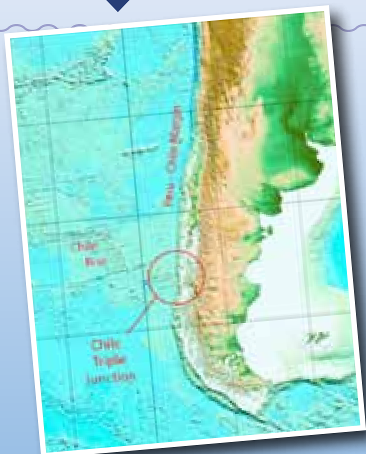
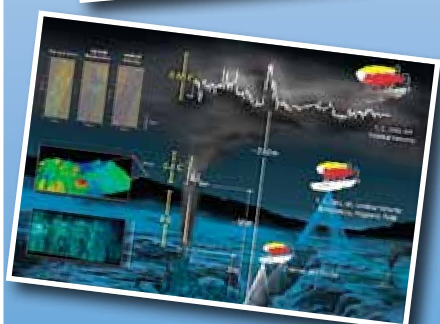
INSPIRE: Chile Margin 2010

When Plates Collide





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lesson plan

Focus

Plate Tectonics – Movement of plates, results of plate movement, and the Chile Triple Junction

Grade Level

5-6 (Physical Science)

Focus Question

How do tectonic plates move, and what are the consequences of these movements?

Learning Objectives

- Students will describe the motion of tectonic plates.
- Students will compare and contrast three typical boundary types that occur between tectonic plates.
- Students will describe the plate boundaries that occur at the Chile Triple Junction.
- Students will explain why a variety of chemosynthetic communities are expected to occur in the vicinity of the Chile Triple Junction.

Materials

- ❑ Copies of Figure 4 (Appendix B, page 15) on cover stock or glued onto poster board for jigsaw puzzles (see Learning Procedure, Step 2)
- ❑ (Optional) Food coloring and container of hot water to demonstrate convection currents (see Learning Procedure, Step 3)
- ❑ Materials to make oobleck (see Learning Procedure, Step 3 and Appendix A); about 1.5 cups for each student group
- ❑ Pieces of rigid foam insulation or foamcore, approximately 3” x 3”; two for each student group
- ❑ Ceramic tiles or pieces of hardboard, approximately 3” x 3”; two for each student group
- ❑ Serving trays or cake pans (to contain oobleck during Learning Procedure Step 4); one for each student group

Audio-Visual Materials

- ❑ (Optional) Video or computer projection equipment; see Learning Procedure Step 1(b).

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Groups of three to four students

Maximum Number of Students

32

Key Words

Core
Magma
Mantle
Crust
Tectonic plate
Plate boundaries

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

Earthquakes and volcanoes are among Earth's most spectacular and terrifying geological events. The Mount St. Helens eruption of 1980 and the Haiti (7.0 magnitude) and Chile (8.8 magnitude) earthquakes of 2010 are recent and memorable examples of the extreme power that often accompanies these events. The Indian Ocean tsunami of 2004 was caused by an underwater earthquake that is estimated to have released the energy of 23,000 Hiroshima-type atomic bombs, and caused the deaths of more than 150,000 people.

Volcanoes and earthquakes are both linked to movements of tectonic plates, which are portions of the Earth's outer crust (the lithosphere) about 5 km thick, as well as the upper 60 - 75 km of the underlying mantle. These plates move on a hot flowing mantle layer called the asthenosphere, which is several hundred kilometers thick. Heat within the asthenosphere creates convection currents (similar to the currents that can be seen if food coloring is added to a heated container of water). Movement of convection currents causes tectonic plates to move several centimeters per year relative to each other.

Where tectonic plates slide horizontally past each other, the boundary between the plates is known as a transform plate boundary. As the plates rub against each other, huge stresses are set up that can cause portions of the rock to break, resulting in earthquakes. Places where these breaks occur are called faults. A well-known example of a

Images from Page 1 top to bottom:
Map of the Southeast Pacific Ocean and South American continent showing the Chile Rise spreading center, the Peru-Chile Margin, and the location of the Chile Triple Junction. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/geology/media/geology1.html

Our 3-phased approach to ocean exploration with ABE. First, guided by chemical measurements made aboard ship, we program ABE to fly around within the water column "sniffing" for where the chemical signals are strongest using specialized in situ sensors. Second, once we know where the strongest chemical signals from a hydrothermal vent are, we program ABE to fly closer to the seafloor, making detailed maps of the seabed and, ideally, also intercepting the stems of hot buoyant hydrothermal plumes of water rising up above the seafloor. Third, and finally, we program ABE up once more to descend to right above the seabed and drive to and fro, very carefully – using obstacle avoidance techniques to stop it from crashing into the rough rocky terrain it finds – while taking photographs of whatever it is we have found: hydrothermal vents, cold seeps, and whatever new and unique animals they might host. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration2.html

