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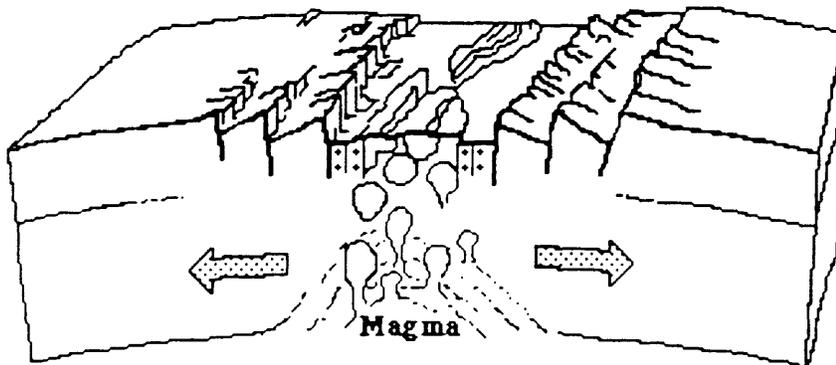
# Sea-Floor Spreading

A computer animation and paper model

By

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Open-file Report 95-573



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Teachers Guide:



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## SEA-FLOOR SPREADING

### INTRODUCTION

The Earth is far more dynamic than most people realize. Movement at the edges of large, rigid slabs of the earth's outer shell account for many of the dynamic features of the earth's surface: mountain building, volcanic activity, and earthquakes. Movement of these large rigid slabs is explained by what is known as the **theory of plate tectonics**. Tectonics (Tektonikso = to construct) refers to the building of the earth's crustal features.

The concept of a dynamic earth evolved from an earlier model called "**continental drift**." Alfred Wegener (a German meteorologist) presented abundant evidence suggesting that the continents moved great distances (thousands of kilometers) over time. Wegener viewed the continents as traveling across the ocean floor like rafts through the sea. The prevailing view at the time held that the ocean basins were fixed in "locked" position. Unfortunately, the concept of "continental drift" was rejected because Wegener was unsuccessful in describing a natural process that could explain how the movement of the continents could be brought about.

Exploration of the ocean floor in the 1950's and 60's produced a vast amount of scientific data, and, in the early 1960's great linear mountain ranges were mapped on the ocean floor. A magnetic survey of the ocean off the west coast of California, in 1961, produced a remarkable pattern of **magnetic lineations**. In a California laboratory (U.S. Geological Survey, Menlo Park), A. Cox, R.R. Doell, and G.B. Dalrymple dated a series of young onshore volcanic rocks where the magnetic signatures known as normal and reversed magnetic polarities were already known. This established the first **geomagnetic time scale**. Harry Hess, a professor of geology at Princeton University, wrote a paper suggesting that some oceanic margins had been overridden by continents, the ocean sediments at those margins were pulled down, and the ocean floor was welded to the continent. Using these ideas of sea-floor spreading and the recurring reversals of the Earth's magnetic field (the geomagnetic time scale), Vine and Matthews solved the puzzle of the magnetic lineations of the ocean floor.



As the ocean floor spreads apart along mid-ocean ridges (called spreading centers), the molten material that comes up along this linear belt is initially unmagnetized. As the material cools it acquires the direction of the existing magnetic field of the Earth, normal or reversed. The present-day magnetic field of the Earth is called "normal." When the Earth's magnetic field is the opposite of today's magnetic field it is called "reversed." The above information has allowed scientists to develop a dynamic model of the earth which we commonly call the theory of plate tectonics. This report illustrates how to build a model that can be used to teach two basic principles of plate tectonics: 1) the formation of an oceanic ridge system (sea-floor spreading) and 2) formation of transform fault boundaries.

## STRUCTURE OF THE EARTH

Three fundamental units make up the Earth, the **crust**, **mantle**, and **core**. The uppermost 100 kilometers (62 miles) under the oceans is called the lithosphere, a relatively cool, ridged shell that includes the crust and part of the upper mantle. The outer most layer of the earth is a thin crust, 4 to 60 kilometers (2.5 to 37 miles) thick, which is relatively light in weight. This outermost layer makes up only 0.4 percent of Earth's total mass. If the Earth were the size of an apple, this outermost layer would be about as thick as the skin of the apple. This outer layer consists of either continental or oceanic crust. Oceanic crust, 4 to 10 kilometers (2.5 to 6.2 miles) thick, consists of dark- to medium-dark-colored rock commonly known as **basalt**. The continental crust, 35 to 60 kilometers (22 to 37 miles) thick, and is composed of light-colored rock called **granite**. Together the crust and the uppermost part of the mantle make up the **lithosphere** (lithos = rock). The lithosphere is broken up into a dozen or more plates, which rest on the **asthenosphere**. Underlying the lithosphere is a high-temperature layer within the mantle called the asthenosphere (asthenos = soft), which is capable of plastic deformation and can flow slowly, allowing the rigid lithospheric plates to move.



The Earth's magnetic field is believed to be caused by the motion of the fluid outer core of the earth. Radioactive decay occurring in the core releases energy in the form of heat. The heat causes a series of convection cells to form in the mantle. Heat moves to the surface through these convection cells.

Zones of weakness in the crust may allow **magma** (molten rock) to flow up from the asthenosphere to the surface at the spreading axis. As the magma pours out onto the surface, newly created crust tends to move horizontally away from both sides of the zone of weakness. These zones of cracks and fissures form a system of underwater mountain ranges called **mid-oceanic ridges and rises**. The axes of oceanic ridges and rises are referred to as spreading centers, hence the term sea-floor spreading.

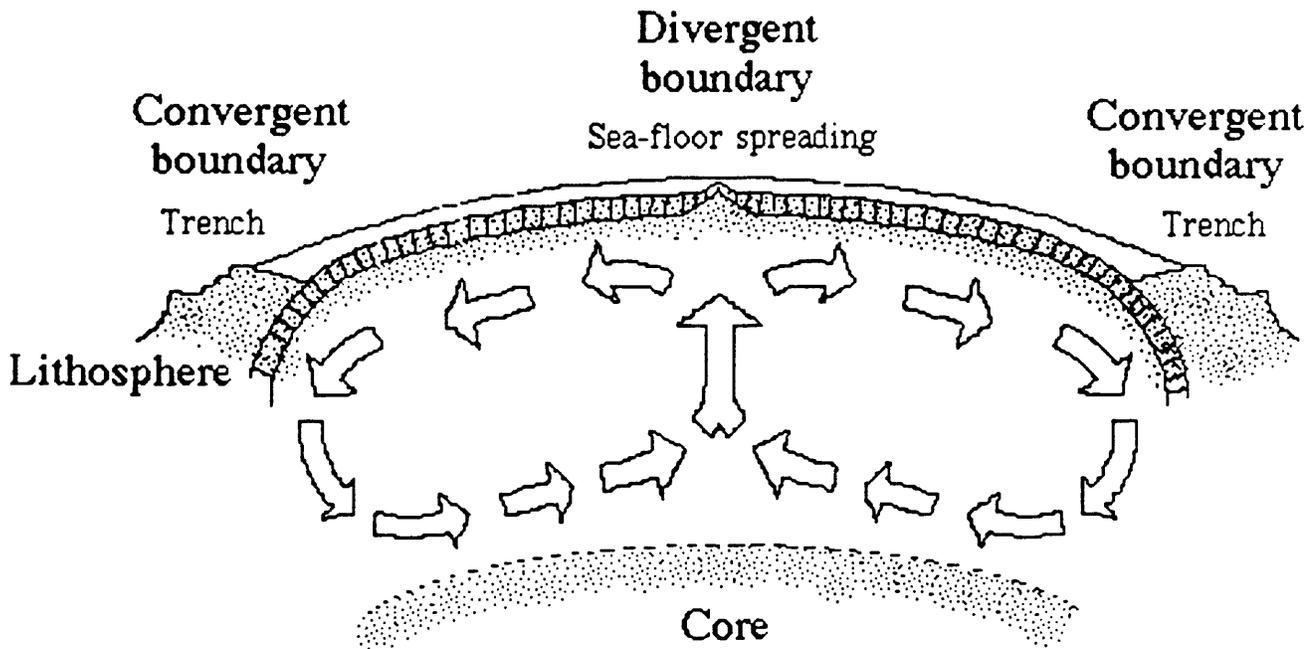


Fig. 1 Asthenosphere convection.



