Teaching About Plate Tectonics and Faulting Using Foam Models[Ó]

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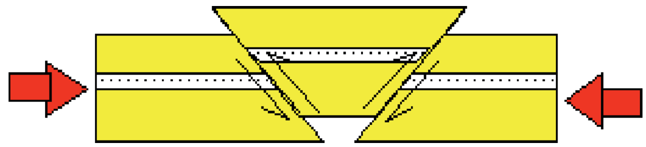

September, 2000

Objective: Demonstrate plate tectonic principles, plate boundary interactions and the geometry and relative motions of faulting of geologic layers using 3-D foam models. The foam models aid in visualization and understanding of plate motions and faulting because the models are three-dimensional, concrete rather than abstract descriptions or diagrams, can be manipulated by the instructor and the students, and the models can show the motions of the plates and faults through time in addition to the three-dimensional configuration of the plates or layers. The fault and plate boundary models shown here illustrate relatively simple motions and geologic structures. Although these models are accurate representations of real Earth faulting and plate tectonic structures and motions, the spherical shape of the Earth and the complexity of geological features caused by varying rock types and rock properties and geological development over many millions or hundreds of millions of years, result in significant complexity and variability of actual fault systems and plate tectonic boundaries.

Materials:

Foam (open cell, foam mattress type) “blocks” shown in Figure 1A
Felt pens (permanent marker, red and black)
Manila folders or thin poster board
Rubber cement
Closed cell foam (“sleeping bag pads,” camping equipment) as shown in Figures 3 and 5
Pins
Open cell foam as shown in Figure 3A
Styrofoam core poster board, 0.6 cm (1/4 in) thick, as shown in Figure 3B
Razor blade knife
Metric ruler

Procedure:

1. Faulting and Plate Boundaries - Prepare foam block models as shown in Figure 1A. The cardboard (cut from manila folders or thin poster board) attached to both faces of the fault plane allows the

blocks to slip easily along the fault as forces are applied to the blocks. Use the block models to demonstrate extensional (normal) faulting as the two outer blocks are moved apart as shown in Figure 1B. This procedure is best performed by holding the blocks "in the air" in front of you, supporting the model by the two outer blocks, rather than on a table. Note that as the two outer blocks are moved apart, the inner block drops downward or "subsides." This relationship between extensional motion of geologic layers and downdropped fault blocks (graben or rift valley if the downdropped block is bounded on both sides by normal faults, as in this block model) produces normal faulting (Figure 2) and also represents the extensional motion and resultant rift development associated with divergent plate boundaries (Table 1). Examples of divergent plate boundaries, where extensional faulting is prominent, are the mid-ocean ridge system in which a narrow rift or graben (downdropped fault block) is commonly observed along the highest part of the ridge (see section 2 below) and the East African Rift in which extension has been occurring in the continental lithosphere for about 30 million years and the resulting rift system of normal faults is beginning to break apart the continent. In a plate-tectonic-related, but not plate boundary environment, the Basin and Range area of the Western United States displays a prominent topographic signature of extensional faulting with many adjacent downdropped fault blocks or grabens (the topographic "high" areas between the grabens are called horsts; see IRIS poster on western US seismicity and topography).

To demonstrate compressional motion and resulting reverse (also called thrust) faults (Figure 2), hold the foam block models as described above and then move the two outer blocks together as in Figure 1C. The inner block will be thrust upwards producing reverse faults and an uplifted block. In a plate tectonic setting, such compressional motion is associated with convergent plate boundaries (Table 1) where two lithospheric plates are moving together or colliding (see also section 3 below). Not surprisingly, these convergent zones are associated with mountain ranges (Himalayas, Alps, Andes, Cascades, etc.).

To demonstrate horizontal slip or strike-slip fault motion, prepare foam blocks as shown in Figure 1D. Moving the blocks horizontally on a tabletop, as shown in Figure 1E, demonstrates strike-slip (Figure 2) or horizontal slip fault motion. This motion along a plate boundary is also called transform (Table 1). The San Andreas fault zone is a system of strike-slip faults which form the transform plate boundary at the western edge of the North American Plate. Transform faults also occur as oceanic fracture zones between segments of the mid-ocean ridge spreading zones (see ocean bathymetry map in a world atlas, such as the National Geographic World Atlas, or view ocean bathymetry on the Internet at: http://www.ngdc.noaa.gov/mgg/announcements/images_predict.HTML; click on one of the regions containing a mid-ocean ridge to see details of ridge crest and transform fault topography of the ocean floor).

