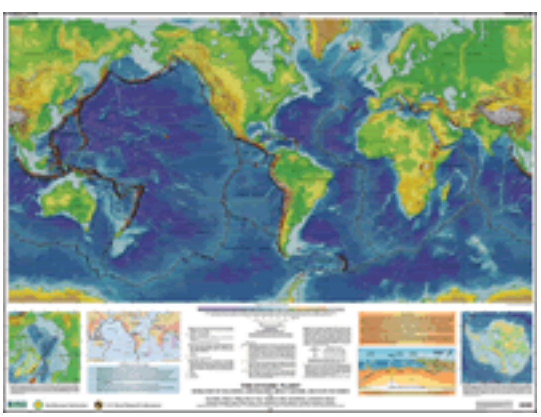
BRIEF OVERVIEW OF PLATE TECTONICS

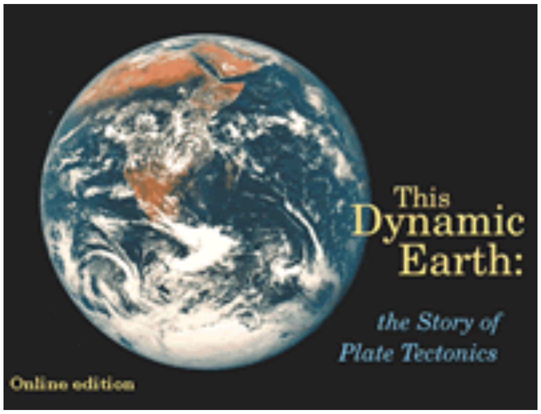
Since ancient times, the name Terra Firma (meaning "solid ground" in Latin) sometimes has been and occasionally still is used for planet Earth. While our planet is for the most part "solid" and firm, its outermost layer is everywhere in ceaseless motion, shifting at measurable average rates of several centimeters per year. This ever–moving layer upon which we live is a thin skin of solid crust and the rigid uppermost mantle making up Earth's lithosphere. The lithosphere is broken up into slabs that geologists call lithospheric plates or tectonic plates. During the 20th century, a major scientific concept—Theory of Plate Tectonics—emerged to explain why and how these plates move about and interact (see Plate Tectonics in a Nutshell). This theory has unified the study of the Earth and proven to be as relevant to the earth sciences as was the discovery of the structure of the atom to physics and chemistry, and as was the theory of evolution to the life sciences. Even though the plate tectonics theory is now widely accepted by the scientific community, some aspects of it are still being vigorously debated today.

THIS DYNAMIC PLANET MAP AND THIS DYNAMIC EARTH BOOKLET



In June 2006, the U.S. Geological Survey (USGS) and the Smithsonian Institution produced the Third Edition of <u>This Dynamic Planet: A World Map of Volcanoes, Earthquakes, and Plate Tectonics</u>. Like its two previous editions (1989 and 1994), this map—the all–time best–selling map of the USGS–remains exceptionally popular and widely distributed. Yet, despite the availability of this map, specifically intended for educational purposes, numerous and continued requests have been received from teachers for classroom materials that expand on the map's explanatory text. In response, a general–interest, non–jargon booklet called <u>This Dynamic Earth: The Story of Plate Tectonics</u> was published in 1996 to complement the map. This booklet partially filled the need, but additional classroom–specific activities and exercises are still being requested.

The Development of This Dynamic Planet: A Teaching Companion



The educators' continuing requests spurred an intermittent effort, which began in the 1990s, to develop a collection of classroom exercises—A Teaching Companion—specifically geared to the existing USGS plate tectonics map and booklet. This Teaching Companion is intended to assist teachers to teach plate tectonics, primarily for grades 6–14. Through several workshops held during 1990s at the USGS Menlo Park Center, dozens of teachers from across the country worked together, not only with authors of both the map and booklet but also other USGS experts, in developing classroom activities.

The Launch of the First This Dynamic Planet: A Teaching Companion Exercises

The first Teaching Companion Exercise released electronically is *Wegener's Puzzling Evidence*. This activity is based on Alfred Wegener's pioneering studies that demonstrated that the scattered distribution of certain fossil plants and animals on present–day, widely separated continents would form coherent patterns if the continents are rejoined as the pre–existing supercontinent Gondwanaland (web link to booklet).

The "Wegener's Puzzling Evidence" activity was selected to be released first because of its historical significance in the development of the Theory of Plate Tectonics. While the notion that continents may have not always been fixed in their present positions was suspected long before Wegener's time. Early map makers, for example Abraham Ortelius, noted as early as the late 16th century the similarity of the coastlines of the American and African continents and speculated that these continents might have once been joined. However, Wegener's analysis was the first to use geological and fossil evidence rather than merely fitting similar–looking coastlines.

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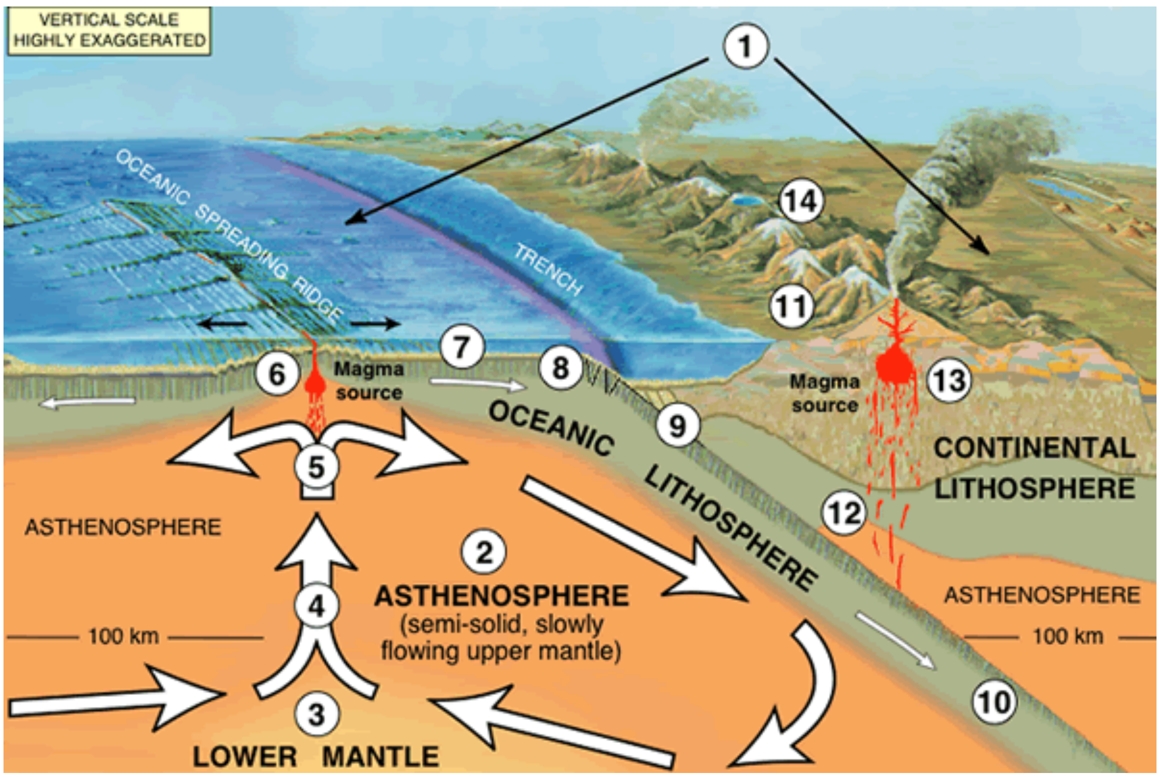
Plate Tectonics in a Nutshell

The theory of plate tectonics is a relatively new scientific concept. While its forerunner—the theory of continental drift—had its inception as early as the late 16th century, plate tectonics only emerged and matured as a widely accepted theory since the 1960s (see This Dynamic Earth booklet). In a nutshell, this theory states that the Earth's outermost layer is fragmented into a dozen or more large and small solid slabs, called lithospheric plates or tectonic plates, that are moving relative to one another as they ride atop hotter, more mobile mantle material (called the asthenosphere). The average rates of motion of these restless plates—in the past as well as the present—range from less than 1 to more than 15 centimeters per year. With some notable exceptions, nearly all the world's earthquake and volcanic activity occur along or near boundaries between plates.



Using the Diagram to Discuss How Plate Tectonics Works

To learn more about how plate tectonics work, start at the diagram (Appendix 1) and explanation labeled (1). Although this diagram shows the interaction between continental and oceanic plates, the processes illustrated generally apply for the interaction between two oceanic plates.

1. There are two basic types of LITHOSPHERE: continental and oceanic. CONTINENTAL lithosphere has a low density because it is made of relatively light-weight minerals. OCEANIC lithosphere is denser than continental lithosphere because it is composed of heavier minerals. A plate may be made up entirely of oceanic or continental lithosphere, but most are partly oceanic and partly continental.

2. Beneath the lithospheric plates lies the ASTHENOSPHERE, a layer of the mantle composed of denser semi-solid rock. Because the plates are less dense than the asthenosphere beneath them, they are floating on top of the asthenosphere.

3. Deep within the asthenosphere the pressure and temperature are so high that the rock can soften and partly melt. The softened but dense rock can flow very slowly (think of Silly Putty) over geologic time. Where temperature instabilities exist near the core/mantle boundary, slowly moving convection currents may form within the semi-solid asthenosphere.

4. Once formed, convection currents bring hot material from deeper within the mantle up toward the surface.

5. As they rise and approach the surface, convection currents diverge at the base of the lithosphere. The diverging currents exert a weak tension or “pull” on the solid plate above it. Tension and high heat flow weakens the floating, solid plate, causing it to break apart. The two sides of the now-split plate then move away from each other, forming a DIVERGENT PLATE BOUNDARY.