When molten rock cools and hardens, the direction of magnetic field of the Earth at the time of the cooling is set into the rocks. Molten basalt rock (magma) has temperatures in excess of 1000° C (1800° F.) All igneous rocks contain some particles of magnetite, which align with the direction of the earth's magnetic field at the time the rocks cool. The volcanic rocks which make up the oceanic crust have a high magnetite content and thus provide good recording of the direction of the Earth's magnetic field.

The Earth's magnetic field reverses at irregular intervals about once every 300,000 to 500,000 years (at least ten reversals in the last 4 million years). Thus rocks found on the ocean floor act similar to a giant magnetic tape recorder, preserving in their minerals the direction of the magnetic field at the time of their formation. Since the ages of these reversals are now known, the pattern of normally and reversed rocks found on the ocean floor provides the best evidence of the rate of plate motions.

### SEA-FLOOR SPREADING

The deformation behavior of rock is determined by three factors: (1) temperature, (2) pressure, and (3) rate at which a deforming force (stress) is applied. When force is applied to a solid mass, such as the rigid shell of the Earth, the crust, several things can happen. The solid mass is either (1) squeezed (compression), (2) pulled apart (tension), or (3) slides (shear). Geologists now recognize three distinctive boundaries between crustal plates. These boundaries are usually marked by earthquakes, volcanism, and rugged mountain topography. The three types of plate boundaries are known as (1) divergent boundaries, (2) convergent boundaries, and (3) transform plate boundaries. Crustal blocks are pulled apart (tension) at divergent boundaries, squeezed (compressed) at convergent boundaries, and slide past each other (shear) at transform boundaries.

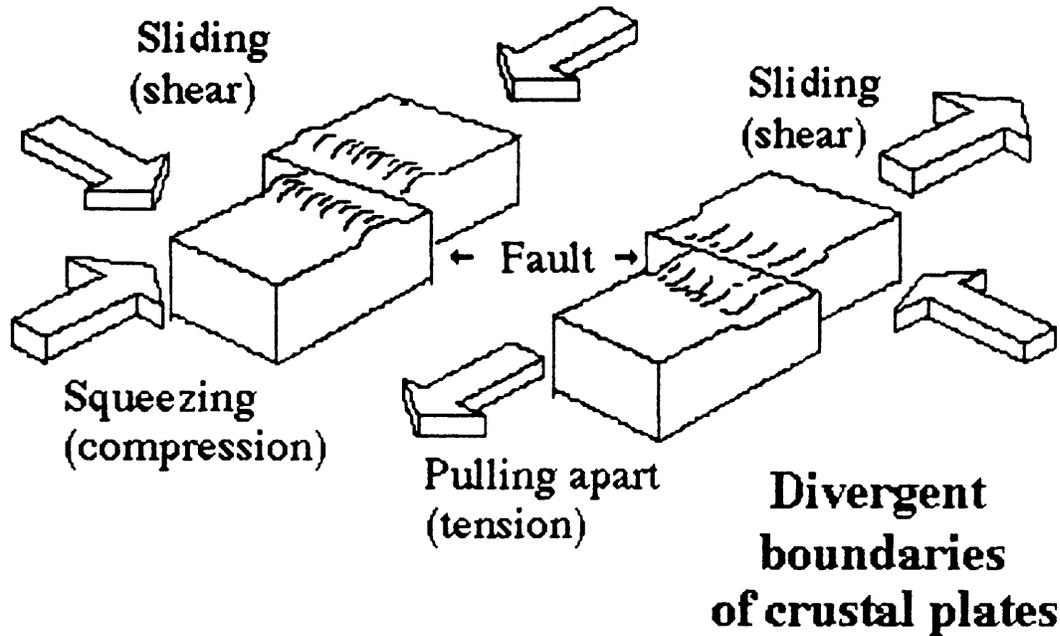


Fig. 2. Force applied to a solid mass.

### Activity

Demonstration using two samples of silly putty: have one student warm one sample in his hands for about five minutes. While the first student is warming the silly putty, have another student pull sharply on the other sample of silly putty. The putty should fracture, due to its brittle nature when cool. Have the second student pull on the warm silly putty. It should stretch without breaking. If the temperature is warm plastic deformation can also be demonstrated by placing a ball of silly putty on a table. It will deform under its own weight and form a puddle. Brittle deformation can be demonstrated by hitting a cool ball of silly putty with the heel of your hand. It will shatter due to its brittle nature. These are examples of how the same material can behave differently under different physical conditions.



The lithosphere, the outer hard shell of the earth, is broken into a dozen or so major pieces called plates. These plates are moving with respect to one another. In the past, the plates of North America, South America, Europe, and Africa were joined together forming one giant land mass. These plates have since spread apart, and the present ocean basins that separate them were formed. As the plates were pulled apart along zones of weakness, the resulting fractures were repeatedly filled with magma, which cooled and formed new oceanic crust. This process of forming new crust continues today.

The global system of sea-floor spreading forms a nearly continuous ridge system that resembles a mountain chain meandering its way through the major ocean basins. These mountainous features are called oceanic ridges or rises depending on the steepness of their slopes. These areas are where new features form. New oceanic crust is created as molten rock rises into the crustal fractures and is solidified, or is erupted forming volcanoes on the ocean floor. Together these processes produce approximately 20 cubic kilometers (4.8 cubic miles) of new oceanic crust each year. This nearly continuous ridge system extends across some 65,000 kilometers (40,400 miles) of the deep ocean basin and is the largest physiographic feature on Earth.

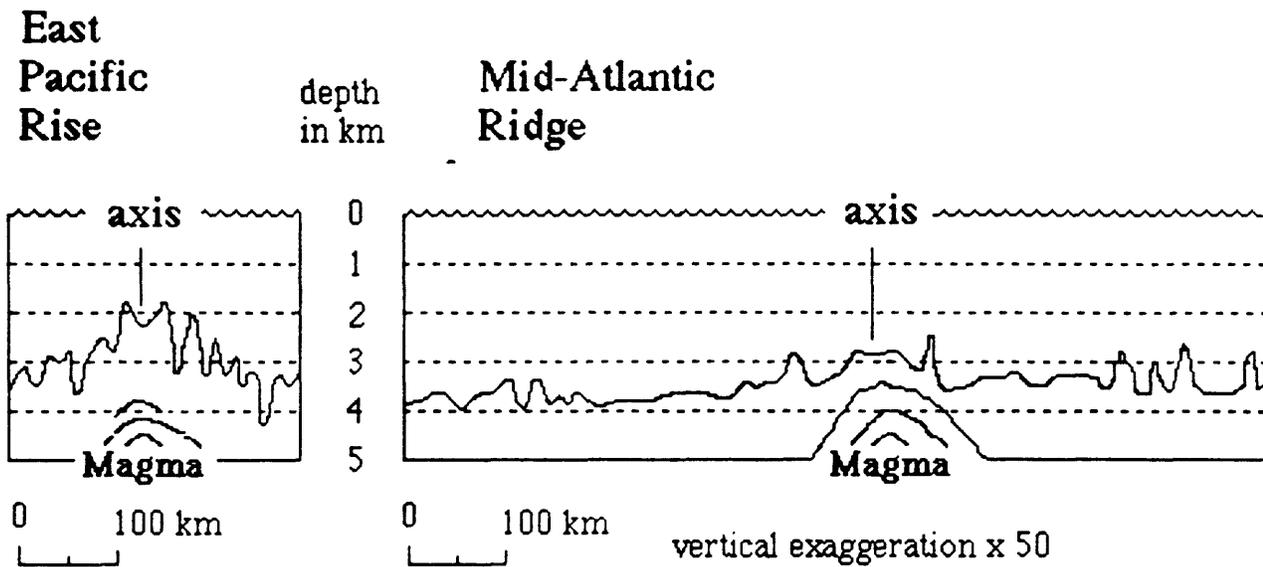


Fig. 3. Representative topographic (bathymetric) profiles across the ocean floor.