2. Divergent Plate Boundary and Sea Floor Spreading - Prepare the foam pieces that represent the oceanic lithosphere at a spreading center (mid-ocean ridge divergent plate boundary) as shown in Figure 3A. Cut 10 one cm by 20 cm strips of the closed-cell foam material. Color half of the strips black with the felt pen and label all of the foam pieces as shown in Figure 3A. Construct a "ridge" (optional) to form the base for the sea floor spreading model. The ridge surface represents the top of the asthenosphere in the upper mantle and the foam layer above the base is the oceanic lithosphere - typically about 50-100 km thick in the Earth. The base also provides a mid-ocean ridge topography in which the spreading and extension occurs along the narrow rift zone along the ridge crest.

To demonstrate the concepts of a divergent plate boundary and mid-ocean ridge spreading centers, begin by placing the two 20 x 20 cm foam pieces on the base (Figure 3B) with one edge adjoined at the ridge crest and the arrows on the foam pieces pointing outward (Figure 3A). These squares will represent oceanic lithosphere at a time five million years ago and thus contain oceanic crust (the upper layer of the lithosphere) that is 5 million years old and older. Slide the two foam squares away from each other about 2 cm (this process represents the passage of time and the extension of the lithosphere in the region of the ridge crest, and rift valley, by plate tectonic motions which are typically a few centimeters per year, equivalent to a few tens of km per million years) and place the two strips labeled 4 million years in the space that is created. Attach one strip to each edge of the squares using pins. In the real mid-ocean ridge, a void space or opening between the plates created by the spreading process, would not actually develop. Instead, as extension occurs, volcanic and igneous intrusion processes will relatively continuously fill in the extended lithosphere, in the process creating new lithosphere. Because the oceanic crustal layer in this new lithosphere is formed from igneous (volcanic and intrusive) processes, it cools from a liquid and the rocks acquire a remanent magnetic direction that is consistent with the Earth's magnetic field direction at that time. Because the Earth's magnetic field occasionally reverses its polarity (north and south magnetic poles switch), the lithosphere created at mid-ocean ridges displays "stripes" of normal and reversed magnetic polarity crust approximately parallel to the ridge crest. Additional information on these magnetic stripes and mid-ocean ridge processes can be found in "This Dynamic Earth". The igneous rocks which are formed at the ridge crest can also be "dated" using radiometric dating of rock samples to determine the age of the volcanism and intrusion.

Continue to extend the two plates away from each other at the ridge crest and add the new pieces of lithosphere (attach with pins) which are labeled in decreasing age (3, 2, 1 and 0 million years old). When you are finished, the mid-ocean ridge divergent plate boundary and adjacent lithosphere should look like the diagram shown in Figure 3A and represent a modern (zero million years old) mid-ocean ridge spreading center. Note that the youngest rocks are in the center, along the ridge crest, and the rocks are progressively older (to 4 million years old in the strips and 5 million years old and older in the lithosphere represented by the squares of foam) away from the ridge crest.

3. Convergent Plate Boundary and Subduction - Arrange two tables of identical height to be next to each other and about 30 cm apart as shown in Figure 4. Place the two pieces of one-inch thick foam on the tables and begin to move one piece of foam (the one without the cardboard edge) toward the other and allow it to be "thrust" beneath the other piece of foam. The foam pieces represent two lithospheric plates. As the convergence continues, the underthrust plate will form a subducted slab of lithosphere (extending to at least 600 km into the mantle in the Earth) as shown in Figure 4. Earthquakes commonly occur along the length of the subducted slab and compressional structures (folds and faults) are often associated with the compressional zone near the colliding plates. The subducted lithosphere consists of relatively low-melting-point rocks (sediments and oceanic crust form the upper layers of the oceanic lithosphere) which can melt at depths of 100-150 km as the slab is subducted into the mantle. These molten materials can then ascend through the overlying mantle and crust and form volcanoes which are often situated in a linear chain or arc about 100-200 km away from the collision zone. A deep ocean trench also forms above the point of convergence of the two plates as the oceanic lithosphere is bent downwards by the collision.