6. The space between these diverging plates is filled with molten rocks (magma) from below. Contact with seawater cools the magma, which quickly solidifies, forming new oceanic lithosphere. This continuous process, operating over millions of years, builds a chain of submarine volcanoes and rift valleys called a MID-OCEAN RIDGE or an OCEANIC SPREADING RIDGE.

7. As new molten rock continues to be extruded at the mid-ocean ridge and added to the oceanic plate (6), the older (earlier formed) part of the plate moves away from the ridge where it was originally created.

8. As the oceanic plate moves farther and farther away from the active, hot spreading ridge, it gradually cools down. The colder the plate gets, the denser (“heavier”) it becomes. Eventually, the edge of the plate that is farthest from the spreading ridges cools so much that it becomes denser than the asthenosphere beneath it.

9. As you know, denser materials sink, and that’s exactly what happens to the oceanic plate—it starts to sink into the asthenosphere! Where one plate sinks beneath another a subduction zone forms.

10. The sinking lead edge of the oceanic plate actually “pulls” the rest of the plate behind it—evidence suggests this is the main driving force of subduction. Geologists are not sure how deep the oceanic plate sinks before it begins to melt and lose its identity as a rigid slab, but we do know that it remains solid far beyond depths of 100 km beneath the Earth’s surface.

11. Subduction zones are one type of CONVERGENT PLATE BOUNDARY, the type of plate boundary that forms where two plates are moving toward one another. Notice that although the cool oceanic plate is sinking, the cool but less dense continental plate floats like a cork on top of the denser asthenosphere.

12. When the subducting oceanic plate sinks deep below the Earth’s surface, the great temperature and pressure at depth cause the fluids to “sweat” from the sinking plate. The fluids sweated out percolate upward, helping to locally melt the overlying solid mantle above the subducting plate to form pockets of liquid rock (magma).

13. The newly generated molten mantle (magma) is less dense than the surrounding rock, so it rises toward the surface. Most of the magma cools and solidifies as large bodies of plutonic (intrusive) rocks far below the Earth's surface. These large bodies, when later exposed by erosion, commonly form cores of many great mountain ranges [such as the Sierra Nevada (California) or the Andes (South America)] that are created along the subduction zones where the plates converge.

14. Some of the molten rock may reach the Earth's surface to erupt as the pent-up gas pressure in the magma is suddenly released, forming volcanic (extrusive) rocks. Over time, lava and ash erupted each time magma reaches the surface will accumulate—layer upon layer—to construct volcanic mountain ranges and plateaus, such as the Cascade Range and the Columbia River Plateau (Pacific Northwest, U.S.A.).

TECTONIC TIDBITS: MISCELLANEOUS SALIENT FACTS

- Plate tectonics processes almost certainly have been operating since the formation of the Earth (~ 4.6 billions years ago). However, the evidence of such processes very early in Earth's history have been masked or obliterated by younger geologic processes and deposits.

- Present-day continents are much older geologically than the seafloor of present-day ocean basins. Earliest recognized and dated continental rock (in Australia) was formed about 4.3 billion years ago. In contrast, the geologically oldest seafloor formed about 180 million years ago.

- Why this huge difference in geologic age between continental and oceanic rocks? Answer: the new crust formed along the ocean ridge crests is carried away by plate movement, and is ultimately "recycled" deep into the earth along subduction zones. But because continental crust is thicker and less dense than thinner, younger oceanic, most does not sink deep enough to be recycled and remains largely preserved on land.

- Present-day continents are fragments of a "supercontinent" (Pangaea) that broke up about 225 million years.

- There were a number of pre-Pangaea supercontinents, although the evidence becomes more and more obscure/problematic the farther back in geologic time. Pangaea itself was the product of accretion of fragments of pre-Pangaea supercontinent.

- More than 80% of the world's earthquakes and volcanoes occur along or near boundaries of the tectonic plates.

- Discovery and mapping of the rugged topography (e.g., huge mountain ranges, deep canyons) and the "magnetic striping" of the ocean floor were important milestones in the development of the plate tectonics theory.

- Earth is the only planetary body in our solar system that exhibits plate tectonics in action—at present as well as in the geologic past. To date, space-based planetary geological studies have not discovered any evidence of extra-terrestrial plate tectonics.

Wegener's Puzzling Evidence Exercise (6th Grade)

Although Alfred Wegener was not the first to suggest that continents have moved about the Earth, his presentation of carefully compiled evidence for continental drift inspired decades of scientific debate. Wegener's evidence, in concert with compelling evidence provided by post World War II technology, eventually led to universal acceptance of the theory of Plate Tectonics in the scientific community. The following pages are needed for this exercise: Teacher Overview (Appendix 2), (For Teachers) Wegener's Key to Continental Positions for grade 6 (Appendix 3), Student Puzzle Pieces (Appendix 4), Key/Legend to Wegener's Evidence sheet (Appendix 5), and Student Map of the World Today (Appendix 6). If students need additional hints beyond those provided below, there is a Puzzle Outline Hint (Appendix 7) to be used as a base for the puzzle.

Objectives

- Students will observe and analyze scientific evidence used by Wegener.
- Students will read and interpret maps and map symbols.
- Students will use the evidence to try to reconstruct the continents.
- Students will interpret the evidence to formulate a hypothesis.
- Students will defend their position on continental drift.

The Student Puzzle Pieces and Legend

To start this activity the teacher will present background information on Wegener (http://pubs.usgs.gov/gip/dynamic/wegener.html). Students will then be placed into groups of 2 to 3 and work to piece together continent cut-outs using this evidence. As students fit the continents together they find that isolated pieces of geologic information are no longer isolated. Groups describe what they have found, and must defend their conclusion by explaining how the evidence supports or refutes continental drift.

Time frame

1-2 class periods. Time frame can vary according to how much work is done in class and how much is done as outside assignments.

National standards references

The National Science Standards:

- UC&P - Unifying Concepts and Processes
- A2 - Understandings about scientific inquiry
- D1 - Structure of the Earth system
- G3 - History of science

The National Geography Standards:

- STANDARD 1: How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information.
- STANDARD 3: How to analyze the spatial organization of people, places, and environments on Earth's surface.
- STANDARD 17: How to apply geography to interpret the past.

Links across the curriculum

Geography - reading and drawing maps
Social Studies - History of science researchers, climate/culture of scientific community at the time of the research
Language Arts - Writing persuasive essays, presentations

Materials

For teacher:

Wegener's Key to Continental Positions for grade 6 – Appendix 3 (can made into an overhead).
This Dynamic Planet Booklet (http://pubs.usgs.gov/gip/dynamic/).

FOR EACH STUDENT GROUP:

Student Map of the World Today – Appendix 6
Key/Legend to Wegener's Evidence sheet – Appendix 5
Student Puzzle Pieces – Appendix 4
Crayons or markers
Scissors
Glue or tape
Paper

REFERENCE TO THIS DYNAMIC EARTH AND THIS DYNAMIC PLANET

pp. 1, 5, 8-13; Includes the present positions and the shapes of the continents on the map at http://pubs.usgs.gov/gip/dynamic/dynamic.html.

CONTENT BACKGROUND FOR TEACHERS

- Continents do NOT fit together smoothly! The important concept of this activity is that the evidence matches up.
- Background on Alfred Wegener can be found on pages 5, 9 -11 in This Dynamic Earth.

INSTRUCTIONS FOR ACTIVITY

Briefly present background on Wegener. Stress that although others had recognized the fit of Africa and South America, it was Wegener who gathered other scientific data to support his theory.

- Divide students into groups of two or three. These small groups allow students to discuss the significance of different lines of evidence as they piece together the continental puzzle.
- Each group is given a cut-out sheet containing fossil evidence (Student Puzzle Pieces), the Key to Wegener's Evidence sheet, the Student Map of the World Today reference sheet, crayons or markers, and a pair of scissors.
- Groups label the continents or land mass on each piece. The students then color each fossil type and the Key to Wegener's Evidence sheet. Then cut out the land masses from the evidence sheets.
- Have the students arrange the puzzle pieces using the Key to Wegener's Evidence to support their arrangement.
- The final puzzle configuration should be attached to paper with glue or tape.
- When finished, each group will present and defend their reconstruction.

- You may compare the students' reconstructions with Wegener's Key to Continental Positions about 250 million years ago (Teacher Copy)

Hints for Solving the Puzzle

1. Have the students look for all the pieces with the fossil remains of Cynognathus and then put them together (South America and Africa).
2. Then look for fossils that extend beyond the plate boundary such as the fern Glossopteris and the land-dwelling reptile Lystrosaurus. Put all of the continents with Glossopteris and Lystrosaurus near each other. Notice how two of the continents (Africa and Antartica) have the end regions of Lystrosaurus. Lystrosaurus is the key to solving the puzzle. What happens to the other continent (India) if you put Antartica next to Africa? The students must place India next to Africa to complete the puzzle.
3. You can also use the Puzzle Outline Hint (Appendix 7) as a base for the puzzles.

Teacher answer key

It is okay if students don't get the "correct" answer or the same solution Wegener proposed as long as they can explain their thought process and how they used the evidence to arrive at their conclusion. There is much information missing from the picture. For example, ancient shorelines were not the same as they are today due to changes in sea level and the tectonic process (continents colliding and pulling apart, causing rocks to be added or torn off). Scientists still debate the fine details of paleogeographic (ancient geography) reconstruction. It is far more important to have students grasp the concept of how scientists look for clues, or evidence, and put the pieces together to solve a problem.

Students should understand that using the shape of the continents to fit them back together is using one type of evidence. Using the presence of the same type and age fossils is another. The presence of the same rock types is another form of evidence. Ask students if they can think of other types of evidence to search for that might be useful in solving their puzzle.

See also illustrations on pages 1 and 8 of This Dynamic Earth.