The Mid-Atlantic Ridge and East-Pacific Rise are complete mountain systems composed entirely of lavas with basaltic composition and extend an average of 2.5 kilometers (1.5 mile) above the ocean floor. Magma is extruded and intruded along the median zone of ridges, a process accompanied by the separation of the flanking lithospheric plates, so that new ocean floor is being continually formed. The rate of sea-floor spreading is more or less symmetrical about the ridge, adding to the plates on either side at the same average rate, and the direction of sea-floor spreading is usually approximately perpendicular to the ridge. The Mid-Atlantic Ridge separates at a rate of 1 - 2 cm (0.4 to 0.8 inches)/year compared to the East Pacific Rise, a fast moving spreading center that separates at an average rate of 6 to 8 cm (2.4 to 3.1 inches)/year.



TRANSFORM-FAULT BOUNDARIES

Newly formed oceanic crust moves away from the mid-ocean spreading centers, but since our planet is shaped like a sphere, the new crust cannot flow out in flat even sheets, the new crust must conform to the planet's round shape. That's why cracks must form perpendicular to the axes of sea-floor spreading. These cracks are called fracture zones. Where spreading centers are offset along these fractures (and where fault movement is in the opposite direction), the crack is called a **transform fault**.

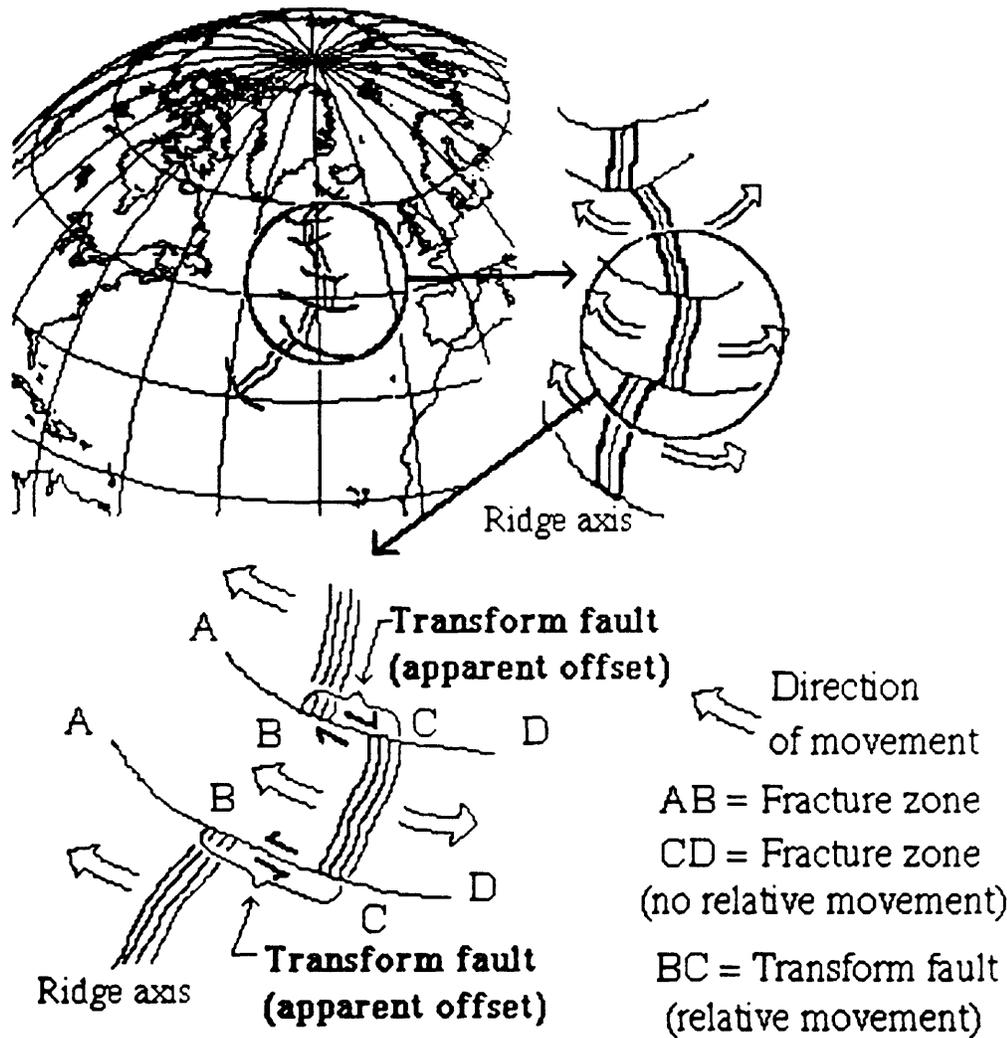


Fig.4. Transform fault boundaries.



Thus, ridge axes may be offset along transform faults, where oceanic plates slip sideways past each other. Transform faults are so called because they link two points at the ends of adjacent ridge segments where spreading motion is transformed into sideways motion. Because of the opposing motions of the plates on either side of the transform faults, these faults are seismically active and produce earthquakes.

The extension of a transform fault beyond the ridge lies within a single plate. The extension has no opposed lateral motion across it, and therefore shows no major seismic (**earthquake**) activity. Such a feature is called a **fracture zone**. Transform faults and fracture zones are usually expressed as bathymetric features such as scarps and cliffs on the ocean floor. Movement on the fractures cause the elevation of the ocean floor to be different on opposite sides of transform faults and fracture zones. Topographic highs are formed along the zones, producing a nearly continuous mountainous ridge system that extends across the deep ocean basin. A good way to demonstrate fracture zones and transform faults is to glue together two or three of the models shown here in a slightly offset position.

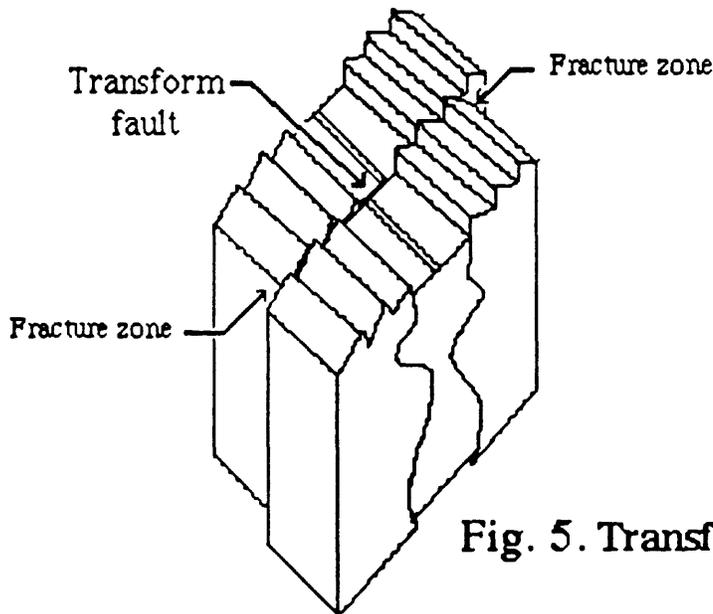


Fig. 5. Transform fault



## Fundamental Concepts

"Scientific literacy for all students is a National goal. The *National Science Education Standards* is a contribution toward achieving that goal." (Draft, November 1994, National Science Education Standards, prepared by the National Research Council, National Academy of Science)

After building this model and reading the text, all students should have developed a basic understanding of the following fundamental concepts for Earth and Space Science as recommended in the *National Science Education Standards*. These fundamental concepts for grades 5-8 and 9-12 are highlighted below.