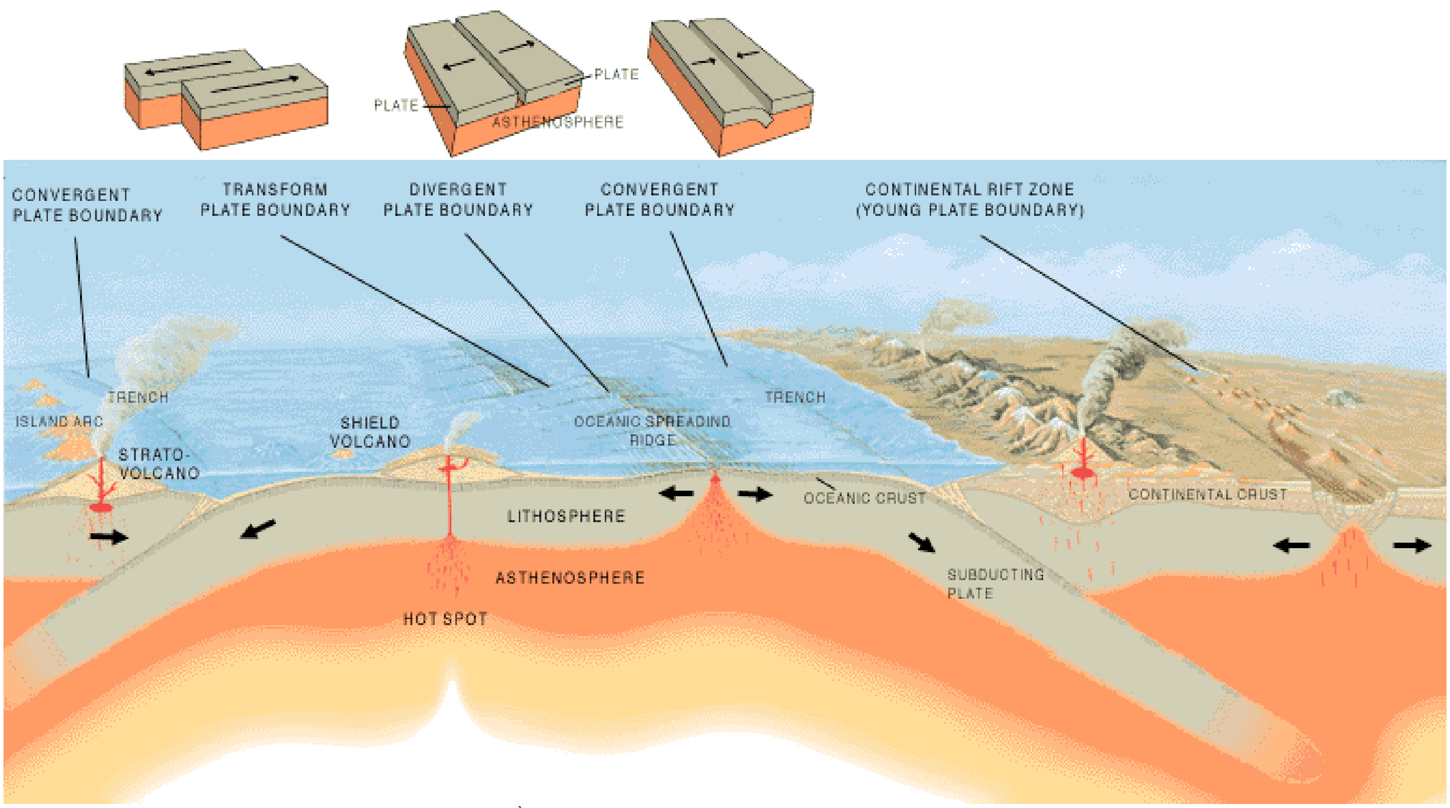
The ABE (Autonomous Benthic Explorer) autonomous underwater vehicle (free-swimming robot) about to be set loose to explore the bottom of the SW Indian Ocean from aboard the Chinese research ship RV Da Yang Yi Hao in Spring 2007. Over the past 5 years, ABE has been used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and from Brazil to Ecuador. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/plan/media/missionplan3.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

transform plate boundary is the San Andreas fault in California. View animations of different types of plate boundaries at: http://www.seed.slb.com/flash/science/features/earth/livingplanet/plate_boundaries/en/index.html.