Assessment suggestions

- Students evaluate Wegener's hypothesis based on the evidence they observe. Student groups each write a 'position paper' on whether the evidence they researched is compelling and conclusive enough for scientific acceptance of the Theory of Continental Drift.
- Each group then presents their conclusion as they would at a professional scientific meeting, explaining their research and how they came to this conclusion. Other students are encouraged to ask probing (but polite!) questions.
- For self assessment, the teacher may hand out the Wegener's Key to Continental Positions.

Extensions

Assign students to two groups, those who have determined that the evidence supports the theory of continental drift, and those who believe that the evidence does not support the theory. Have these two groups debate their positions. For an interesting twist, put students into groups opposite to their view.

Ask students to think about continental reconstructions older than 250 million years ago. What would be the difficulties in creating a paleogeographic reconstruction of the continents 1 billion years ago?

Additional resources

A good animation of plate movement over time can be found at http://www.scotese.com.

PLATE TECTONICS TENNIS BALL GLOBE

OVERVIEW

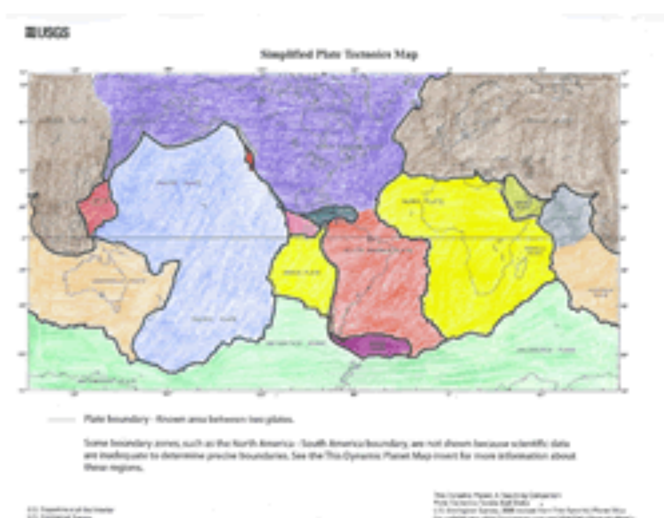
This activity creates a mini globe that shows the major plate boundaries of the world. It provides each student with his or her own physical model of the Earth's plates and helps teach how hard it is to accurately portray a sphere (three-dimensional) on a flat map (two-dimensional). The following files are needed for this exercise: Teacher Instructions (Appendix 8), Student Instructions (Appendix 9), Simplified Plate Tectonics Map (Appendix 10), and Plate Tectonics Tennis Ball Globe (Appendix 11). If you do not have a copy of the This Dynamic Planet Map (download at http://pubs.usgs.gov/imap/2800/) (Interactive version available - http://volcano.si.edu/tdpmap/), you will want to download parts of it, in particular, the interpretive map (Appendix 12).

OBJECTIVES

- Students will examine one method for creating a two-dimensional map of a spherical surface.
- Students will create a model of the earth that they can hold and examine.
- Students will examine plate boundaries, continents, and oceans on a globe.
- Students will examine divergent, convergent, and transform plate boundaries.
- Students will draw plate boundaries on a map and learn that more scientific data are needed to more accurately locate certain boundaries.
- Students will compare the features on a map that fits on a sphere with the same features on a more standard flat, two-dimensional, map to learn how our standard maps are distorted towards the poles.

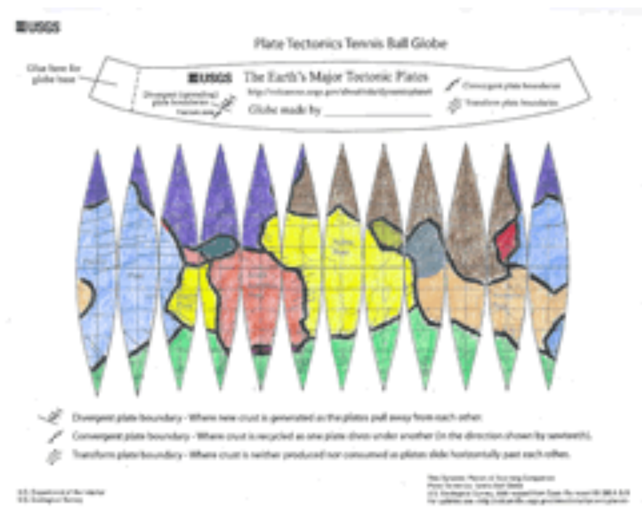
COLORED SIMPLIFIED PLATE TECTONICS MAP AND TENNIS BALL GLOBE MAP

TIME FRAME



This activity should take 2 class periods. Younger students could take several class sessions to finish because of the cutting and gluing. If you would like to complete the exercise in one class period, create a few completed tennis ball models beforehand and have the class do everything except the cutting and gluing to the tennis balls.

NATIONAL STANDARDS REFERENCES



See Science and Geography Standards matrices on pages X- Y.

Links across the curriculum

- Art
- Geography
- Mathematics - Geometry

Materials

For teacher:

This Dynamic Planet map http://volcano.si.edu/tdpmap/
This Dynamic Planet Booklet http://pubs.usgs.gov/gip/dynamic/
Teacher Instructions – Appendix 8
Plate Tectonics Tennis Ball Globe – Appendix 11(complete the model to show a finished product)
Simplified Plate Tectonics Map – Appendix 10 (color in to show an example)

For each student:

Student Instructions – Appendix 9
Simplified Plate Tectonics Map – Appendix 10
Plate Tectonics Tennis Ball Globe – Appendix 11
Old tennis ball
White glue
Coloring items - pencils, markers, sharp crayons
Scissors

Reference to Dynamic Earth booklet and Dynamic Planet map

- This Dynamic Planet map
- This Dynamic Earth: p. 2, 6, 7, 15, 16, 29, 30-38, 43, 50, 52, 56

ADDITIONAL INFORMATION FOR TEACHER

- The data on the small globe have been simplified for the small size of the project.
- Cutting the map takes dexterity and patience.
- Not all the plate boundaries are easy to see. For some, there is not enough scientific data to determine the precise locations. The students will need to use the insert Interpretive Map on the This Dynamic Planet map (available as a pdf).
- New tennis balls will work, but since they are very fuzzy, they will be more difficult to glue onto. Tennis ball sizes vary slightly and the model may not fit exactly.
- Tennis balls are usually available if you have a tennis club or courts nearby and you let people there that you need them for a science project. A bag or box should be supplied to collect them.
- We recommend using six or more colors for coloring the map. The map can be colored with only four different colors but it's a classic logic puzzle and math problem (four color theorem) - see extensions below.

INSTRUCTIONS FOR ACTIVITY

(TEACHER INSTRUCTIONS INCLUDES ANSWERS TO QUESTIONS ON STUDENT INSTRUCTIONS)

1. Photocopy the three student pages. If possible, make extra copies of the Student Plate Tectonics Tennis Ball Globe handout and the Simplified Plate Tectonics Map in case of error. Make sure all students have an old tennis ball.
2. Have the students color the plates on their copy of the Simplified Plate Tectonics Map. No touching plates should be the same color so some planning will be needed.
3. Have the students answer the questions on their Instruction Sheet throughout the activity.
4. Have the students color in the different plate boundaries in black referring to the Simplified Plate Tectonics Map. Then color in the plates making sure that touching plates are not the same color.
5. Students then cut out their map.
6. Apply glue across the back of the equator. Apply to center of the tennis ball making sure both poles cover the ball.
7. Carefully brush glue on a flap and press down to ball. Repeat to glue the rest of the ball.
8. Cut out the base and glue its ends together to form a ring. When dry, rest globe on the base.

QUESTIONS FROM STUDENT INSTRUCTION SHEET AND ANSWERS

After the students have colored the plates on their copy of the Simplified Plate Tectonics Map

1. **Which plates look the largest to you?**

There is no 'right' answer. Many plates may look large but the goal is to have the kids compare the polar regions on both maps. Make sure students notice that most plates contain both continental and oceanic material.

2. Plate boundary types are not always the same across the entire boundary. Suggested answers are given to each question below. The India – Australia and North America – South America boundaries are not well defined and should not be included in the answers to this set of questions.