### Grades 5 - 8

- o The solid Earth is layered, with a thin brittle crust, a hot convecting mantle, and a dense metallic core.
- o Crustal plates on the scale of continents and oceans constantly move. Major geologic events, such as earthquakes, volcanoes, and mountain building, result from these plate motions.
- o The Earth processes we see today are similar to those that occurred in the past.

### Grades 9 - 12

- o The outward transfer of Earth's internal heat drives convection circulation in the mantle that propels the crustal plates.
- o Geologic time can be estimated by observing rock sequences.



## What's in it for me?

Why study sea-floor spreading? Many of the world's geologic hazards are directly related to the movement of oceanic plates. Geologic hazards are those hazards that pose a danger to human life and can cause widespread destruction of buildings and roads. Major geologic events, such as earthquakes, volcanoes, and mountain building, are the direct result of the movement of crustal plates. The worldwide distribution of earthquakes and volcanoes on the ocean floor is not random, but linked to the margins of the moving crustal plates. A large earthquake occurring offshore can generate a tsunami (tsunami = "harbor wave" in Japanese and refers to dangerous, fast-moving waves) capable of killing thousands of people and destroying cities which are located near the coast. The study of sea-floor spreading helps geologists understand the distribution of earthquakes and volcanoes. This knowledge can help scientists and government agencies reduce the potential damage caused by earthquakes and volcanic eruptions. As the oceanic plates pull apart, an underwater system of mountain chains is formed. These underwater mountains and volcanoes meander their way across the major ocean basins. It is also FUN to learn that there are mountains, canyons, and volcanoes on the ocean floor and how they got there!



### Questions for further study

Is the floor of the ocean flat? Are there mountains and volcanoes located in the floor of the ocean?

Are the plates that make up the Earth's crust located on land or in the oceans? What is the largest plate?

If one could cut the Earth in half and see its interior, what are the three fundamental units that make up the Earth?

Are the crust and upper part of the mantle that includes the plates called the lithosphere or asthenosphere?

What are the differences between crust and lithosphere?

Are sea-floor spreading centers located at the edges of plates or in the middle of plates?

Are sea-floor spreading centers single points or linear features?

Do the rocks forming today from sea-floor spreading have normal or reversed magnetic polarity?

There are three distinct types of boundaries between crustal plates, divergent (pulled apart), convergent (squeezed), and one more. What is it? Hint. This type of boundary is found onshore near central California.

Is plate tectonics a recent phenomenon or has it been going on for most of the Earth's history?



## Glossary

**Asthenosphere:** (asthenos = soft or weak) A weak, high-temperature plastic layer underlying the lithosphere that is capable of plastic deformation and can flow slowly, allowing the rigid lithospheric plates resting at its upper surface to move.

**Basalt:** A dark- to medium-dark igneous (volcanic) rock.

**Continental drift:** A general term used to describe the large-scale horizontal movement or displacement of the continents by sea-floor spreading.

**Core:** The central zone of the Earth's interior. Earth's magnetic field originates in the core. One of the three fundamental units which make up the Earth—the crust, mantle, and core.

**Crust:** The thin outermost layer of the Earth. The crust is 4 to 60 kilometers (2.5 to 37 miles) thick. One of the three fundamental units which make up the Earth—the crust, mantle, and core.

**Earthquake:** A sudden shaking of the Earth caused by the abrupt release of stress that had been slowly accumulating.

**Fracture:** A general term for any break in rock, whether it is by displacement, mechanical failure, or stress. Fractures include cracks, joints, and faults.

**Fracture zone:** A long, narrow zone of irregular breaks on the ocean floor which displaces (offsets) mid-oceanic ridges and rises at nearly right angles to the spreading axes.

**Geomagnetic time scale:** A chronology based on dated reversals of the Earth's magnetic field.



## Glossary (cont'd)

**Lithosphere:** The uppermost 100 kilometers (62 miles) under the oceans is called the lithosphere, a relatively cool, rigid shell that includes the crust and part of the upper mantle.

**Magma:** Hot molten rock generated within the Earth.

**Magnetic lineations:** Local magnetic anomalies in oceanic crust due to variation in rock magnetization caused by reversals of the Earth's geomagnetic field.

**Mantle:** The zone of the Earth below the crust. One of the three fundamental units which make up the Earth—the crust, mantle, and core.

**Mid-oceanic ridges and rises:** An undersea mountain range system produced by faulting and the creation of new crustal material at a spreading center.

**Theory of plate tectonics:** A global model of the Earth to explain the movement of crustal plates.

**Transform faults:** A transform fault represents active displacement of the ridge axis where one plate slides past another.



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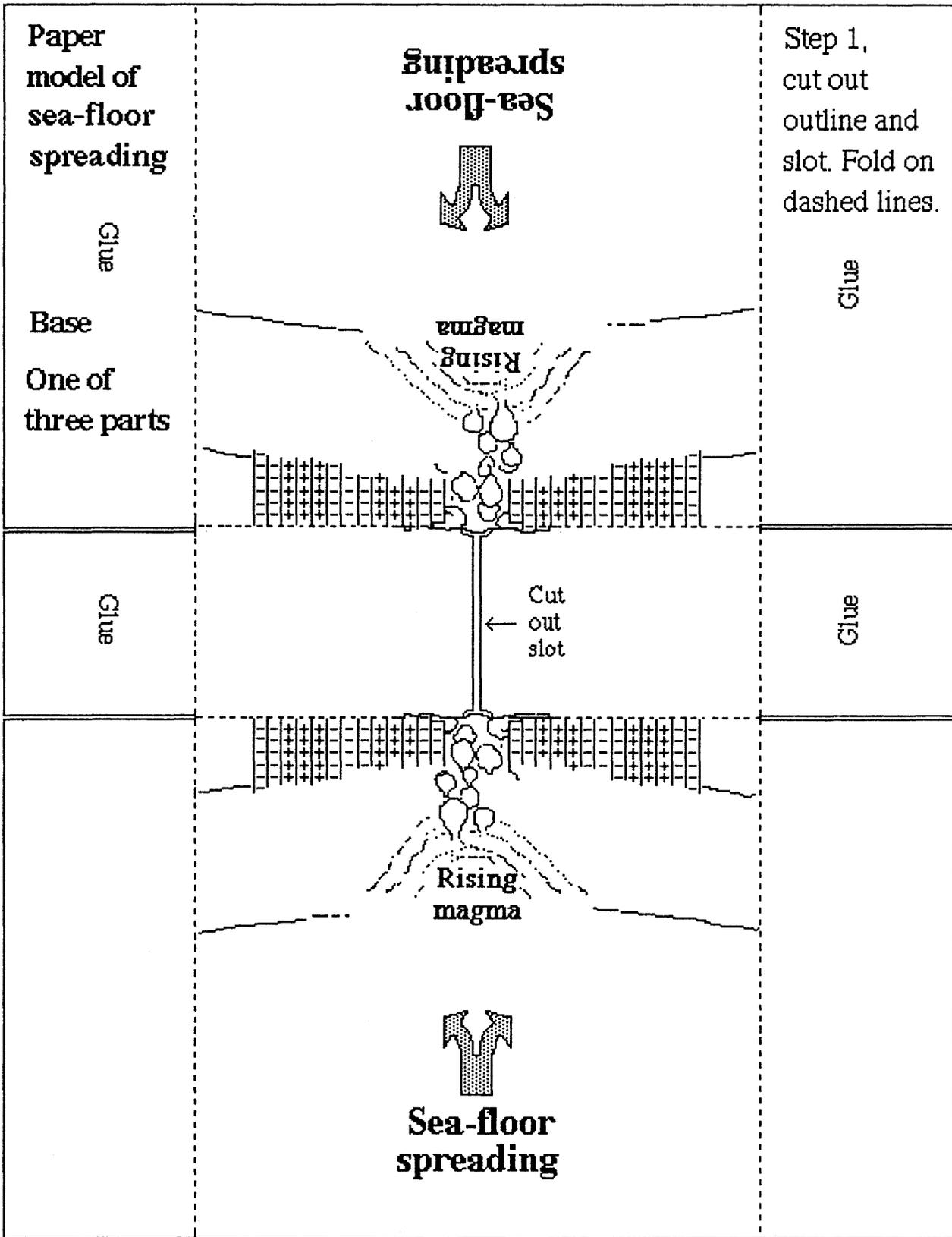
**Additional Models and Animations (cont'd)**