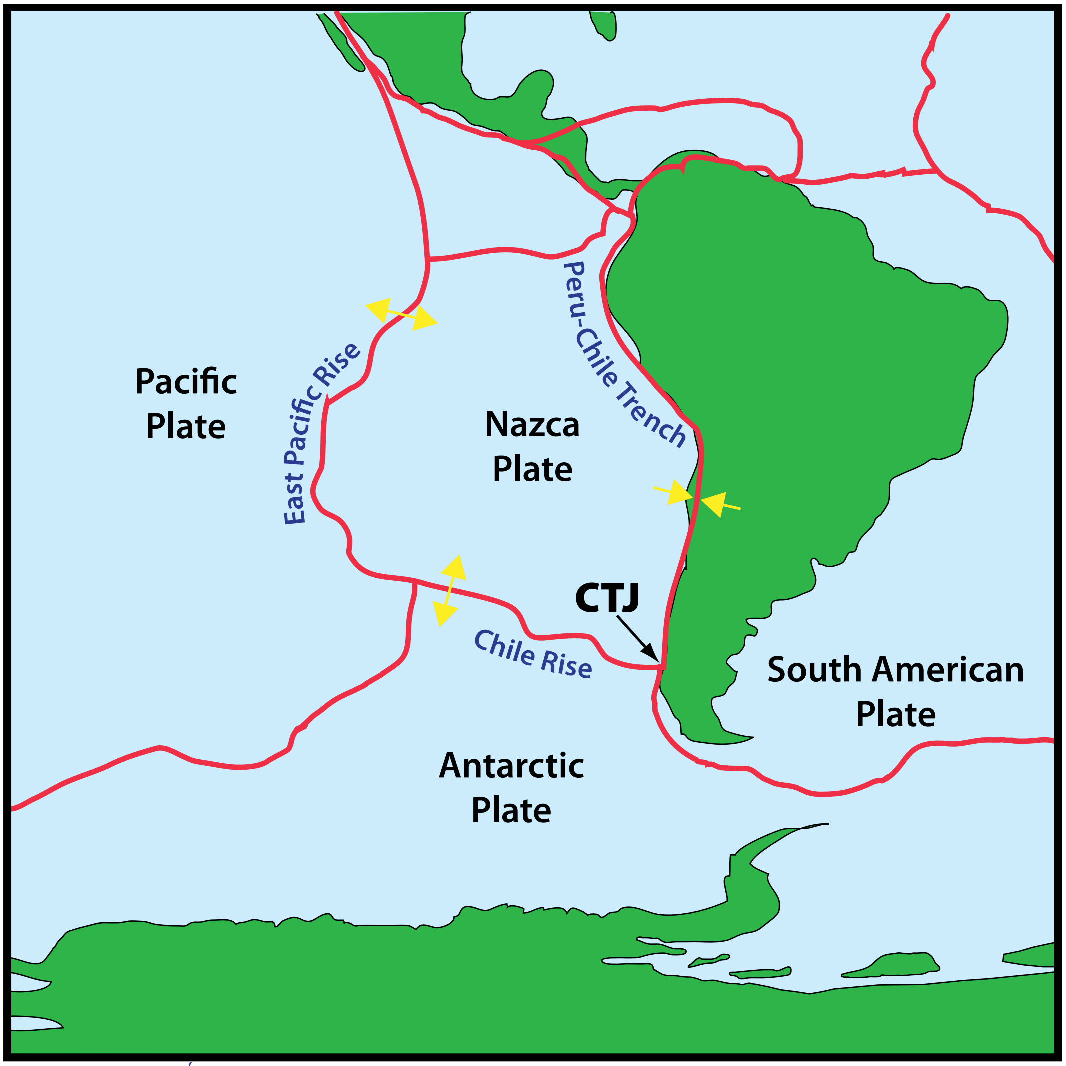
A convergent plate boundary is formed when tectonic plates collide more or less head-on. When two continental plates collide, they may cause rock to be thrust upward at the point of collision, resulting in mountain-building. (The Himalayas were formed by the collision of the Indo-Australian Plate with the Eurasian Plate). When an oceanic plate and a continental plate collide, the oceanic plate moves beneath the continental plate in a process known as subduction. Deep trenches are often formed where tectonic plates are being subducted, and earthquakes are common. As the sinking plate moves deeper into the mantle, fluids are released from the rock causing the overlying mantle to partially melt. The new magma (molten rock) rises and may erupt violently to form volcanoes, often forming arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. View the 3-dimensional structure of a subduction zone at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html.