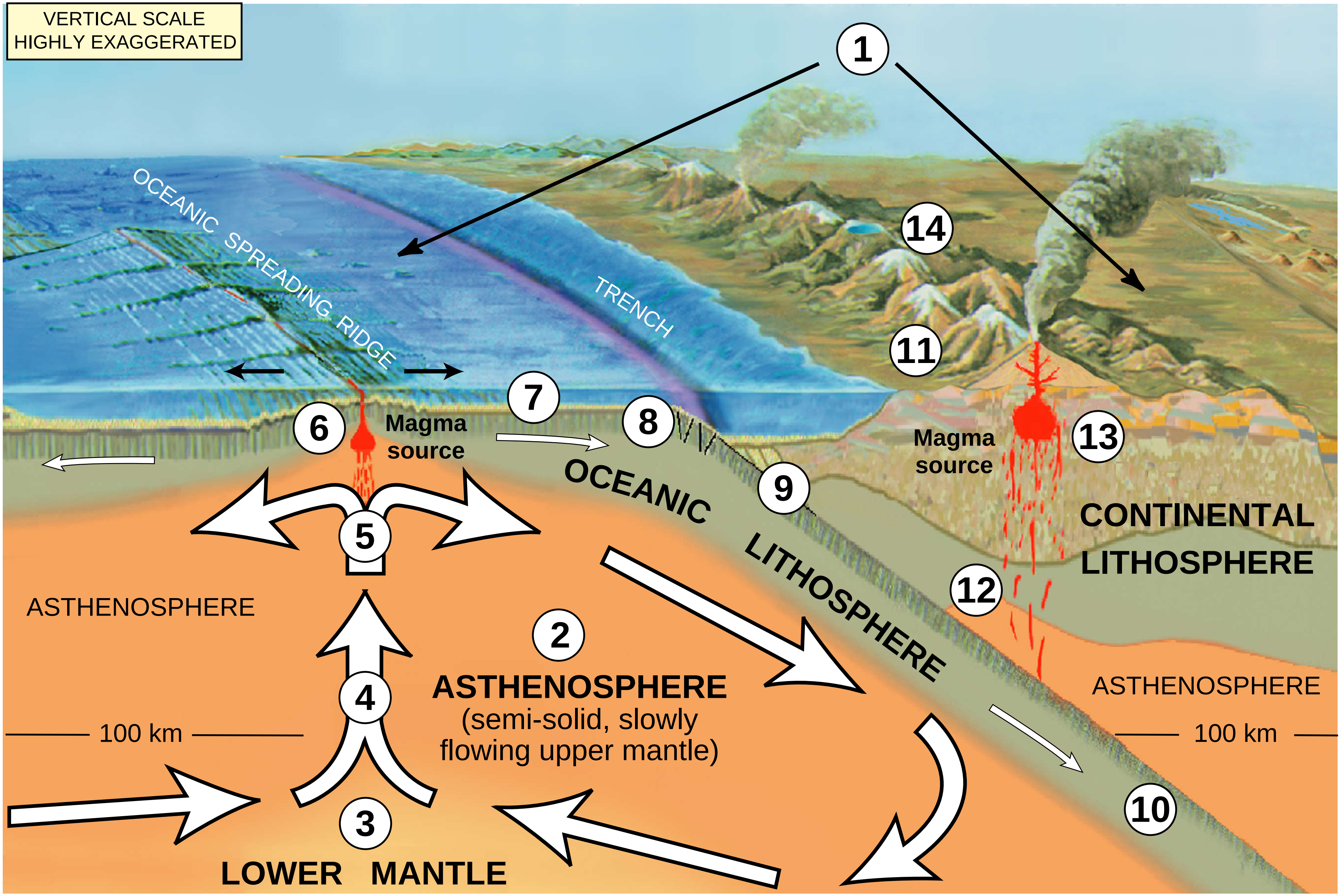
    - **List three divergent boundaries not including the example.** Example: There is a divergent boundary between the Nazca and Pacific plates.
      Antarctic and Australia, Pacific, South America, Nubia Nubia and South America, India, Antarctic Australia and Antarctic North America and Nubia, Eurasia (on one side), Pacific (in two areas)
    - **List two convergent boundaries.** Pacific and North America, Eurasia India and Eurasia Nubia and Eurasia Australia and Eurasia, Pacific
    - **Give an example of a transform plate boundary.** North America and Carribean, Pacific South America and Carribean Australia and Pacific
3. After coloring the plate boundaries on your Plate Tectonics Tennis Ball Globe handout in black. Are all the plate boundaries easy to see? Compare your two maps to the This Dynamic Planet map. What boundaries are not as obvious as other boundaries? No. The following are difficult to see: North America – South America, India – Australia. Scientists do not have enough data to determine the plate boundaries in those areas.
4. Color the plates on your Plate Tectonics Tennis Ball Globe following your Simplified Plate Tectonics Map such that no adjacent plates are the same color.
    - **Which plates look the largest to you?**
      Here only the plates near the equator should look large.
    - **How are the plates near the north and south poles different on your Plate Tectonics Tennis Ball Globe map than on your Simplified Plate Tectonics Map?**
      The Plate Tectonics Tennis Ball Globe map is not a rectangle, it has multiple areas that are "cut out" to fit a sphere. Many students may not have seen the shape of a flattened sphere. This exercise will help reinforce geometry concepts about maps. In order to make a map from the flattened sphere, multiple calculations are used to "fill in" the spaces. The students should notice that the closer they look towards the poles, the more distorted the Simplified Plate Tectonics Map is.
    - **What do your observations tell you about making maps?**
      It's impossible to accurately represent an entire sphere on a flat map.
5. Compare your globe with the This Dynamic Planet Map.
   Where are the majority of the earthquakes and volcanoes?
   The vast majority of earthquakes and volcanoes are near or at plate boundaries.

Assessment suggestions

The questions from the student instruction sheet can be used with this activity.

Extensions and Additional Resources

- Use mandarin oranges or other fruits that are easy to peel to show how difficult it is to go from a three-dimensional object to a two-dimensional surface. Have students try to flatten the peel.
- Talk about the accuracy of maps of different sizes, for example, a map of your school versus a map of the world.
- Discuss the four-color theorem and let students try to figure out how to color the map using only four colors. Background: Francis Guthrie, in 1852, noticed that only four different colors were needed to color the map of counties of England such that no two adjacent regions are the same color. The Simplified Plate Tectonics Map can be colored using only four colors.



VERTICAL SCALE
HIGHLY EXAGGERATED
1
OCEANIC SPREADING RIDGE
TRENCH
14
11
7
8
6
Magma
source
Magma
source
13
9
OCEANIC
LITHOSPHERE
CONTINENTAL
LITHOSPHERE
5
ASTHENOSPHERE
12
2
ASTHENOSPHERE
4
ASTHENOSPHERE
(semi-solid, slowly
flowing upper mantle)
100 km
100 km
10
3
LOWER MANTLE

WEGENER'S PUZZLING CONTINENTAL DRIFT EVIDENCE – 6TH GRADE

Overview

Although Alfred Wegener was not the first to suggest that continents have moved about the Earth, his presentation of carefully compiled evidence for continental drift inspired decades of scientific debate. Wegener's evidence, in concert with compelling evidence provided by post World War II technology, eventually led to universal acceptance of the theory of Plate Tectonics in the scientific community

Objectives

- Students will observe and analyze scientific evidence used by Wegener.
- Students will read and interpret maps and map symbols.
- Students will use the evidence to try to reconstruct the continents.
- Students will interpret the evidence to formulate a hypothesis.
- Students will defend their position on continental drift.

To start this activity the teacher will present background information on Wegener. Students will then be placed into groups of 2 to 3 and work to piece together continent cut-outs using this evidence. As students fit the continents together they find that isolated pieces of geologic information are no longer isolated. Groups describe what they have found, and must defend their conclusion by explaining how the evidence supports or refutes continental drift. [Materials available online at http://volcanoes.usgs.gov/about/edu/dynamicplanet]

Time frame

1-2 class periods. Time frame can vary according to how much work is done in class and how much is done as outside assignments.

National standards references

The National Science Standards:

- UC&P - Unifying Concepts and Processes
- A2 - Understandings about scientific inquiry
- D1 - Structure of the Earth system
- G3 - History of science

The National Geography Standards:

- STANDARD 1: How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information.

- STANDARD 3: How to analyze the spatial organization of people, places, and environments on Earth's surface.
- STANDARD 17: How to apply geography to interpret the past.

Links across the curriculum

Geography - reading and drawing maps
Social Studies - History of science researchers, climate/culture of scientific community at the time of the research
Language Arts - Writing persuasive essays, presentations

Materials

For teacher:

- Teacher Copy of Wegener's Key to Continental Positions (can made into an overhead)
- *This Dynamic Planet* map;

For each student group:

- Student Map of the World Today
- Key to Wegener's Evidence sheet
- Student Puzzle Pieces
- Crayons or markers
- Scissors
- Glue or tape
- Paper

Reference to *This Dynamic Earth* & *This Dynamic Planet*
pp. 1, 5, 8-13; Includes the present positions and the shapes of the continents on the map**.**
http://pubs.usgs.gov/gip/dynamic/dynamic.html

Content background for teachers

- Continents do NOT fit together smoothly! The important concept of this activity is that the evidence matches up.
- Background on Alfred Wegener can be found on pages 5, 9 -11 in *This Dynamic Earth.*

Teacher instructions for activity
Briefly present background on Wegener. Stress that although others had recognized the fit of Africa and South America, it was Wegener who gathered other scientific data to support his theory.

- Divide students into groups of two or three. These small groups allow students to discuss the significance of different lines of evidence as they piece together the continental puzzle.
- Each group is given a cut-out sheet containing fossil evidence (Student Puzzle Pieces), the Key to Wegener's Evidence sheet, the Student Map of the World Today reference sheet, crayons or markers, and a pair of scissors.
- Groups label the continents or land mass on each piece. The students then color each

fossil type and the Key to Wegener's Evidence sheet. Then cut out the land masses from the evidence sheets.

- Have the students arrange the puzzle pieces using the Key to Wegener's Evidence to support their arrangement.
- The final puzzle configuration should be attached to paper with glue or tape.
- When finished, each group will present and defend their reconstruction.
- You may compare the students' reconstructions with Wegener's Key to Continental Positions about 250 million years ago (Teacher Copy)

Hints for solving the puzzle

- Have the students look for all the pieces with the fossil remains of Cynognathus and then put them together (South America and Africa).
- Then look for fossils that extend beyond the plate boundary such as the fern Glossopteris and the land-dwelling reptile Lystrosaurus. Put all of the continents with Glossopteris and Lystrosaurus near each other. Notice how two of the continents (Africa and Antartica) have the end regions of Lystrosaurus. Lystrosaurus is the key to solving the puzzle. What happens to the other continent (India) if you put Antartica next to Africa? The students must place India next to Africa to complete the puzzle.
- You can also use the Puzzle Outline Hint as a base for the puzzles.

Teacher answer key

It is okay if students don't get the "correct" answer or the same solution Wegener proposed. There is much information missing from the picture. For example, ancient shorelines were not the same as they are today due to changes in sea level and the tectonic process (continents colliding and pulling apart, causing rocks to be added or torn off). Scientists still debate the fine details of paleogeographic (ancient geography) reconstruction. It is far more important to have students grasp the concept of how scientists look for clues, or evidence, and put the pieces together to solve a problem.

Students should understand that using the shape of the continents to fit them back together is using one type of evidence. Using the presence of the same rock types is another form of evidence, and the presence of the same type and age fossils is yet another. Ask students if they can think of other types of evidence to search for that might be useful in solving their puzzle.

See also illustrations on pages 1 and 8 of *This Dynamic Earth*.