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Make your own paper fossils, a computer animation and paper  
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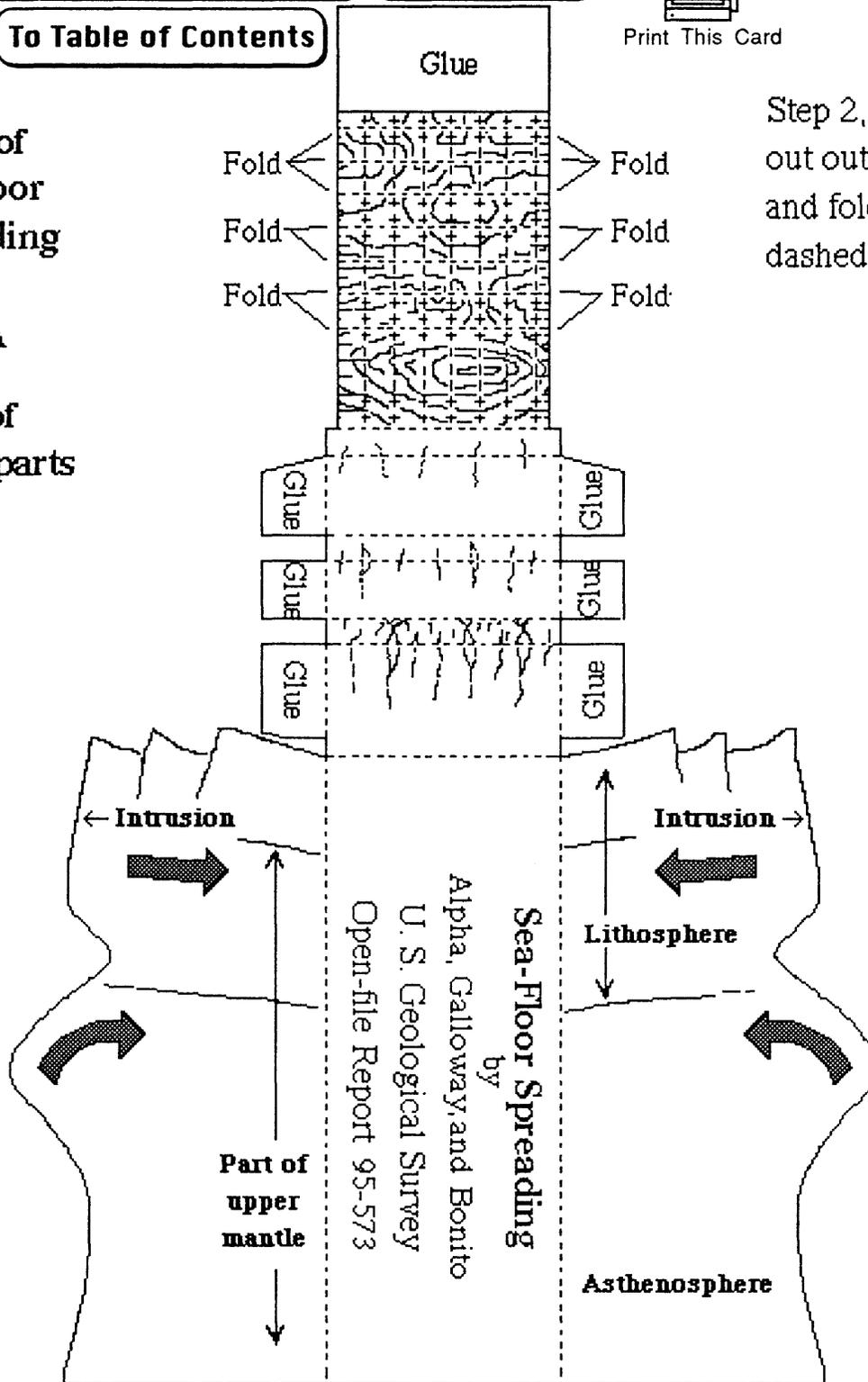
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Paper model of sea-floor spreading

Side A

Two of three parts

Step 2, cut out outline and fold on dashed lines.



Go to the first of three parts

Instructions

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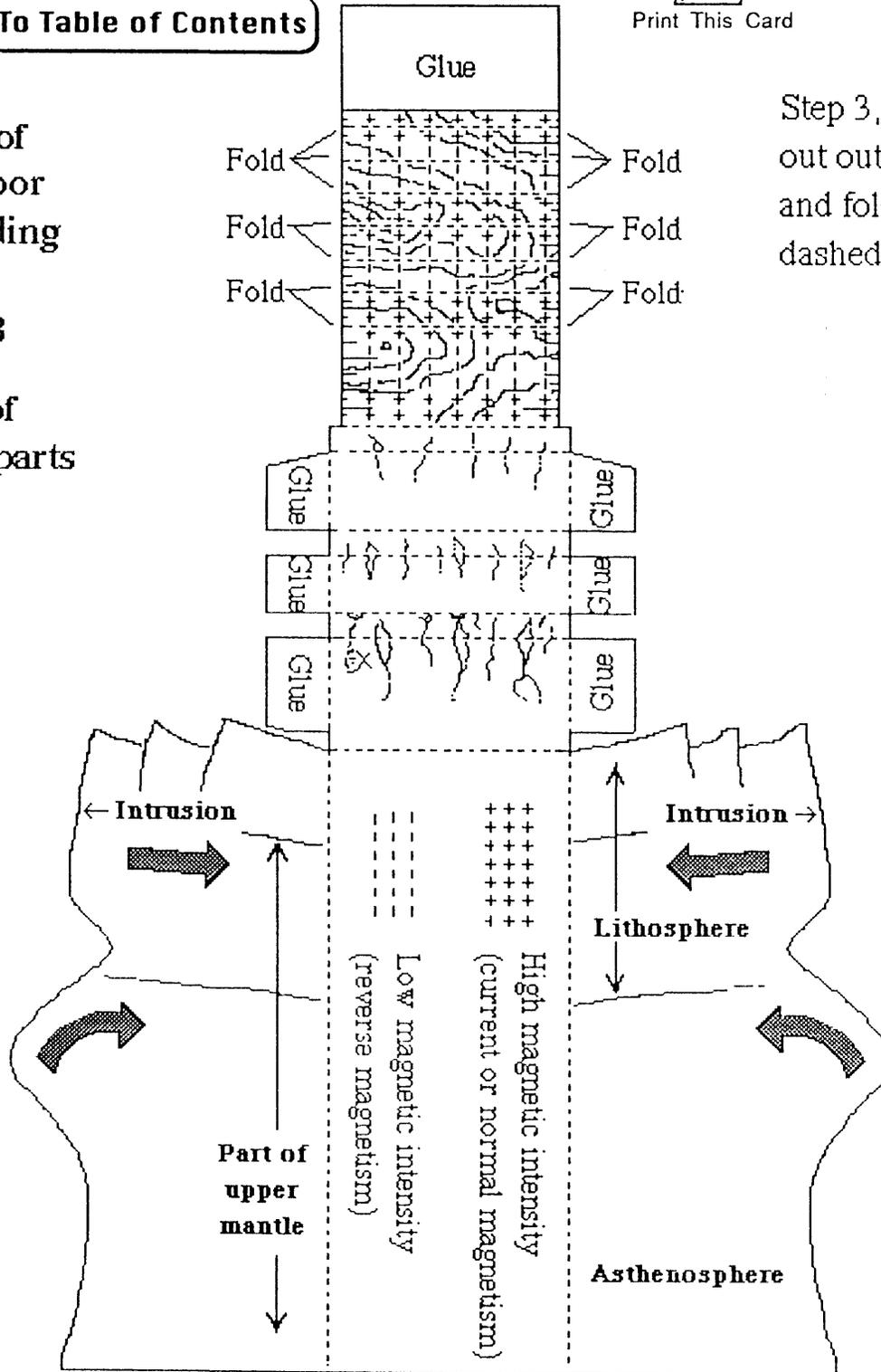
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Paper model of sea-floor spreading