Figure 1: Types of Plate Boundaries



Artist's cross section illustrating the main types of plate boundaries. (Cross section by José F. Vigil from This Dynamic Planet -- a wall map produced jointly by the U.S. Geological Survey, the Smithsonian Institution, and the U.S. Naval Research Laboratory.) http://pubs.usgs.gov/gip/dynamic/Vigil.html

Figure 2: Chile Triple Junction



Where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate boundaries, magma rises from deep within the Earth and erupts to form new crust on the lithosphere. Most divergent plate boundaries are underwater (Iceland is an exception), and form submarine mountain ranges called oceanic spreading ridges. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries. View the 3-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

Along the western coast of Chile, three of Earth's tectonic plates intersect in a way that does not occur anywhere else on the planet (see Figure 2). Chile, and the other countries of South America, lie on top of the South American tectonic plate. To the west of Chile, the Nazca Plate extends beneath the Pacific Ocean and meets the Pacific Plate along a divergent plate boundary called the East Pacific Rise. The southern edge of the Nazca Plate adjoins the Antarctic Plate along another divergent plate boundary called the Chile Rise. The eastern edge of the Chile Rise is being subducted beneath the South American plate at the Chile Triple Junction (CTJ), which is unique because it consists of a mid-oceanic ridge being subducted under a continental tectonic plate. The eastern portion of the Nazca Plate is also being subducted along the Peru-Chile Trench, and the Andes mountains are one consequence of this process. Not surprisingly, complex movements of three tectonic plates at the CTJ result in numerous earthquakes. In fact, the largest earthquake ever recorded (magnitude 9.5) occurred along the Peru-Chile Trench in 1960. While earthquakes and volcanoes are often associated with massive destruction and loss of human life, the same processes that cause these events are also responsible for producing unique habitats for very different life forms.

One of the most exciting and significant scientific discoveries in the history of ocean science was made in 1977 at a divergent plate boundary near the Galapagos Islands. Here, researchers found large numbers of animals that had never been seen before clustered around underwater hot springs flowing from cracks in the lava seafloor. Similar hot springs, known as hydrothermal vents, have since been found in many other locations where underwater volcanic processes are active. Hydrothermal vents are formed when the movement of tectonic plates causes deep cracks to form in the ocean floor. Seawater flows into these cracks, is heated by magma, and then rises back to the surface of the seafloor. The water does not boil because of the high pressure in the deep ocean, but may reach temperatures higher than 350° C. This superheated water dissolves minerals in Earth's crust. Hydrothermal vents are locations where the superheated water erupts through the seafloor. The temperature of the surrounding water is near-freezing, which causes some of the dissolved minerals to precipitate from the solution. This makes the hot water plume look like black smoke, and in some cases the precipitated minerals form chimneys or towers.

The presence of thriving biological communities in the deep ocean was a complete surprise, because it was assumed that food energy resources would be scarce in an environment without sunlight to support photosynthesis. Researchers soon discovered that the organisms responsible for this biological abundance do not need photosynthesis, but instead are able to obtain energy from chemical reactions through a process known as chemosynthesis. Photosynthesis and chemosynthesis both require a source of energy that is transferred through a series of chemical reactions into organic molecules that living organisms may use as food. In photosynthesis, light provides this energy. In chemosynthesis, the energy comes from other chemical reactions. Energy for chemosynthesis in the vicinity of hydrothermal vents often comes from hydrogen sulfide.

Ocean explorers have also discovered chemosynthetic communities that use other forms of chemical energy. Cold seeps are areas where hydrocarbon gases (such as methane) or oil seep out of sediments commonly found along continental margins. Like hydrothermal vents, cold seeps are home to many species of organisms that have not been found anywhere else on Earth. Typical features of cold seep communities include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms. Brine pools, containing water four times saltier than normal seawater, have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity. Methane hydrates may be of considerable benefit as a new energy resource, but may also pose substantial risks. See"More About Methane and Methane Hydrates" in the Expedition Education Module for the INSPIRE: Chile Margin 2010 Expedition.

A primary purpose of the INSPIRE: Chile Margin 2010 Expedition is to locate new chemosynthetic ecosystems near the CTJ, and investigate whether the complex and unique interaction between ridge and trench tectonic processes at the CTJ produces different types of ecosystems than have been found in other areas (INSPIRE stands for INternational Southeast Pacific Investigation of Reducing Environments). In this activity, students will create models to accompany explanations of the motion and types of boundaries that occur between tectonic plates, as well as the unique tectonic conditions at the Chile Triple Junction.

Learning Procedure

[NOTE: Because the discovery of hydrothermal vents was so significant and exciting, there is a wealth of information available on the geology and ecology of vent ecosystems. Several sources and potential activities are highlighted below, and educators are encouraged to investigate these, and select combinations that are most appropriate to their own students and specific curriculum needs.]