Assessment suggestions

Students evaluate Wegener's hypothesis based on the evidence they observe.

- Student groups each write a 'position paper' on whether the evidence they researched is compelling and conclusive enough for scientific acceptance of the Theory of Continental Drift.

- Each group then presents their conclusion as they would at a professional scientific meeting, explaining their research and how they came to this conclusion. Other students are encouraged to ask probing (but polite!) questions.

- For self assessment, the teacher may hand out the Wegener's Key to Continental Positions.

Extensions

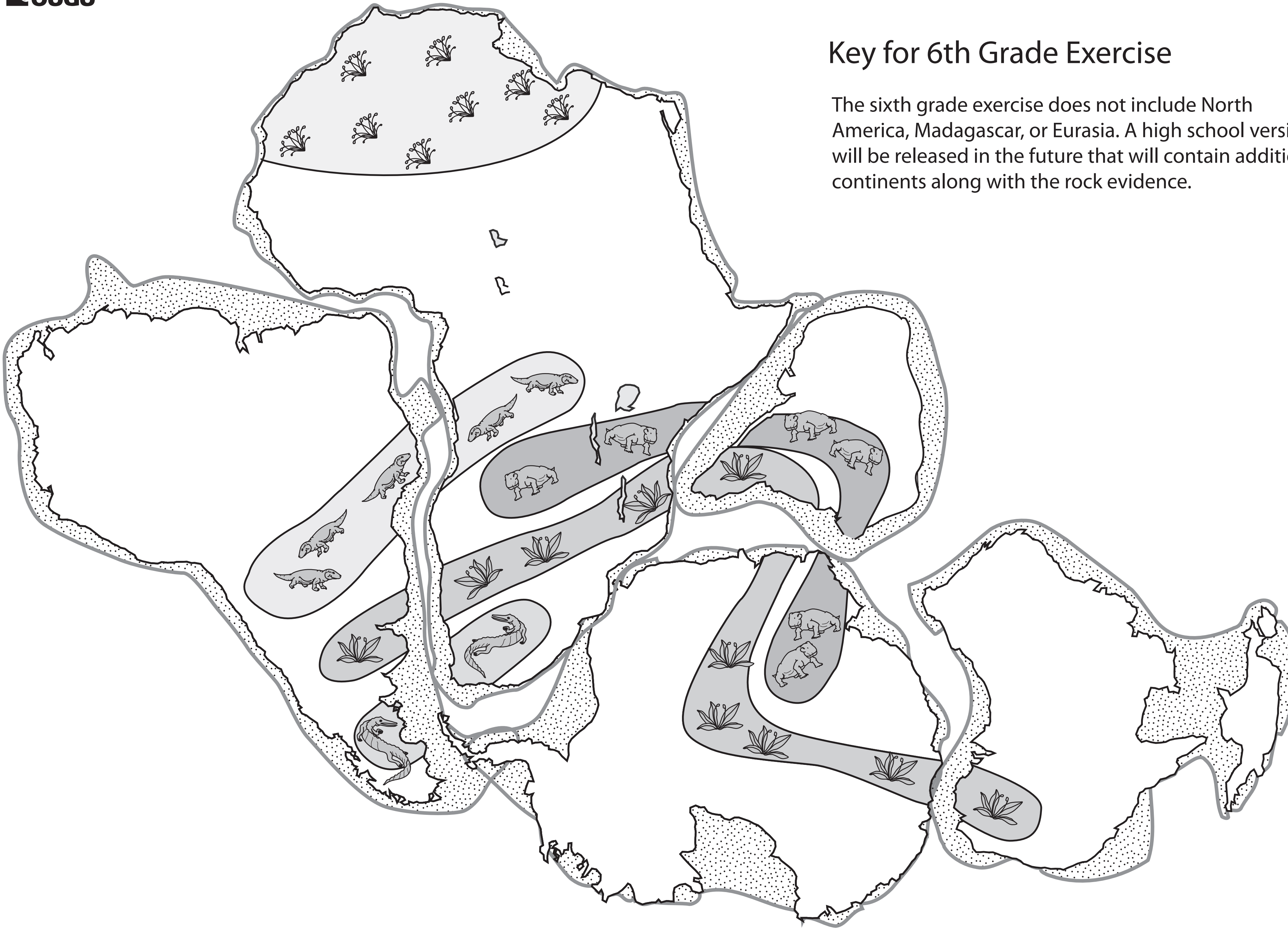
Assign students to two groups, those who have determined that the evidence supports the theory of continental drift, and those who believe that the evidence does not support the theory. Have these two groups debate their positions. For an interesting twist, put students into groups opposite to their view.

Ask students to think about continental reconstructions older than 250 million years ago. What would be the difficulties in creating a paleogeographic reconstruction of the continents 1 billion years ago?

Additional resources
A good animation of plate movement over time can be found at www.scotese.com.

Key for 6th Grade Exercise

The sixth grade exercise does not include North America, Madagascar, or Eurasia. A high school version will be released in the future that will contain additional continents along with the rock evidence.

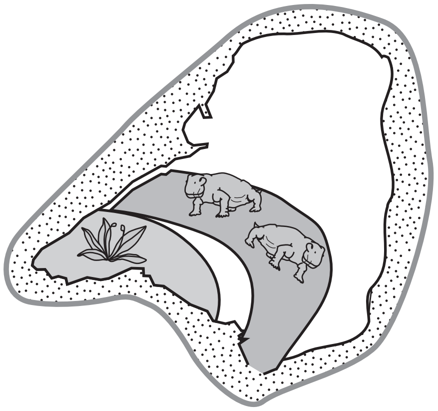


This Dynamic Planet; A Teaching Companion
Wegener's Puzzling Continental Drift Evidence
U.S. Geological Survey, 2008
For updates see <http://volcanoes.usgs.gov/about/edu/dynamicplanet>

U.S. Department of the Interior
U.S. Geological Survey

Fossil Evidence

DIRECTIONS: Cut out each of the continental land masses along the edge of the continental shelf (the outer line).



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USGS

Wegener’s Puzzling Evidence

DIRECTIONS:

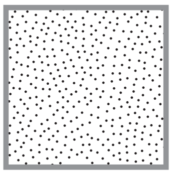
1. Label the land masses on each sheet. Color the fossil areas to match the legend below.

2. Cut out each of the continents along the edge of the continental shelf (the outermost dark line). Alfred Wegener's evidence for continental drift is shown on the cut-outs. Wegener used this evidence to reconstruct the positions of the continents relative to each other in the distant past.

3. Try to logically piece the continents together so that they form a giant supercontinent.

4.When you are satisfied with the 'fit' of the continents, discuss the evidence with your partners and decide if the evidence is compelling or not. Explain your decision and reasoning on the evidence.

Key to Wegener’s Puzzling Evidence - Fossils

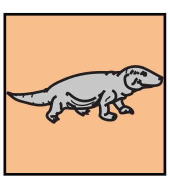


The continents is surrounded by the continental shelf (stippled pattern), which extends beyond the continent until there is a large change in slope.

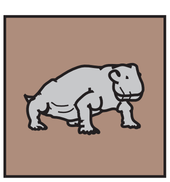
By about 300 million years ago, a unique community of plants had evolved known as the European flora. Fossils of these plants are found in Europe and other areas. Color the areas with these fossils yellow.

Fossils of the fern Glossopteris have been found in these locations . Color the areas with these fossils green.

Fossil remains of the half meter-long fresh or brackish water (reptile) Mesosaurus. Mesosaurs flourished in the early Mesozoic Era, about 240 million years ago. Mesosaurs had limbs for swimming, but could also walk on land. Other fossil evidence found in rocks along with Mesosaurs indicate that they lived in lakes and coastal bays or estuaries. Color the areas with these fossils blue.



Fossil remains of Cynognathus, a land reptile approximately 3 meters long that lived during the Early Mesozoic Era, about 230 million years ago. It was a weak swimmer. Color the areas with these fossils orange.