Side B

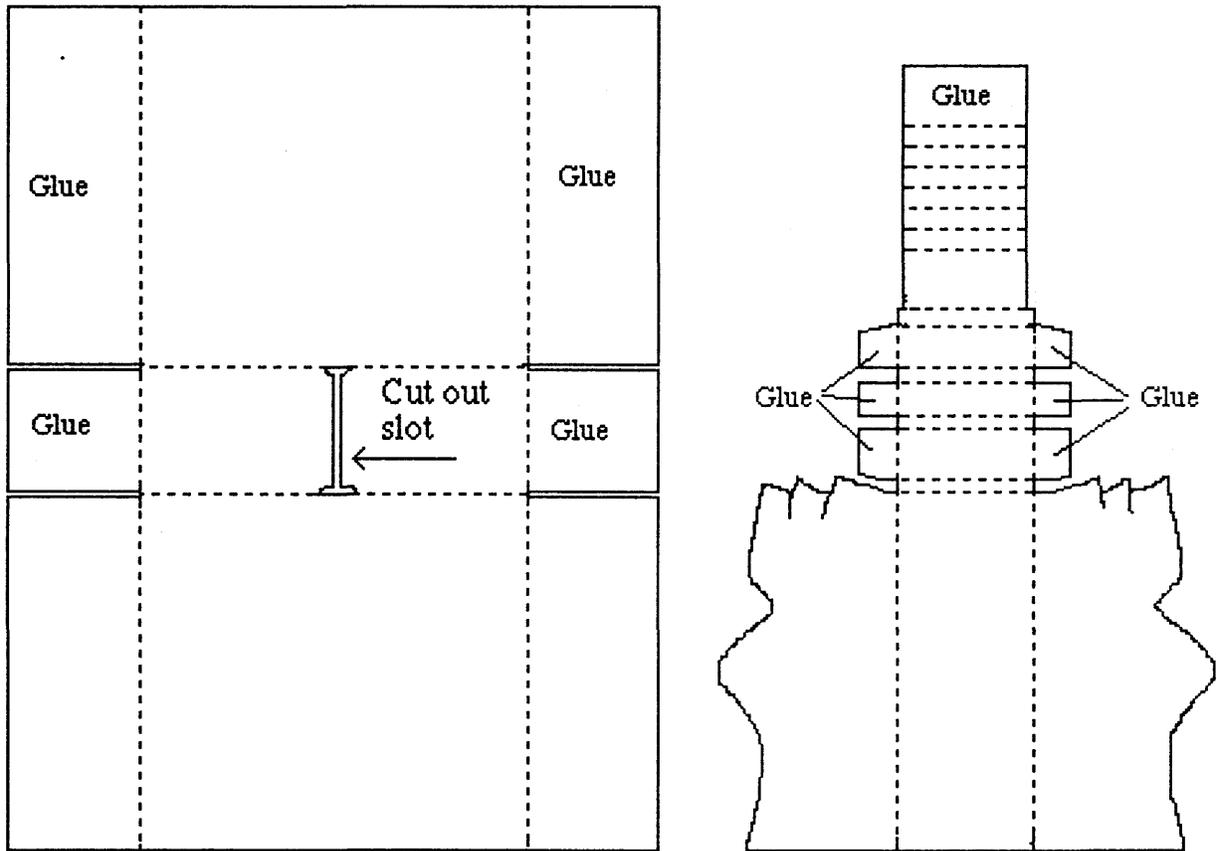
Two of three parts

Step 3, cut out outline and fold on dashed lines.



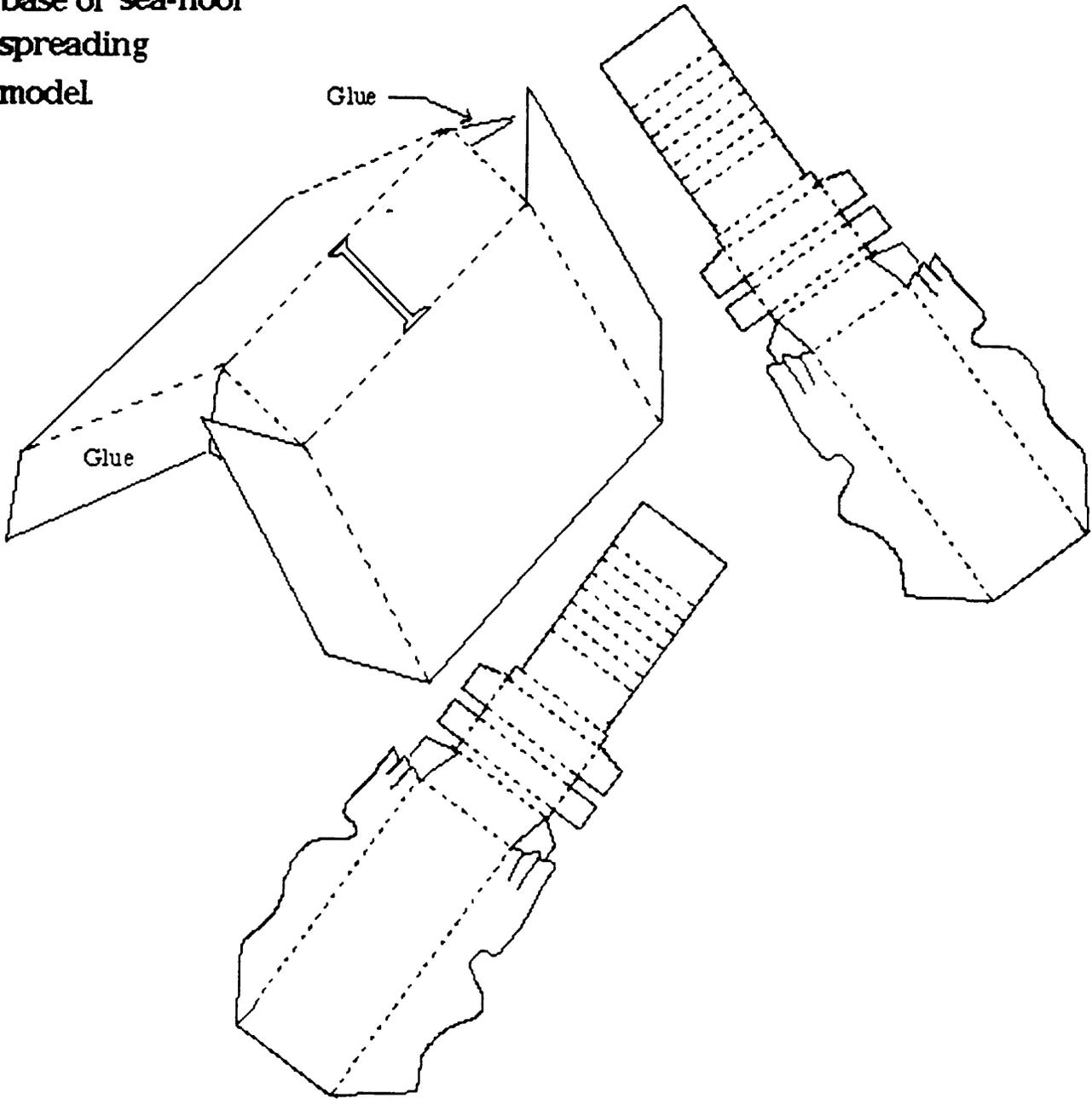


Step 1, Cut out base and both sides of sea-floor spreading model.