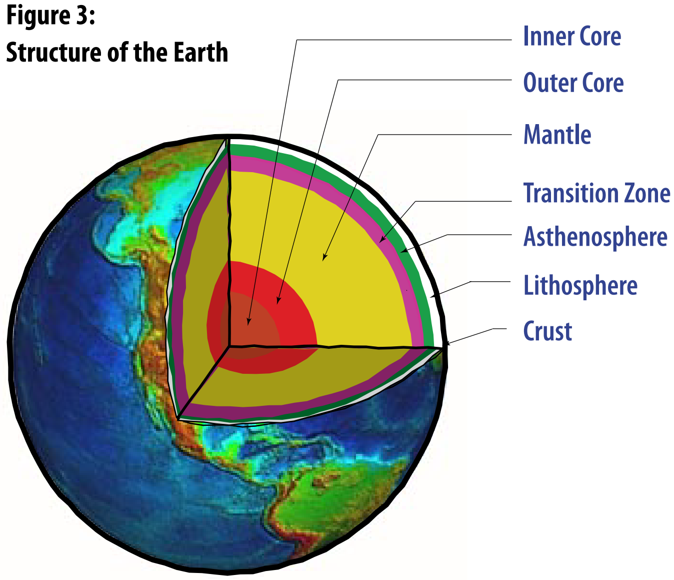
1. To prepare for this lesson:
   (a) Review introductory essays for the INSPIRE: Chile Margin 2010 Expedition at http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html.
   (b) Review illustrations and explanations of plate tectonics in "This Dynamic Earth" and/or "This Dynamic Planet" (see Resources section) for possible use in Step 2. If video or computer projection facilities are available, you may also want to download some images from these materials to show your students.
   (c) Review Multimedia Discovery Missions [http://oceanexplorer.noaa.gov/edu/learning/welcome.html] Lessons 1, 2, and 4 on Plate Tectonics, Mid-Ocean Ridges, and Subduction Zones. Decide how much of this material to use with your students.
   (d) Decide whether you will use jigsaw puzzles in Step 2, and whether

you will make these in advance or have students make them.

(d) Experiment with oobleck recipes (Appendix A) and procedures in Step 4. Decide whether to prepare oobleck for this step in advance or to do this as part of student activities. Note that similar activities have been described using frosting, fruit rollups and graham crackers (e.g., http://www.windows.ucar.edu/tour/link=/teacher_resources/teach_snacktectonics.html), but public health concerns and basic laboratory safety practices do not favor using edible materials in a classroom setting (though you may suggest that students might use such materials to repeat this demonstration at home).

2. Describe Earth's layered structure diagrammed in Figure 3. Be sure students understand the spatial relationship of core, mantle, and crust. Explain the concept of plate tectonics, emphasizing that the plates are solid pieces of Earth's crust that float on a layer of the upper mantle that is partially melted rock. You may want to have student groups make jigsaw puzzles from copies of Figure 4 (Appendix B, page 15) (or make these yourself in advance), and have a contest to see which group can correctly assemble their puzzle in the shortest amount of time.

Figure 3:
Structure of the Earth



3. Tell students that heat from Earth's core causes currents in the molten rock of the mantle (you can demonstrate similar currents by adding food coloring to a heated container of water), and these currents cause movement among Earth's tectonic plates. Introduce the concept of continental drift. Tell students that the junction of two tectonic plates is called a plate boundary, and describe the motion of plates at convergent, divergent, and transform boundaries. Remind students that these plates are huge pieces of rock, and ask them what they think happens when these plates collide. Explain the relationship of volcanoes and

earthquakes to tectonic plate movements. You may want to point out that convergent, divergent, and transform boundaries are each associated with particular types of earthquake and volcanic activity: strong earthquakes and explosive volcanoes at convergent boundaries; slow-flowing volcanoes and weaker earthquakes at divergent boundaries; strong earthquakes, rare volcanoes at transform boundaries. You may also want to discuss some of the energy transfers involved in plate motions, earthquakes, and volcanoes (e.g., heat energy from Earth's core; kinetic energy of plate movements and volcanic eruptions; heat of friction when plates collide with each other). Description and discussion of subduction at convergent plate boundaries also provides an opportunity to introduce the rock cycle.

4. Tell students that their assignment is to model convergent, divergent, and transform boundaries using oobleck, pieces of rigid foam insulation or foamcore, and tiles or pieces of hardboard. The lighter materials should be used to represent continental tectonic plates, which are less dense than oceanic tectonic plates that should be represented by pieces of tile or hardboard.