4. Transform or Strike-Slip Plate Boundaries and Elastic Rebound - Use a razor-blade knife to make the foam "plate" models shown in Figure 5. The foam is 1.25 cm (1/2") thick closed-cell foam often used for "sleeping pads" for camping. It is available at camping supply stores and Wal-Mart and Target. The foam pieces can be used on a table top or on an overhead projector (the slits cut in the foam allow the 10 cm long tabs which bend to be seen projected onto a screen). By continuously sliding the two plates past each other with the "tab" edges touching (Figure 5), the foam pieces represent lithospheric

plates and the "zone" where the plates touch is a strike-slip (transform) fault. Note that as the plates move slowly with respect to each other (just as Earth's lithospheric plates move at speeds of centimeters per year), the area of the plates adjacent to the fault (the tabs) becomes progressively bent (deformed), storing elastic energy. As the process continues, some parts of the fault zone will "slip" releasing some of the stored elastic energy. This slip occurs when the stored elastic energy (bending of the tabs) results in a force along the fault which exceeds the frictional strength of the tabs that are in contact. Sometimes, only small segments of the fault zone (one or two tabs) will slip, representing a small earthquake. At other times, a larger segment of the fault will slip, representing a larger earthquake. Note that although the plate motions are slow and continuous, the slip along the fault is rapid (in the Earth, taking place in a fraction of a second to a few seconds) and discontinuous. The motions and processes illustrated by the foam model effectively demonstrates the processes which occur in actual fault zones and the concept of the elastic rebound theory (Bolt, 1993). A brief segment during the beginning of the video "Earthquake Country" illustrates a similar "stick-slip" motion using a model made of rubber strips.

Extensions, Connections, Enrichment:

1. Good preparatory lessons for these activities are studies of elasticity (a spring and masses can be used to demonstrate the two fundamental characteristics of elasticity - the stretching is proportional to the force (suspended mass) and the existence of the "restoring force" (elastic energy is stored) in that the spring returns to its original length as the force (mass) is removed), and seismic waves which are generated as the fault slips.

2. The stick-slip process is well illustrated in a segment of the NOVA video "Killer Quake" in which USGS geophysicist Dr. Ross Stein demonstrates this process using a brick which is pulled over a rough surface (sandpaper) using an elastic cord (bungy cord). An experiment using this same procedure is described in "Seismic Sleuths" (AGU/FEMA).

3. Additional information on plate tectonics is available in Bolt (1993), Ernst (1991), Simkin et al. (1994), the TASA CD "Plate Tectonics," "This Dynamic Earth," and nearly any secondary school or college level geology textbook. Elastic rebound is well illustrated in Lutgens and Tarbuck (1996), Bolt (1993) and the TASA CD. A color map of the Earth's plates is available on the Internet at: http://www.geo.arizona.edu/saso/Education/Plates. An excellent description of plate tectonics can be found at: http://pubs.usgs.gov/publications/text/understanding.html.

4. An additional plate tectonic activity is the EPIcenter lesson plan "Voyage Through Time - A Plate Tectonics Flip Book" in which continental drift during the past 190 million years - a consequence of plate tectonics - is effectively illustrated; and Plate Puzzle which uses the "This Dynamic Planet" map.

5. Additional plate tectonic activities, especially for younger students, are contained in "Tremor Troop" (NSTA/FEMA).

6. A leading theory explaining <u>why</u> the Earth's plates move is convection currents in the Earth's mantle. The interior structure of the Earth is described in Bolt (1993) and is the subject of the EPIcenter activity "Earth's Interior Structure." Good activities illustrating convection are contained in the GEMs guide "Convection - A Current Event" (Gould, 1988), or "Tremor Troop" (NSTA/FEMA).

References:

Bolt, B.A., *Earthquakes and Geological Discovery*, Scientific American Library, W.H. Freeman, New York, 229 pp., 1993.

Braile, L.W., “Earth’s Interior Structure” - http://www.eas.purdue.edu/~braile/educindex/educindex.htm.

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Ernst, W.G., *The Dynamic Planet*, Columbia University Press, New York, 281 pp., 1990.

FEMA/AGU, *Seismic Sleuths - Earthquakes - A Teachers Package on Earthquakes for Grades 7-12*, American Geophysical Union, Washington, D.C., 367 pp., 1994. (FEMA 253, for free copy, write on school letterhead to: FEMA, PO Box 70274, Washington, DC 20024).

Gould, A., *Convection - A Current Event*, GEMS, Lawrence Hall of Science, Berkeley, California, 47 pp., 1998.