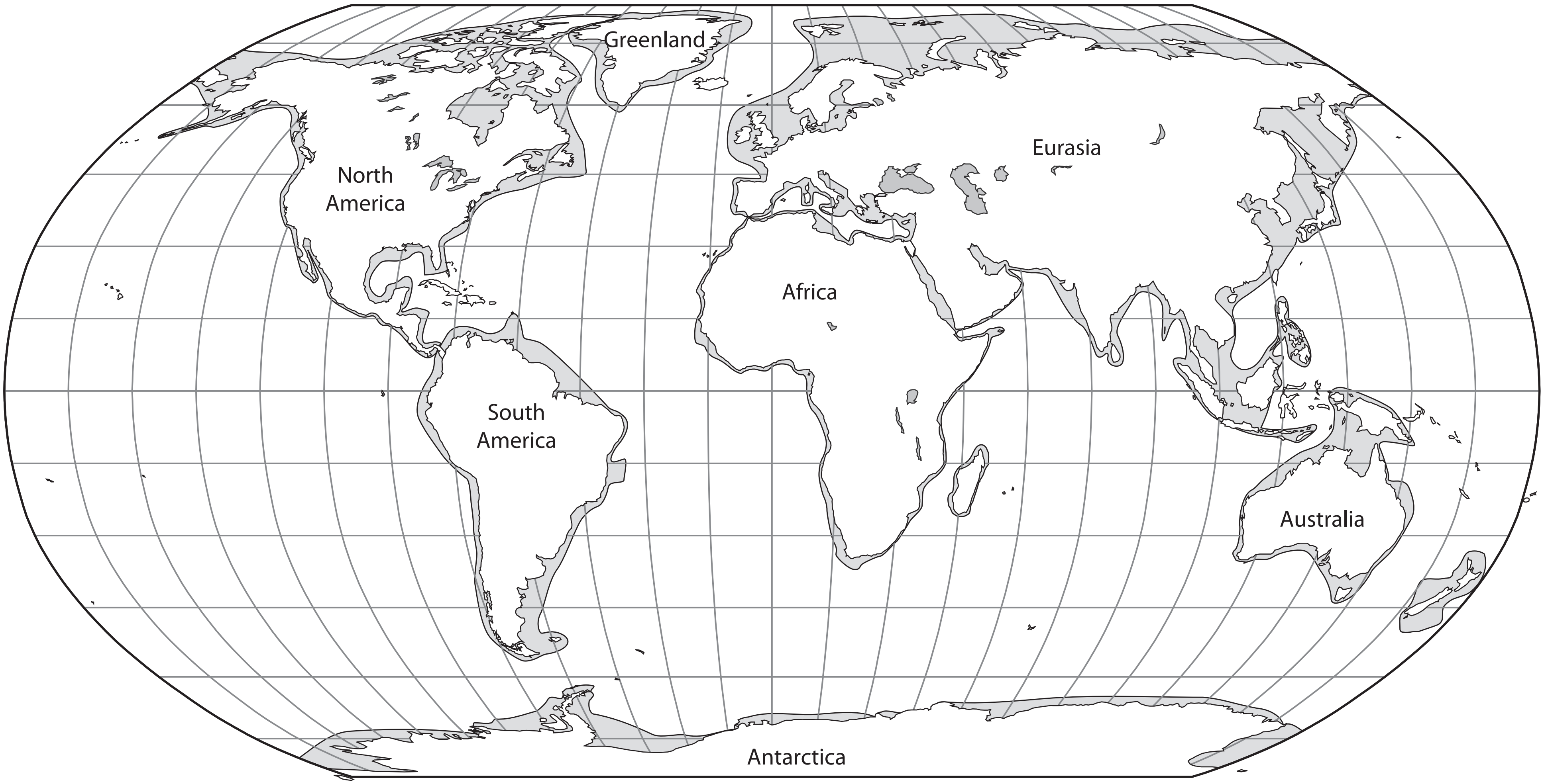
Fossil evidence of the Early Mesozoic, land-dwelling reptile Lystrosaurus. They reproduced by laying eggs on land. In addition, their anatomy suggests that these animals were probably very poor swimmers. Color the areas with these fossils brown.

U.S. Department of the Interior
U.S. Geological Survey

This Dynamic Planet; A Teaching Companion
Wegener’s Puzzling Continental Drift Evidence
U.S. Geological Survey, 2008
For updates see <http://volcanoes.usgs.gov/about/edu/dynamicplanet>

The World Today

This map shows the continents as they appear today. Most of the continental land masses lie above sea level, but the true edges of the continents are not at the shoreline.   The gray areas on this map show the relatively shallow water that covers the fringes of the continents. These sea-covered borders are known as CONTINENTAL SHELVES (gray areas). The margins of the continental shelves mark the true edges of the continents. This map shows the continents as they appear today. Most of the continental land masses lie above sea level, but the true edges of the continents are not at the shoreline. These sea-covered borders are known as CONTINENTAL SHELVES . The margins of the continental shelves mark the true edges of the continents.



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U.S. Geological Survey, 2008
For updates see <http://volcanoes.usgs.gov/about/edu/dynamicplanet>

U.S. Department of the Interior
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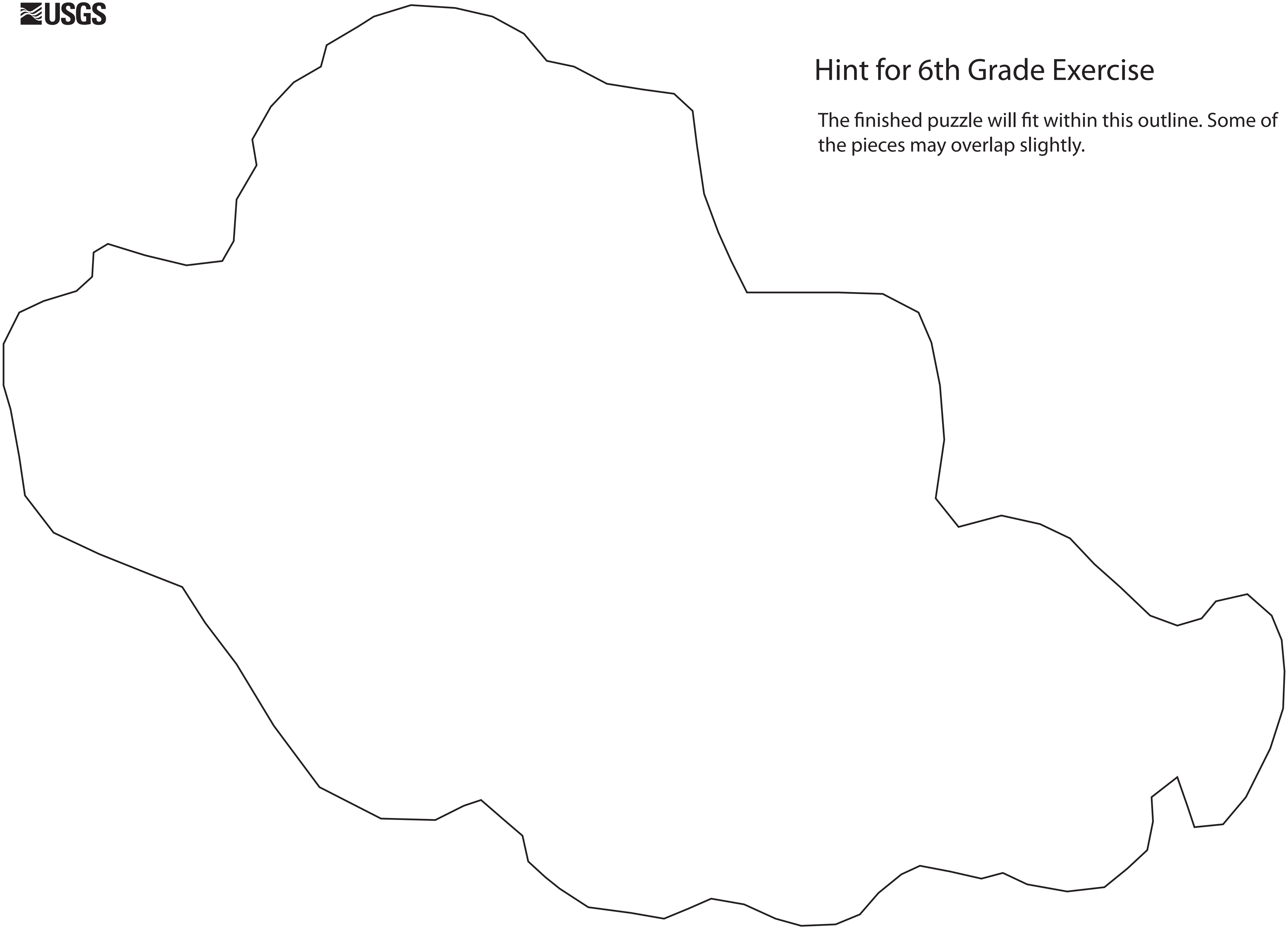
Hint for 6th Grade Exercise

The finished puzzle will fit within this outline. Some of the pieces may overlap slightly.



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U.S. Department of the Interior
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TEACHER NOTES: PLATE TECTONICS TENNIS BALL GLOBE

Overview

This activity creates a mini globe that shows the major plate boundaries of the world. It provides each student with his or her own physical model of the Earth's plates and helps teach how hard it is to accurately portray a sphere (three-dimensional) on a flat map (two-dimensional). See online materials http://volcanoes.usgs.gov/about/edu/dynamicplanet

Time frame

This activity should take 2 class periods. Younger students could take several class sessions to finish because of the cutting and gluing. If you would like to complete the exercise in one class period, create a few models beforehand and have the class do everything except for the cutting and gluing to the tennis balls.

Objectives

- Students will examine one method for creating a two-dimensional map of a spherical surface.
- Students will create a model of the earth that they can hold and examine.
- Students will examine plate boundaries, continents, and oceans on a map and globe.
- Students will examine divergent, convergent, and transform plate boundaries.
- Students will draw plate boundaries on a map and learn that more scientific data are needed to more accurately locate certain boundaries.
- Students will compare the features on a map that fits on a sphere with the same features on a more standard flat, two-dimensional, map to learn how our standard maps are distorted towards the poles.

National standards references
See Science and Geography Standards matrices on pages X- Y.

Links across the curriculum
- Art
- Geography
- Mathematics - Geometry

Materials
For teacher:
- This Dynamic Planet map
- This Dynamic Earth booklet
- Student Plate Tectonics Tennis Ball Globe handout
- Colored Simplified Plate Tectonics Map
- Completed tennis ball model

For each student:

- Student Plate Tectonics Tennis Ball Globe handout
- Simplified Plate Tectonics Map (not colored)
- Old tennis ball
- White glue
- Coloring items—pencils, markers, sharp crayons
- Scissors

Reference to Dynamic Earth booklet and Dynamic Planet map

- This Dynamic Planet map
- This Dynamic Earth: p. 2, 6, 7, 15, 16, 29, 30 – 38, 43, 50, 52, 56

Additional information for teacher

- The data on the small globe have been simplified for the small size of the project.
- Cutting the map takes dexterity and patience.
- Not all the plate boundaries are easy to see. For some, there is not enough scientific data to determine the precise locations. The students will need to use the insert Interpretive Map on the This Dynamic Planet map (available as a pdf at http://volcanoes.usgs.gov/about/edu/dynamicplanet/ballglobe/interpretive.pdf)
- New tennis balls will work, but since they are very fuzzy, they will be more difficult to glue onto. Tennis ball sizes vary slightly and the model may not fit exactly.
- Tennis balls are usually available if you have a tennis club or courts nearby and you let people there that you need them for a science project. A bag or box should be supplied to collect them.
- We recommend using six or more colors for coloring the map. The map can be colored with only four different colors but it's a classic logic puzzle and math problem (four color theorem) – see extensions below.