   A divergent boundary may be modeled by placing two pieces of heavier material side-by-side on a layer of oobleck, then moving them apart while pressing down slightly. This movement should cause the oobleck to be exposed and pushed up where the plates are separated, demonstrating how magma comes to the surface where tectonic plates are moving apart at divergent plate boundaries.

   A convergent boundary may be modeled by placing a piece of heavier material next to a piece of lighter material on a layer of oobleck, and gently pushing the two pieces together until they overlap so that the lighter material (continental plate) is on top and the heavier material (oceanic plate) has been subducted.

   A transform boundary may be modeled by placing two pieces of lighter (continental) material next to each other on a layer of oobleck, then pushing the pieces in opposite directions perpendicular to the direction of the junction.

5. If students are not familiar with the concept of chemosynthesis, briefly describe this process and contrast it with photosynthesis. Tell students that chemosynthetic ecosystems in the deep ocean are found where a source of chemical energy is emerging from the ocean floor. Introduce the INSPIRE: Chile Margin 2010 Expedition. Describe the Chile Triple Junction and have students model the plate movements at the CTJ using materials from Step 4. Say that

one of the objectives of this expedition is to locate new deepwater chemosynthetic ecosystems. Ask students why scientists think the CTJ might be a good place to look for these ecosystems. Students should infer that complex tectonic plate movements in this area are likely to cause cracks in the ocean floor through which sources of chemical energy (e.g., hydrogen sulfide, methane, petroleum) might reach the seafloor surface.

The BRIDGE Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the menu on the left side of the page, then select "Geology" or "Habitats" for activities and links about plate tectonics and chemosynthetic ecosystems.

The "Me" Connection

Have students write a first-hand account of a visit to a plate boundary, describing conditions at the boundary and what they might see there.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Written reports, modeling activities and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html for the latest activities and discoveries by the INSPIRE: Chile Margin 2010 Expedition.
2. Have students repeat their modeling demonstrations at home using edible materials, and submit reports that include comments from family members about their demonstration.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

And Now for Something Completely Different...

(PDF, 172 kb) (from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_dfferent.pdf

Focus - Biological communities at hydrothermal vents (Life Science)

In this activity, students will identify and describe organisms typical of hydrothermal vent communities near the Galapagos Spreading Center, explain why hydrothermal vent communities tend to be short-lived, and identify and discuss lines of evidence which suggested the existence of hydrothermal vents before they were actually discovered.

Entering the Twilight Zone
(PDF, 468 kb) (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_twilight.pdf

Focus - Deep-sea habitats (Life Science)

In this activity, students will be able to describe major features of cold seep communities, and list at least five organisms typical of these communities and will infer probable trophic relationships within and between major deep-sea habitats. Students will also be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe major deep-sea habitats and list at least three organisms typical of each habitat.

InVENT a Deep-Sea Invertebrate
(PDF, 460 kb) (from the 2002 Galapagos Rift Expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l3.pdf

Focus - Galapagos Rift Ecosystem: Structure and Function in Living Systems (Life Science)

In this activity, students will design an invertebrate capable of living near deep-sea hydrothermal vents, and in doing so, will learn about the unique adaptations that organisms must have in order to survive in the extreme environments of the deep sea.

Let's Make a Tubeworm!
(PDF, 464 kb) (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

Focus - Symbiotic relationships in cold-seep communities (Life Science)

In this activity, students will be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold seep communities, and list at least five organisms typical of these communities. Students will also be able to define symbiosis, describe two examples of symbiosis in cold seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Living With the Heat
(PDF, 88 kb) (from the Submarine Ring of Fire 2002 Expedition)
http://oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_living_heat_5_6.pdf

Focus - Hydrothermal vent ecology and transfer of energy among organisms that live near vents. (Life Science/Physical Science)

In this activity, students will be able to describe how hydrothermal vents are formed and characterize the physical conditions at these sites, explain what chemosynthesis is and contrast this process with photosynthesis, identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities, and describe common food pathways between organisms typically found in hydrothermal vent communities.