IRIS, Western US Seismicity and Topography Poster, www.iris.edu.

Lutgens, F.K., and E.J. Tarbuck, *Foundations of Earth Science*, Prentice-Hall, Upper Saddle River, New Jersey, 482 pp., 1996.

NSTA/FEMA, *Tremor Troop - Earthquakes: A teacher’s package for K-6 grades*, NSTA Publications, Washington, DC, 169 pp., 1990. (This book contains a reasonably complete curriculum for teaching earthquake and related Earth science topics; FEMA 159, for free copy, write on school letterhead to: FEMA, PO Box 70274, Wash., DC 20024).

Simkin et al., *This Dynamic Planet*, map, USGS, 1:30,000,000 scale ($7 + $5 shipping), 1994, also at: http://pubs.usgs.gov/pdf/planet.html; 1-888-ASK-USGS.

TASA “Plate Tectonics” CD-Rom - Plate tectonics, earthquakes, faults, ($59 or $155 for site license), (800-293-2725) http://www.tasagraphicarts.com, Mac or Windows.

U.S. Geological Survey, *This Dynamic Earth: The Story of Plate Tectonics*, available from: U.S. Geological Survey, Map Distribution, Federal Center, PO Box 25286, Denver, CO 80225, $6, (800 USA MAPS). Also available (full text and figures) for viewing at: http://pubs.usgs.gov/publications/text/dynamic.html.

Videos (NOVA “Killer Quake,” and “Earthquake Country”) - information available in “Seismology-Resources for Teachers” online at: http://www.eas.purdue.edu/k-12/seismology_resources.html.