Instructions for activity

1. Photocopy the three student pages. If possible, make extra copies of the Student Plate Tectonics Tennis Ball Globe handout and the Simplified Plate Tectonics Map in case of error. Make sure all students have an old tennis ball.
2. Have the students color the plates on their copy of the Simplified Plate Tectonics Map. No touching plates should be the same color so some planning will be needed.
3. Have the students answer the questions on their Instruction Sheet throughout the activity.
4. Have the students color in the different plate boundaries in black referring to the Simplified Plate Tectonics Map. Then color in the plates making sure that touching plates are not the same color.
5. Students then cut out their map.
6. Apply glue across the back of the equator. Apply to center of the tennis ball making sure both poles cover the ball.
7. Carefully brush glue on a flap and press down to ball. Repeat to glue the rest of the

ball.
8. Cut out the base and glue ends together to form a ring. When dry, rest globe on base.

Questions from student instruction sheet and answers

After the students have colored the plates on their copy of the Simplified Plate Tectonics Map

1. Which plates look the largest to you?

There is no ‘right’ answer. Many plates may look large but the goal is to have the kids compare the polar regions on both maps. Make sure students notice that most plates contain both continental and oceanic material.

2. Plate boundary types are not always the same across the entire boundary. Suggested answers are given to each question below. The India – Australia and North America – South America boundaries are not well defined and should not be included in the answers to this set of questions.

List three divergent boundaries not including the example. Example: There is a divergent boundary between the Nazca and Pacific plates.

Antarctic and Australia, Pacific, South America, Nubia
Nubia and South America, India, Antarctic
Australia and Antarctic
North America and Nubia, Eurasia (on one side), Pacific (in two areas)

List two convergent boundaries.

Pacific and North America, Eurasia
India and Eurasia
Nubia and Eurasia
Australia and Eurasia, Pacific

Give an example of a transform plate boundary.

North America and Carribean, Pacific
South America and Carribean
Australia and Pacific

3. After coloring the plate boundaries on your Plate Tectonics Tennis Ball Globe handout in black.

Are all the plate boundaries easy to see? Compare your two maps to the This Dynamic Planet map. What boundaries are not as obvious as other boundaries?

No. The following are difficult to see: North America – South America, India – Australia. Scientists do not have enough data to determine the plate boundaries in those areas.

4. Color the plates on your Plate Tectonics Tennis Ball Globe following your Simplified Plate Tectonics Map such that no adjacent plates are the same color. **Which plates look the largest to you?**

Here only the plates near the equator should look large.

How are the plates near the north and south poles different on your Plate Tectonics Tennis Ball Globe map than on your Simplified Plate Tectonics Map?

The Plate Tectonics Tennis Ball Globe map is not a rectangle, it has multiple areas that are "cut out" to fit a sphere. Many students may not have seen the shape of a flattened sphere. This exercise will help reinforce geometry concepts about maps. In order to make a map from the flattened sphere, multiple calculations are used to "fill in" the spaces. The students should notice that the closer they look towards the poles, the more distorted the Simplified Plate Tectonics Map is.

What do your observations tell you about making maps?

It's impossible to accurately represent an entire sphere on a flat map.

8. **Compare your globe with the This Dynamic Planet Map. Where are the majority of the earthquakes and volcanoes?**

The vast majority of earthquakes and volcanoes are near or at plate boundaries.

Assessment suggestions

The questions from the instruction sheet (answers above) can be used with this activity.

Extensions and Additional Resources

1. Exploring Maps Teacher packet
   http://egsc.usgs.gov/isb/pubs/teachers-packets/exploringmaps/index.html
2. What do Maps Show packet
   http://egsc.usgs.gov/isb/pubs/teachers-packets/mapshow/
3. Investigate how maps are made and different types of projections.
   http://egsc.usgs.gov/isb/pubs/MapProjections/projections.html
4. Use clementines or other fruits that are easy to peel to show how difficult it is to go from a three-dimensional object to a two-dimensional map.
5. Talk about the accuracy of maps of different sizes, for example, a map of your school versus a map of the world.
6. Discuss the four-color theorem and let students try to figure out how to color the map using only four colors. Background: Francis Guthrie, in 1852, noticed that only four different colors were needed to color the map of counties of England such that no two adjacent regions are the same color. The Simplified Plate Tectonics Map can be colored using only four colors.

Plate Tectonics Tennis Ball Globe Instructions

1. Color the plates on your copy of the Simplified Plate Tectonics Map such that no adjacent (sharing a boundary) plates are the same color. Some planning will be needed depending on how many different colors you are using. Notice that most plates contain continents and oceans.
    - Which plates look the largest to you?

2. Now turn to your Plate Tectonics Tennis Ball Globe handout.
    - List three divergent boundaries not including the example. Example: There is a divergent boundary between the Nazca and Pacific plates.
    - List two convergent boundaries.
    - Give an example of a transform plate boundary.

3. Color all the plate boundaries on your Plate Tectonics Tennis Ball Globe handout in black. Use your Simplified Plate Tectonics Map as a guide. As you color, notice which boundaries are divergent, convergent, and transform.
    - Are all the plate boundaries easy to see? Compare your two maps to the This Dynamic Planet map. What boundaries are not as obvious as other boundaries?

4. Color the plates on your Plate Tectonics Tennis Ball Globe following your Simplified Plate Tectonics Map such that no adjacent plates are the same color.
    - Which plates look the largest to you?
    - How are the plates near the north and south poles different on your Plate Tectonics Tennis Ball Globe map than on your Simplified Plate Tectonics Map?
    - What do your observations tell you about making maps?

5. Carefully cut out your Plate Tectonics Tennis Ball Globe.
6. Apply glue across the back of the equator. Press the equator of your map to the center of the tennis ball making sure both poles cover the ball.
7. Carefully brush glue on a flap and press down to ball. Repeat to cover the globe.
8. Cut out the base. Glue the ends together to form a ring. When dry, rest globe on base.
    - Compare the This Dynamic Planet Map with your globe. Where are the majority of the earthquakes and volcanoes?

U.S. Geological Survey's Plate Tectonics Tennis Ball Globe
http://volcanoes.usgs.gov/about/edu/dynamicplanet/ballglobe

USGS

Simplified Plate Tectonics Map

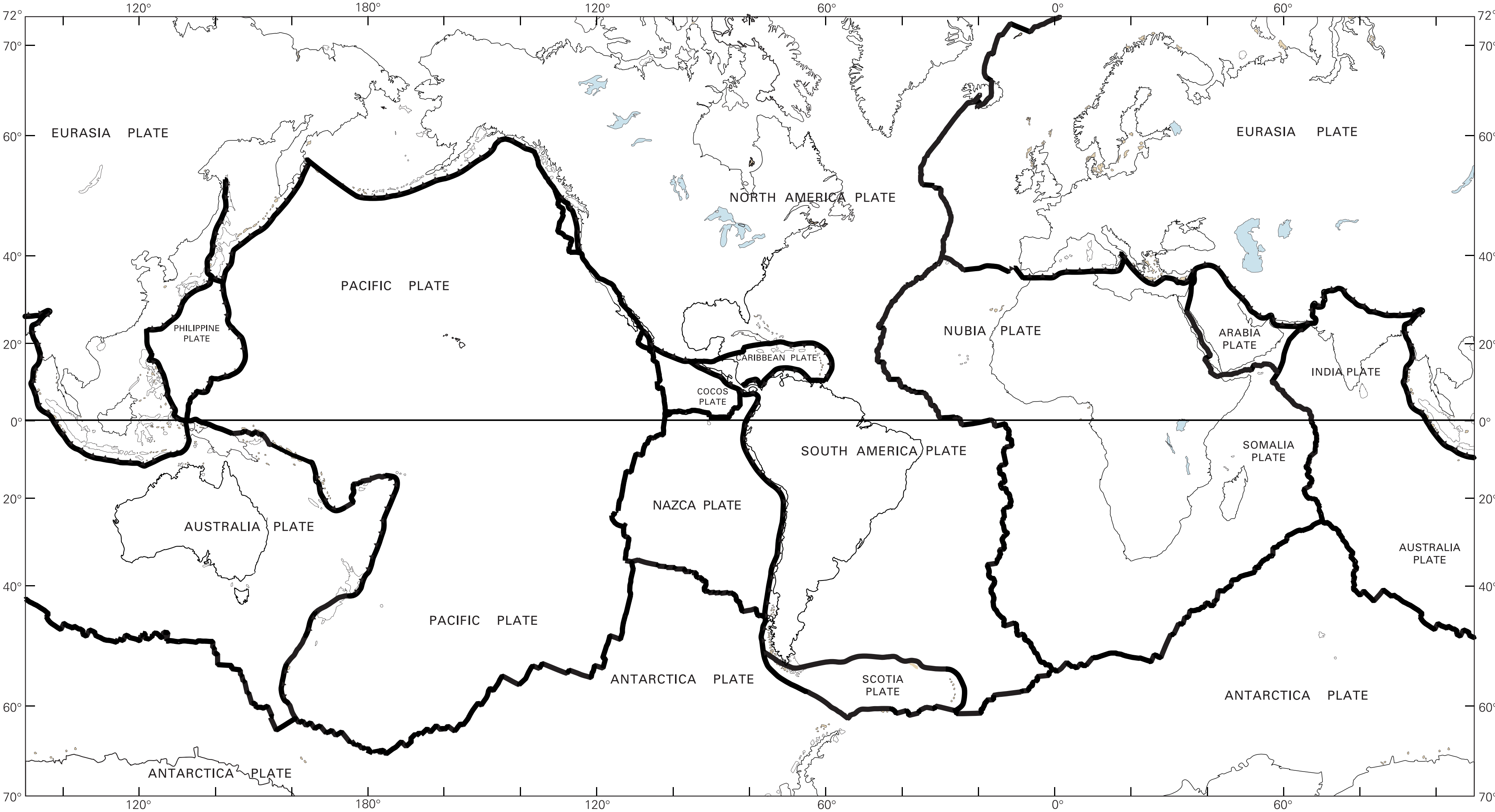

Plate boundary - Known area between two plates.