Animals of the Fire Ice
(PDF, 364 kb) (from the 2003 Windows to the Deep Expedition)
http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_fireice.pdf

Focus - Methane hydrate ice worms and hydrate shrimp (Life Science)

In this activity, students will be able to define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html – Web site for the INSPIRE: Chile Margin 2010 Expedition

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book - A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes

http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 – On-line version of "This Dynamic Earth," a thorough publication of the U.S. Geological Survey on plate tectonics written for a non-technical audience http://pubs.usgs.gov/pdf/planet.html – "This Dynamic Planet," map and explanatory text showing Earth's physiographic features, plate movements, and locations of volcanoes, earthquakes, and impact craters

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

Content Standard D: Earth and Space Science

- Structure of the Earth system
- Earth's history

Content Standard F: Science in Personal and Social Perspectives

- Natural hazards

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.
Fundamental Concept b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.
Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 7.
The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson.
Please send your comments to:
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Appendix A
Recipes for Oobleck

Oobleck is a non-Newtonian fluid whose name comes from the Dr. Seuss book, Bartholomew and the Oobleck. There are a variety of recipes for making oobleck, which include:

Option 1:

The simplest recipe is to slowly add approximately two cups of cornstarch to one cup of water, continuously mixing until the mixture is semi-solid (http://www.instructables.com/id/Oobleck/).

Option 2:

A less sticky version can be made from borax and glue (http://education.jlab.org/beamsactivity/6thgrade/oobleck/overview.html). Make a glue solution with equal volumes of white glue and water. Make a second solution by dissolving 60 ml of dry borax powder in one liter of water (the borax may not dissolve completely). Make oobleck by mixing 30 ml of the glue solution with 10 ml of the borax solution.

Option 3:

Mix 1/2 cup of liquid starch with 1 cup of white glue (http://www.ehow.com/how_2384117_create-oobleck-school-glue.html).

Food coloring may be added to any of these recipes if desired.