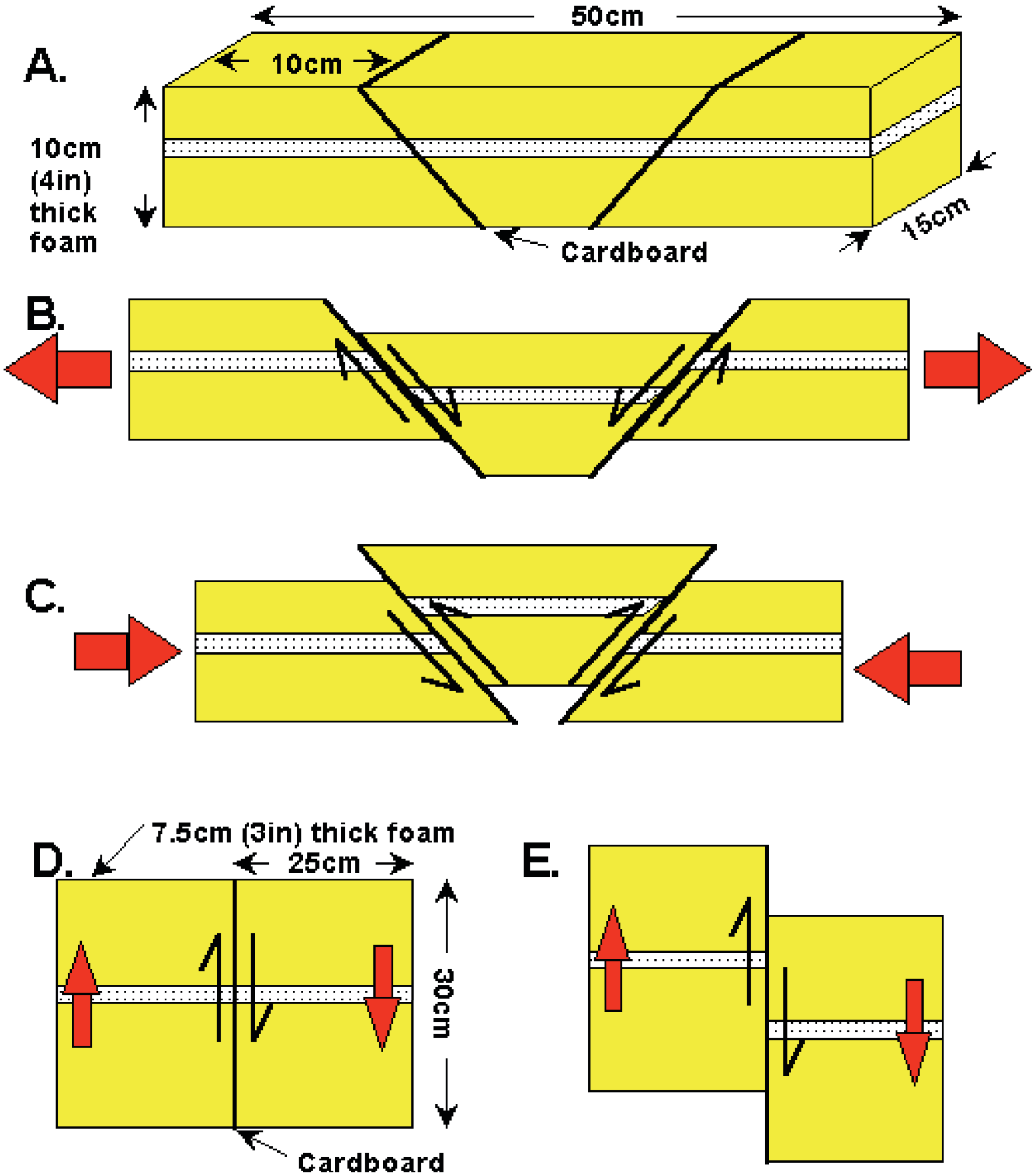

Figure 1. *Foam (soft, open cell foam used for mattresses) blocks for demonstrating faults (normal, reverse and strike-slip) and motions at plate boundaries (divergent and extensional motion; convergent and compressional motion; transform and horizontal slip motion). Large arrows show direction of force or plate motion. Half-arrows along faults show direction of relative motion along the fault plane. Shaded area is red felt pen reference line. A. Foam block with 45° angle cuts (cardboard, cut from manila folders, attached to angled faces with rubber cement) and reference line drawn on the side of the blocks with a felt pen. B. Response of model to extension. C. Response of model to compression. D. Foam blocks used to demonstrate strike-slip motion. Cardboard is attached to the two faces (as shown in Figure) using rubber cement. Reference lines and arrows are drawn on the top of the foam blocks using a felt pen. E. Response of model to horizontal slip motion.*