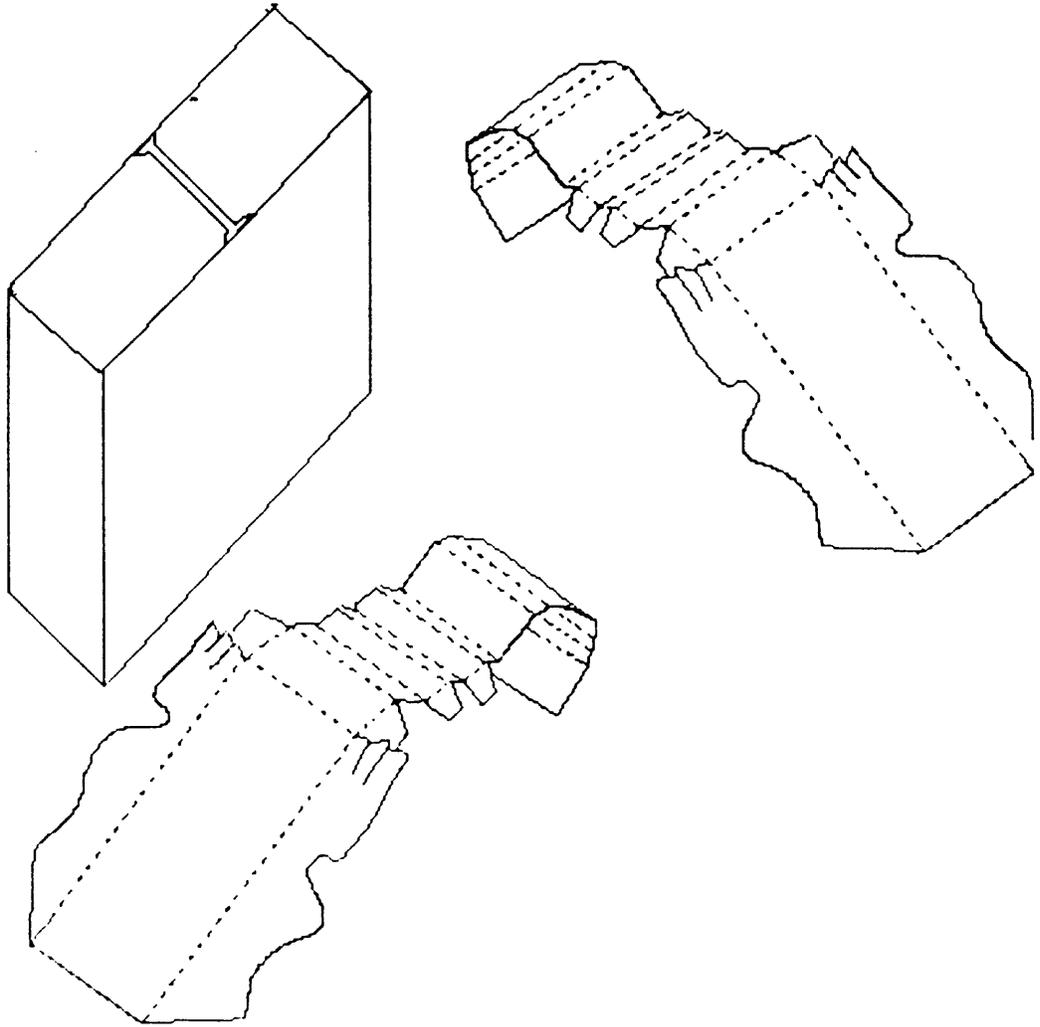


To make straight folds score the dotted line with an inkless ballpoint pen or similar object and a straight edge.

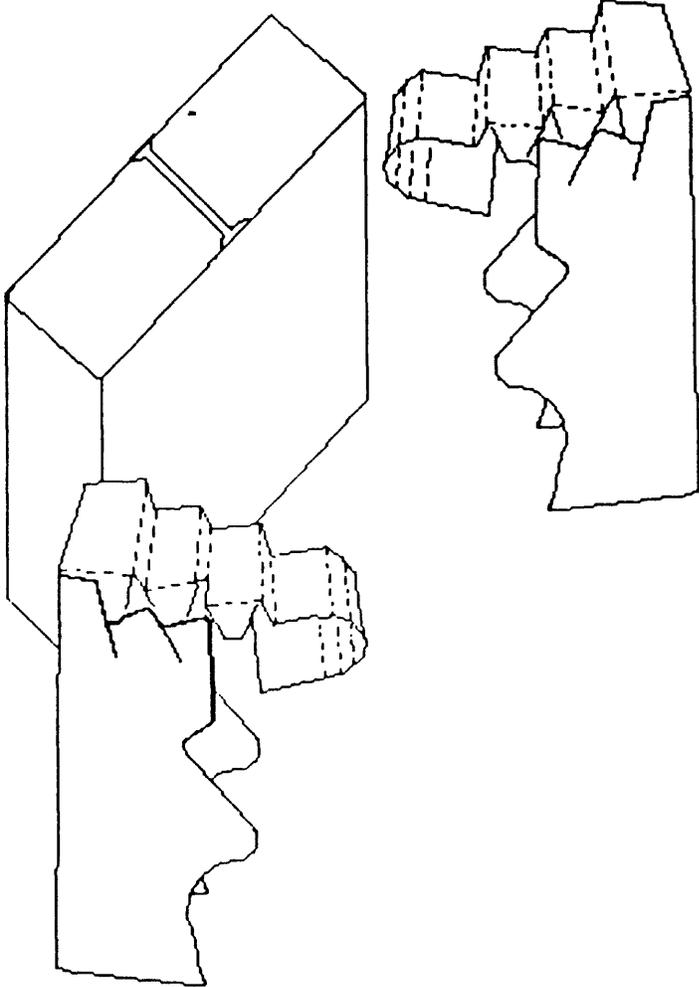
Step 2, Fold and glue  
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spreading  
model.



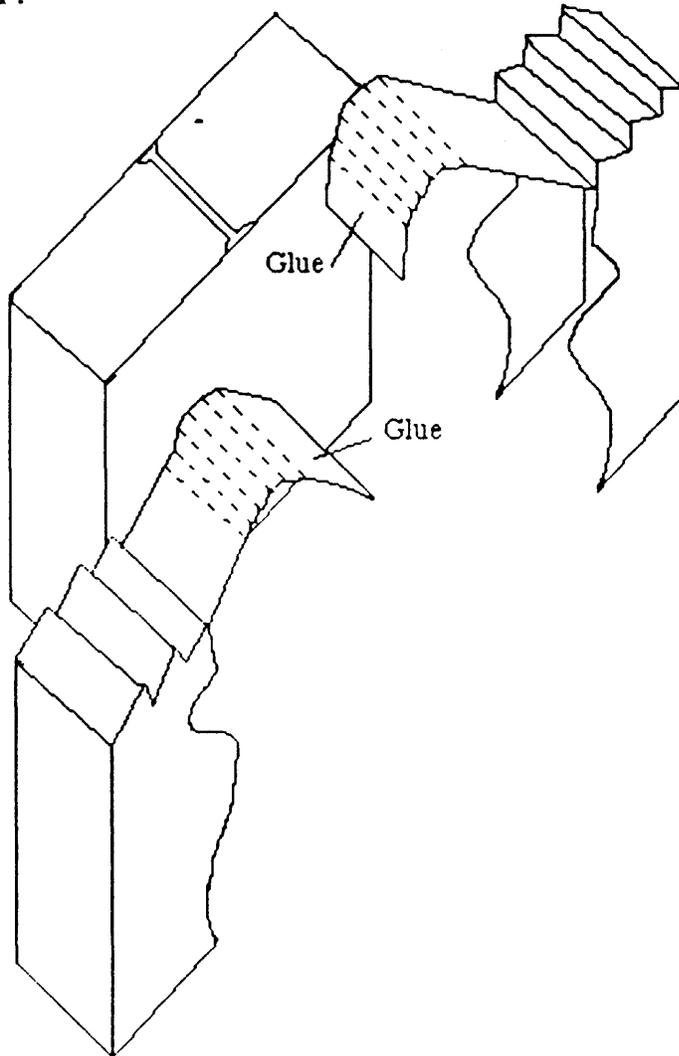
Step 3, Fold both  
side pieces of  
sea-floor spreading  
model.