Some plate boundaries, such as the North America - South America boundary, are not shown because scientific data are inadequate to determine precise locations. See the This Dynamic Planet Map insert for more information about these regions.

This Dynamic Planet; A Teaching Companion
Plate Tectonics Tennis Ball Globe
U.S. Geological Survey, 2008 revised from This Dynamic Planet Map
For updates see <http://volcanoes.usgs.gov/about/edu/dynamicplanet>

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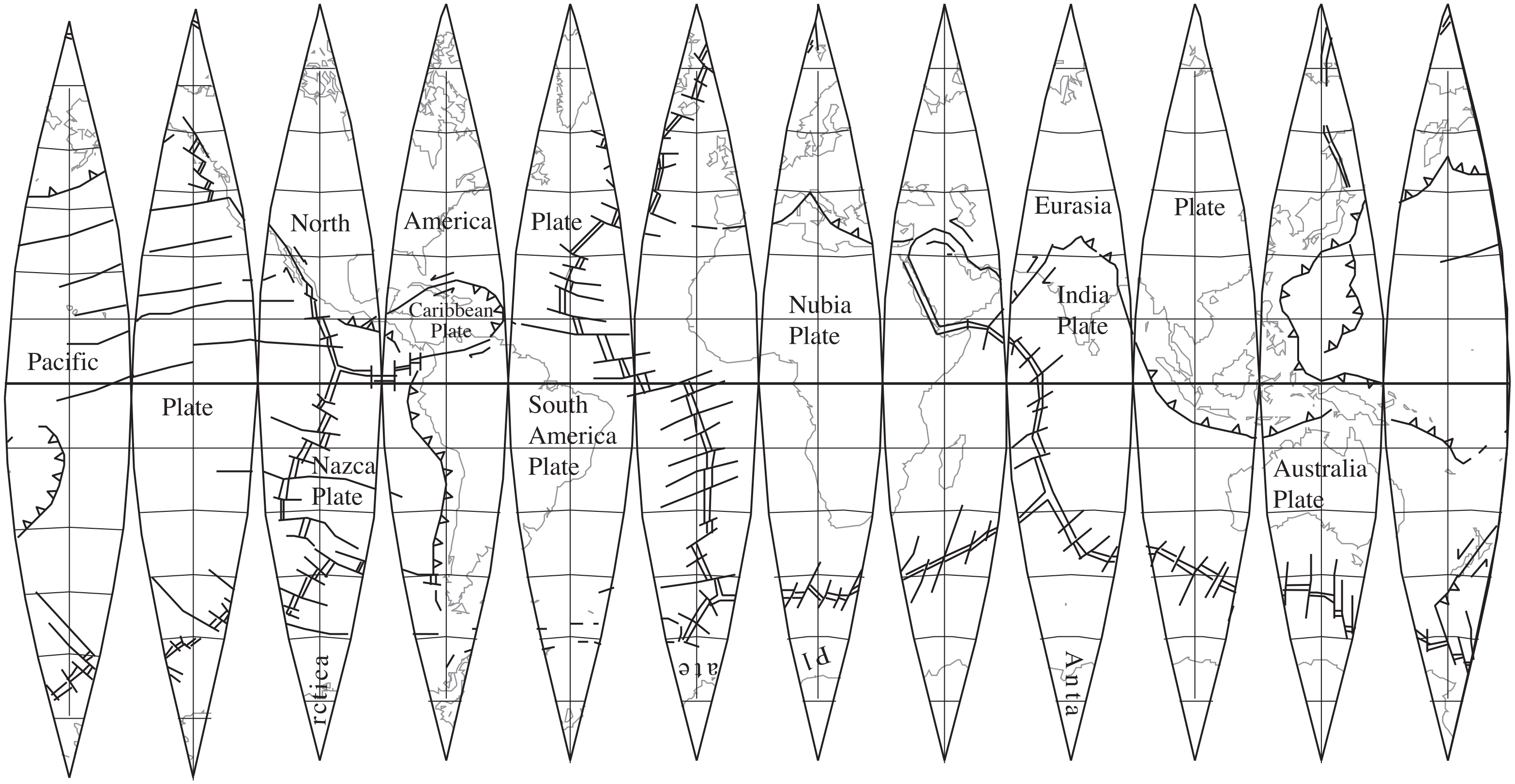
Plate Tectonics Tennis Ball Globe



Divergent plate boundary - Where new crust is generated as the plates pull away from each other.

Convergent plate boundary - Where crust is recycled as one plate dives under another (in the direction shown by sawteeth).

Transform plate boundary - Where crust is neither produced nor consumed as plates slide horizontally past each other.

This Dynamic Planet; A Teaching Companion
Plate Tectonics Tennis Ball Globe
U.S. Geological Survey, 2008 revised from Open-file report 93-380 A & B
For updates see <http://volcanoes.usgs.gov/about/edu/dynamicplanet>

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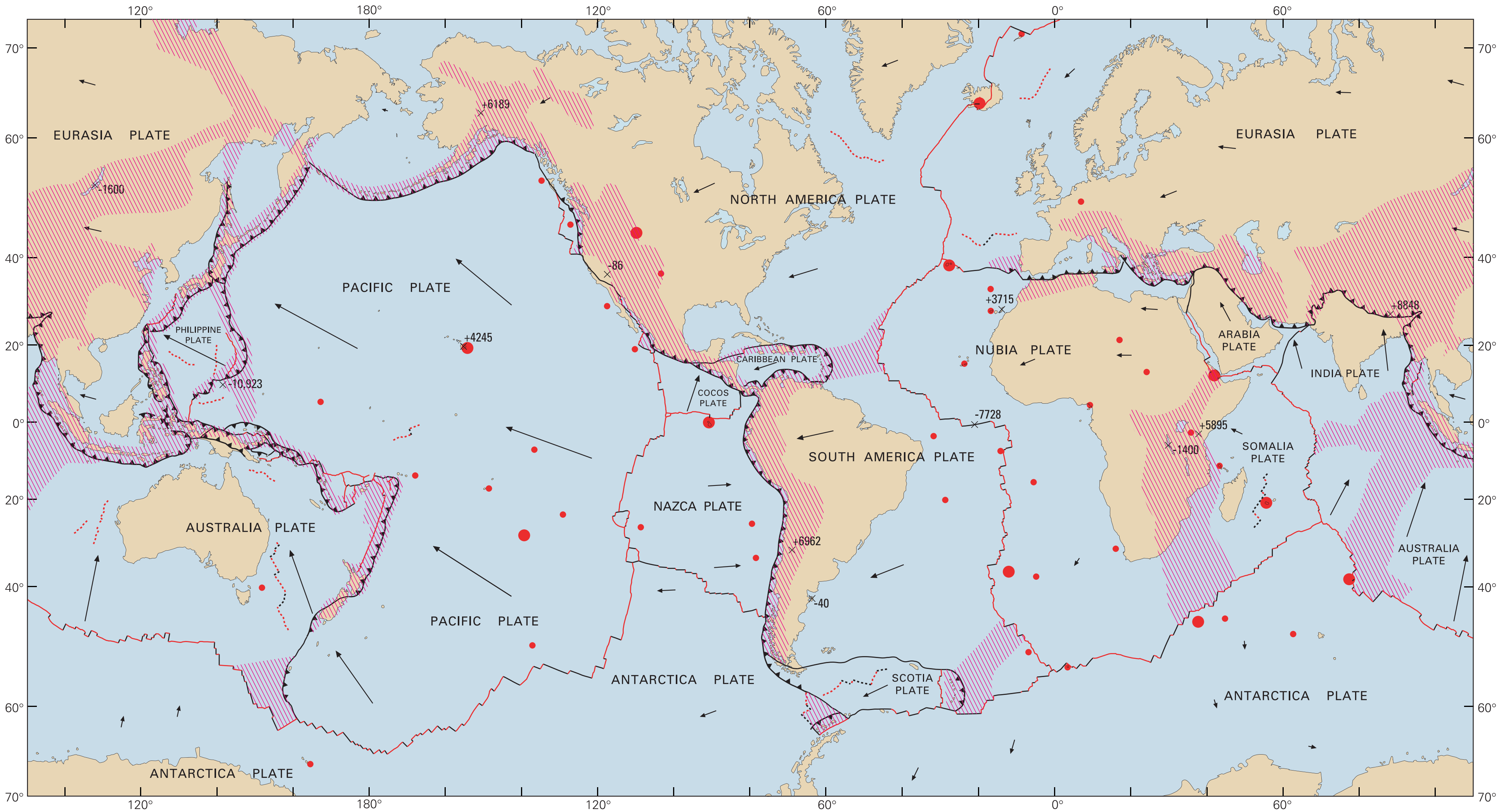

INTERPRETIVE MAP OF PLATE TECTONICS

Divergent plate boundary—Where new crust is generated as the plates pull away from each other

Convergent plate boundary—Where crust is recycled as one plate dives under another (in the direction shown by sawteeth)

Transform plate boundary—Where crust is neither produced nor consumed as plates slide horizontally past each other

Selected fossil boundary—Former plate boundary, now inactive; evidence that plate boundaries are not permanent

Diffuse boundary zone—Broad belt in which deformation occurs over a wide region (from Gordon, 2000); may encompass one or more smaller plates

Selected hotspots—Larger symbol indicates major hotspot; smaller symbol indicates minor hotspot

Plate motion—Length of arrow is roughly proportional to the rate of plate motion (longer=faster; see main map for details)

+4245

Elevation—Highest (+) and lowest (–) points, in meters, on four largest continents and in two oceans

USGS science for a changing world Smithsonian Institution U.S. Naval Research Laboratory