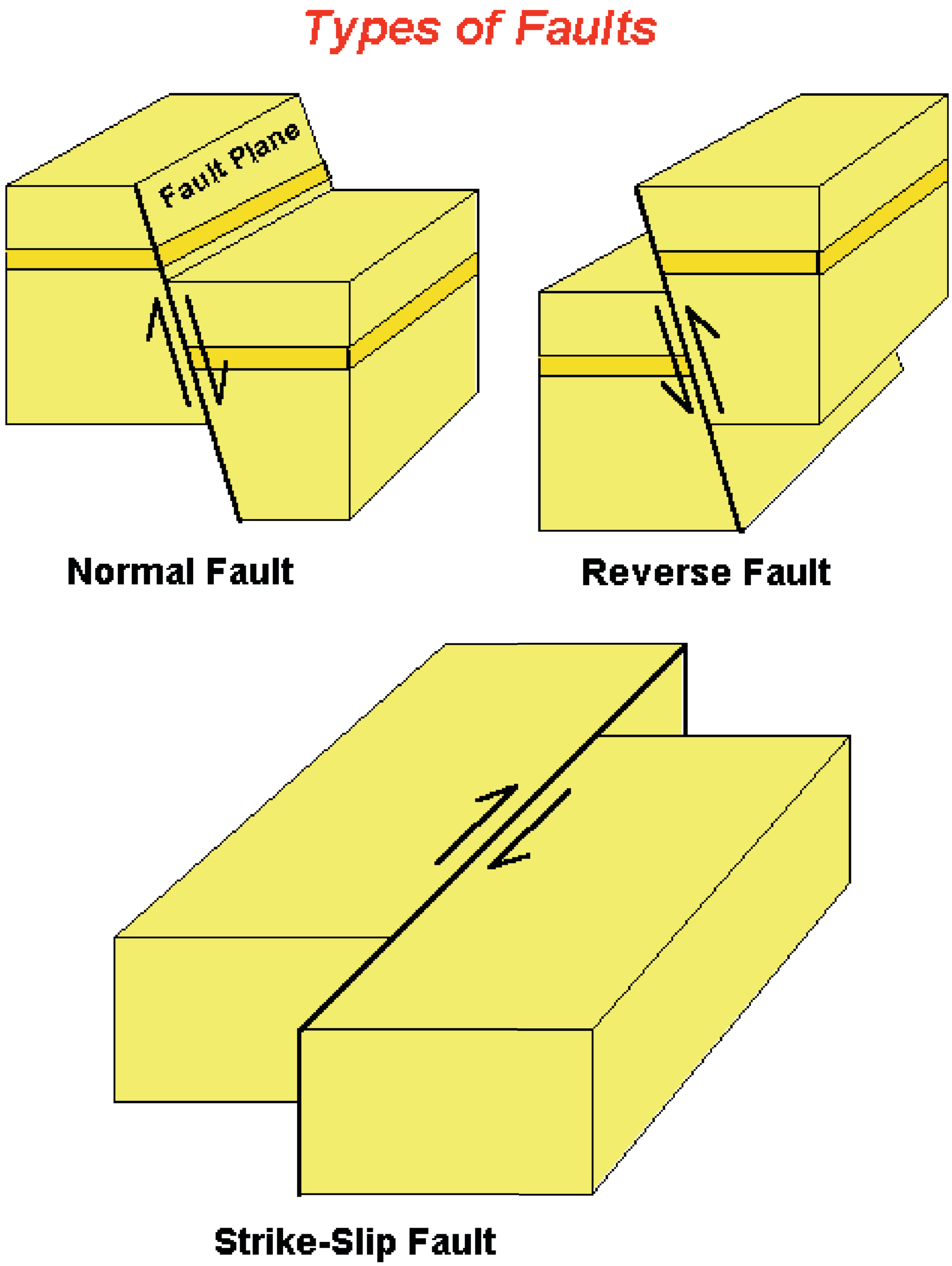

Figure 2. Block diagrams illustrating types of geological faults with resulting offsets of layers. Half-arrows show relative motion of the blocks along the fault plane.