Appendix B
Jigsaw Puzzle

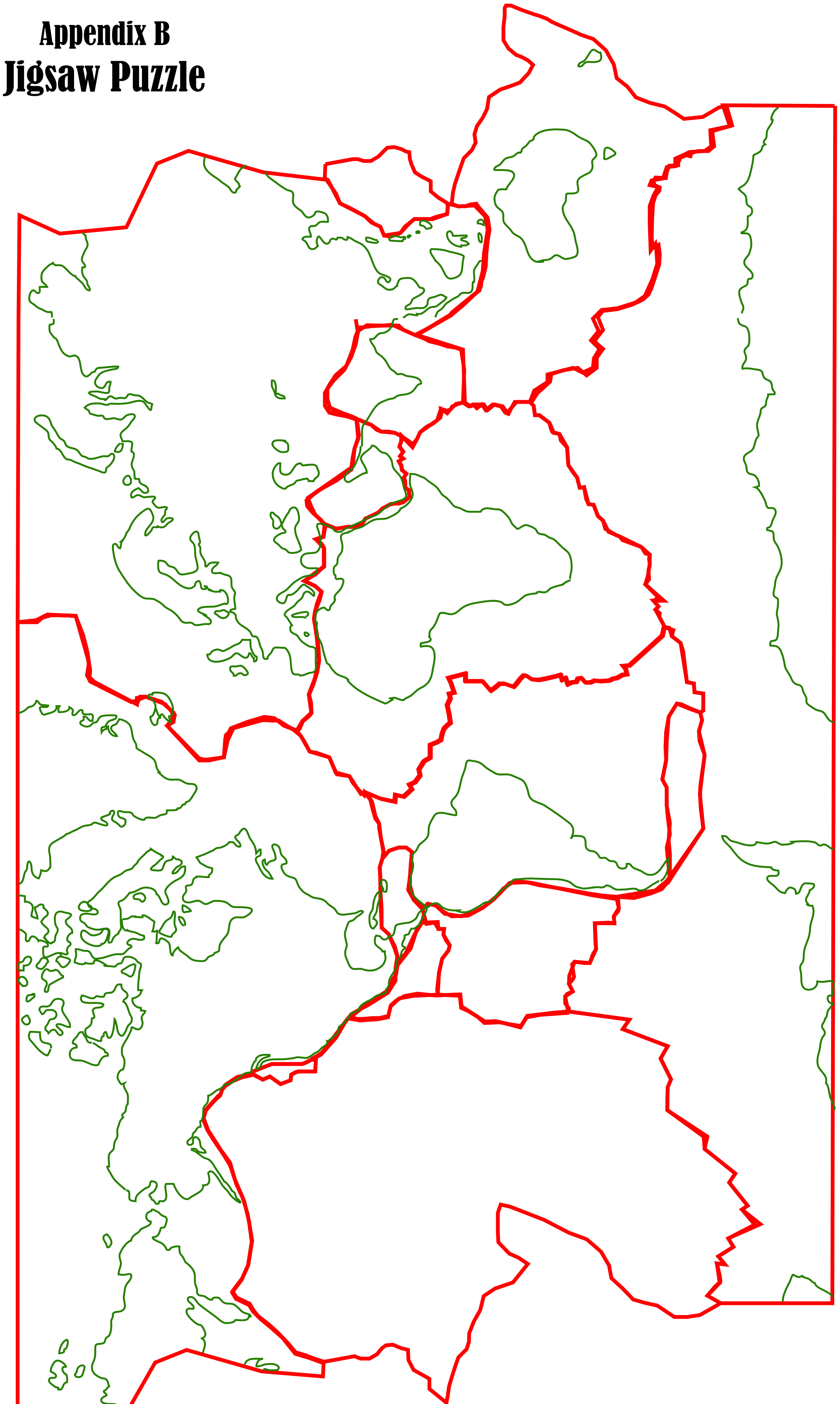

Figure 4:
Tectonic Plates and Continents

Appendix C
Jigsaw Puzzle Key

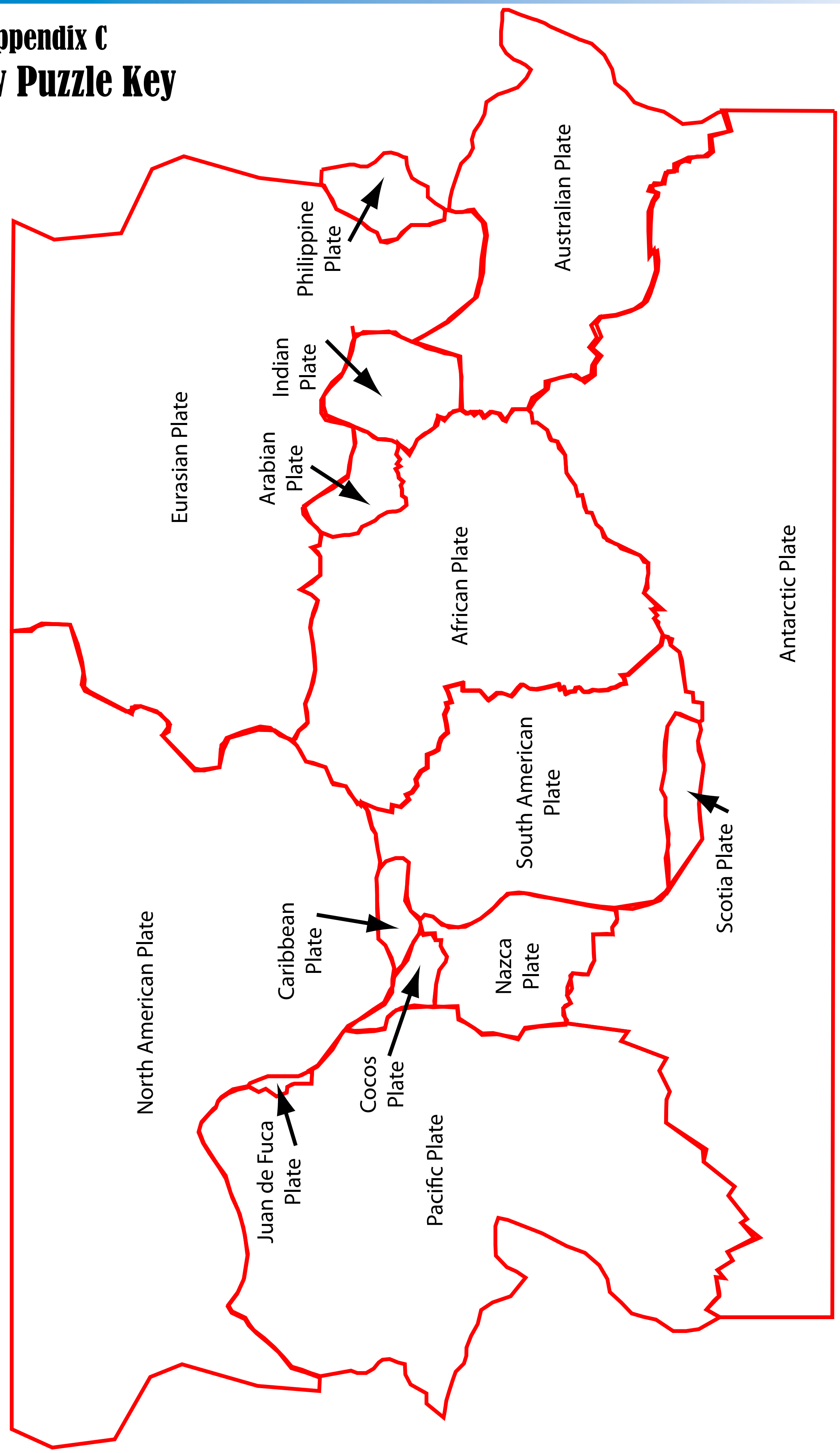

Figure 4a: Tectonic Plates Answer Key