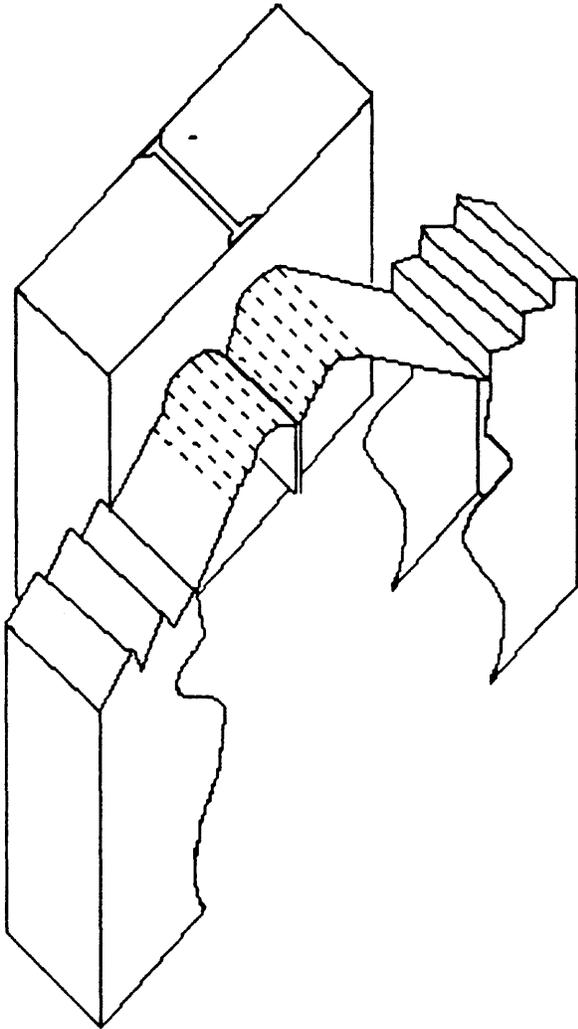
Step 4, Join tabs of  
both side pieces  
of sea-floor spreading  
model.



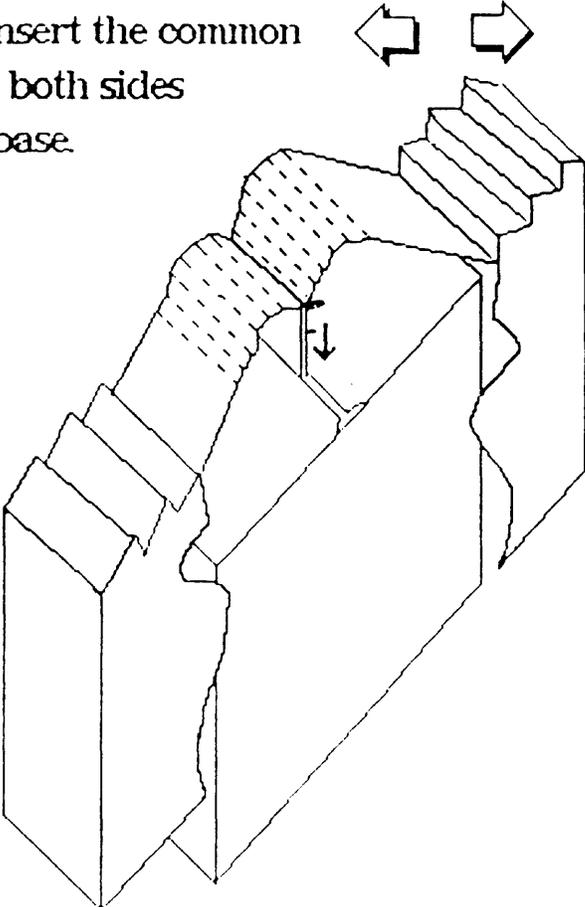
Step 4, Glue both side pieces of sea-floor spreading model together.



Step 5, Insert the common  
tab from both sides  
into the base.



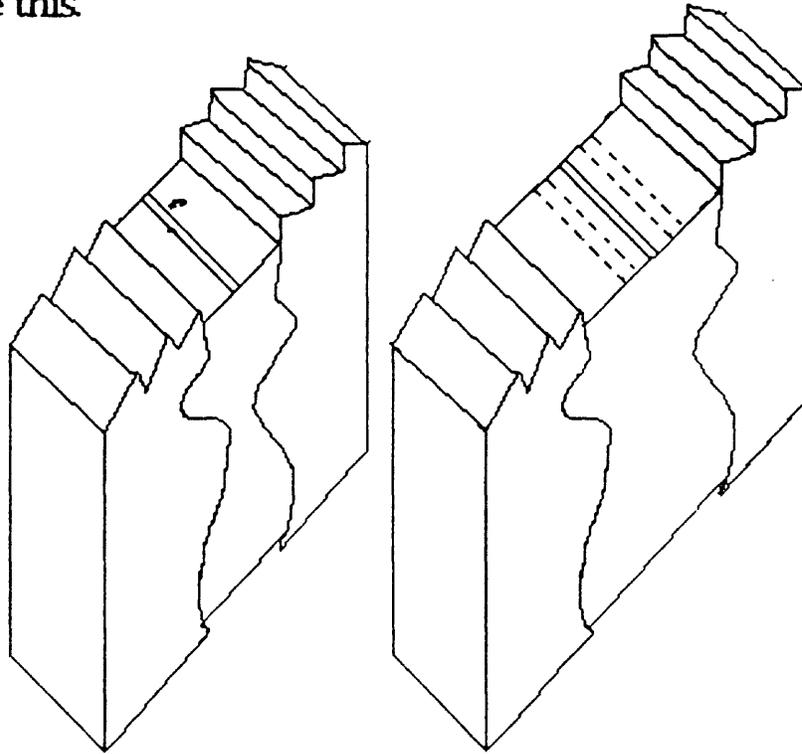
Step 5, Insert the common  
tab from both sides  
into the base.



Finished sea-floor spreading model should look like this.

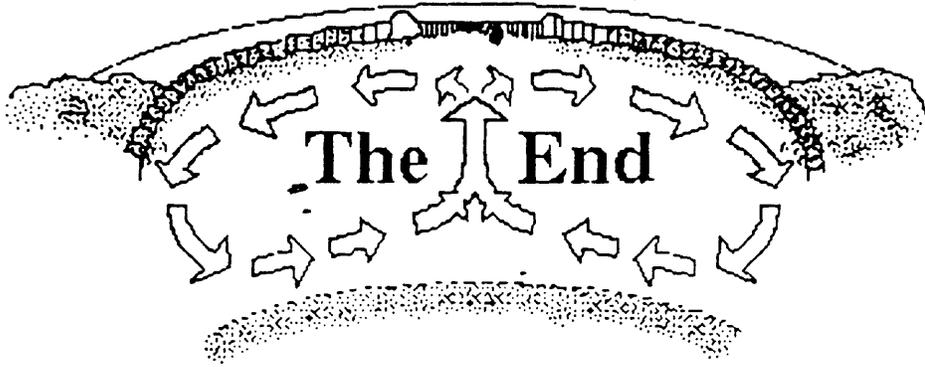


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