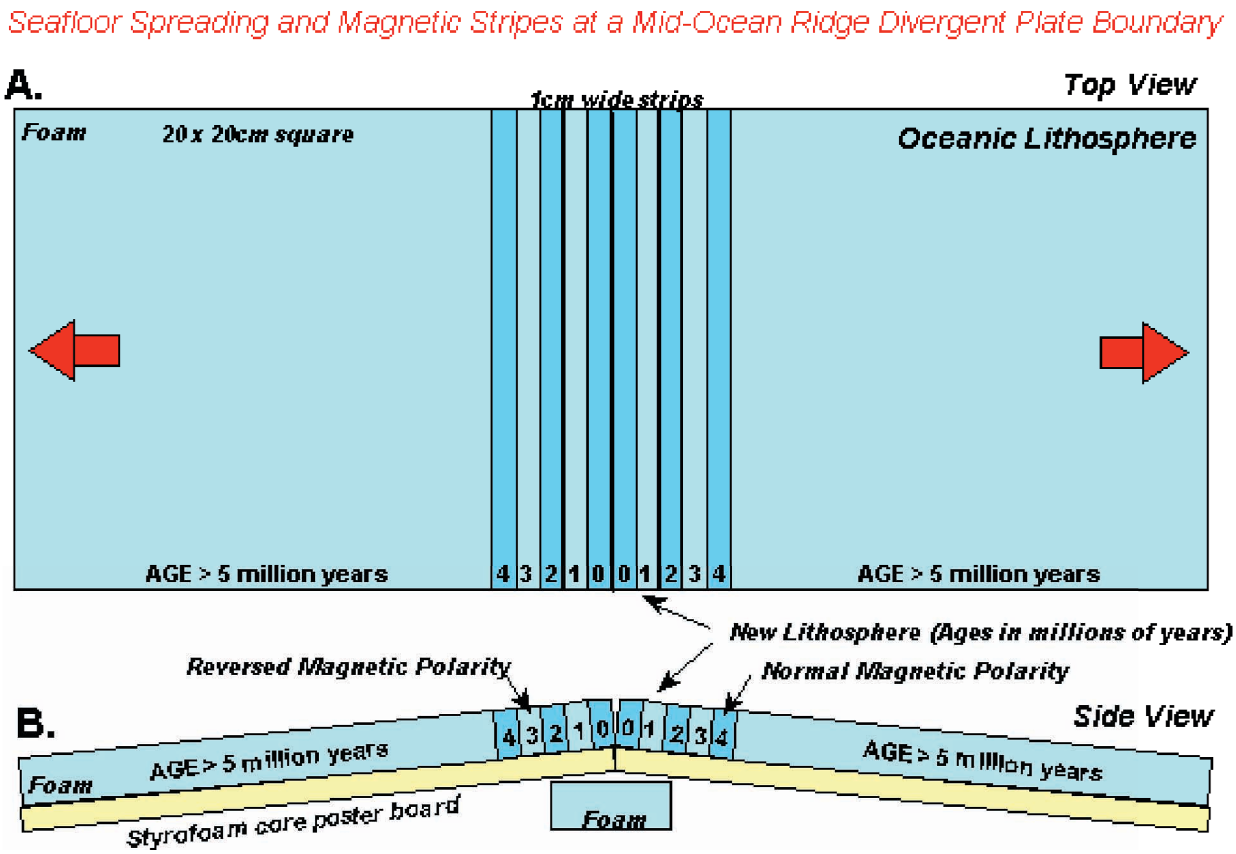

Figure 3. *Foam pieces for demonstrating divergent plate boundaries and a mid-ocean ridge spreading center. Cut out pieces with razor blade knife and straight-edge. A. Top view of foam blocks after assembly (see text) representing 5 million years of extension at the ridge crest and generation of new lithosphere by magmatic (igneous) processes. Numbers are ages in millions of years. In the real Earth, the time periods of normal (shaded) and reversed polarity would not be of equal duration (one million years in this simulation) and thus the 'stripes" would be of varying widths. B. Side view showing foam pieces on top of styrofoam base (two pieces, each 20 cm x 30 cm) which creates slopes representing the mid-ocean ridge. Attach styrofoam with pins to foam piece (2 cm x 20 cm) used to create slope.*

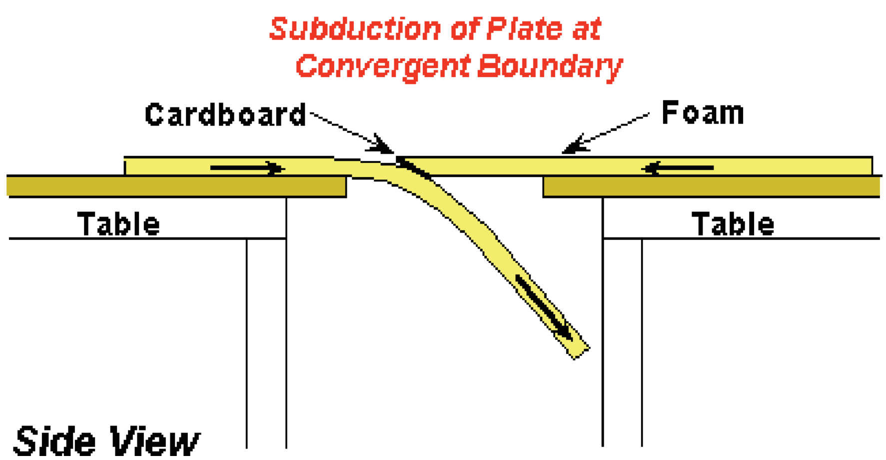

Figure 4. *Foam (soft, open cell foam) pieces (each piece is 50 cm by 15 cm by 2.5 cm (1 in) thick) used to demonstrate convergent plate motions and subduction. Edge of one of the foam pieces is cut at a 45 angle and lined with cardboard (manila folder material), using rubber cement to attach the cardboard*

to the foam.

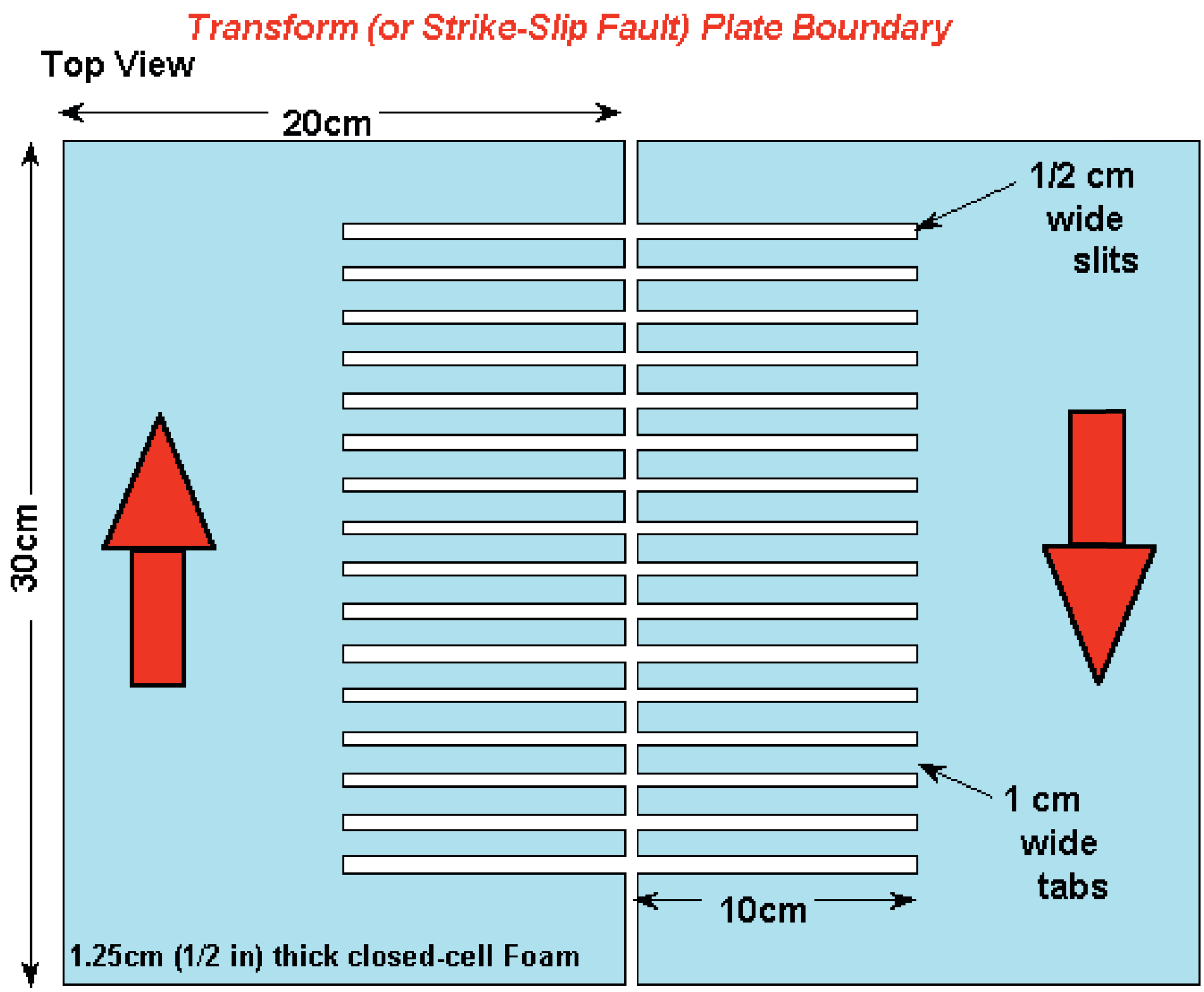

Figure 5. Foam pieces used to demonstrate strike-slip faulting, elastic rebound theory, and slipping along the fault plane during earthquakes. Cut out slits with razor blade knife and straight-edge.

Table 1. Faults, Plate Boundaries and Relative Motions*

Relative Motion of Layers or Plates	Fault Names	Plate Boundary Descriptions	Related Tectonic and Geologic Features
Extension	Normal	Divergent (extensional, moving apart, spreading, construction - because new lithosphere is generated in the extended zone)	Rifts, grabens, sometimes volcanism, regional uplift but local downdropped fault blocks, shallow earthquakes
Compression	Reverse or Thrust	Convergent (compressional, collision, subduction, moving together, destructive - because one	Folded mountain ranges, uplift, reverse faults, volcanic arcs (usually andesitic composite

		plate is often thrust into the mantle beneath the other plate)	volcanoes), deep ocean trenches, shallow and deep earthquakes in subducted slab
Translation or horizontal slip	Strike-slip	Transform (horizontal slip, translation)	Linear topographic features, offset stream channels, lakes in eroded fault zone, pull-apart basins and local uplifts along fault bends or "steps" between offset fault segments, oceanic fracture zones, offsets of mid-ocean ridges

*Many terms and geological "jargon" are associated with faults and plate boundaries. While these terms are useful to Earth scientists and are included here and in the accompanying text for completeness, the most important concepts such as extension, moving apart, downdropped blocks, etc., can be discussed and understood without unnecessary jargon. Additional information on the terms and concepts used here can be found in virtually any introductory geology textbook or in the USGS booklet "This Dynamic Earth - The Story of Plate Tectonics."