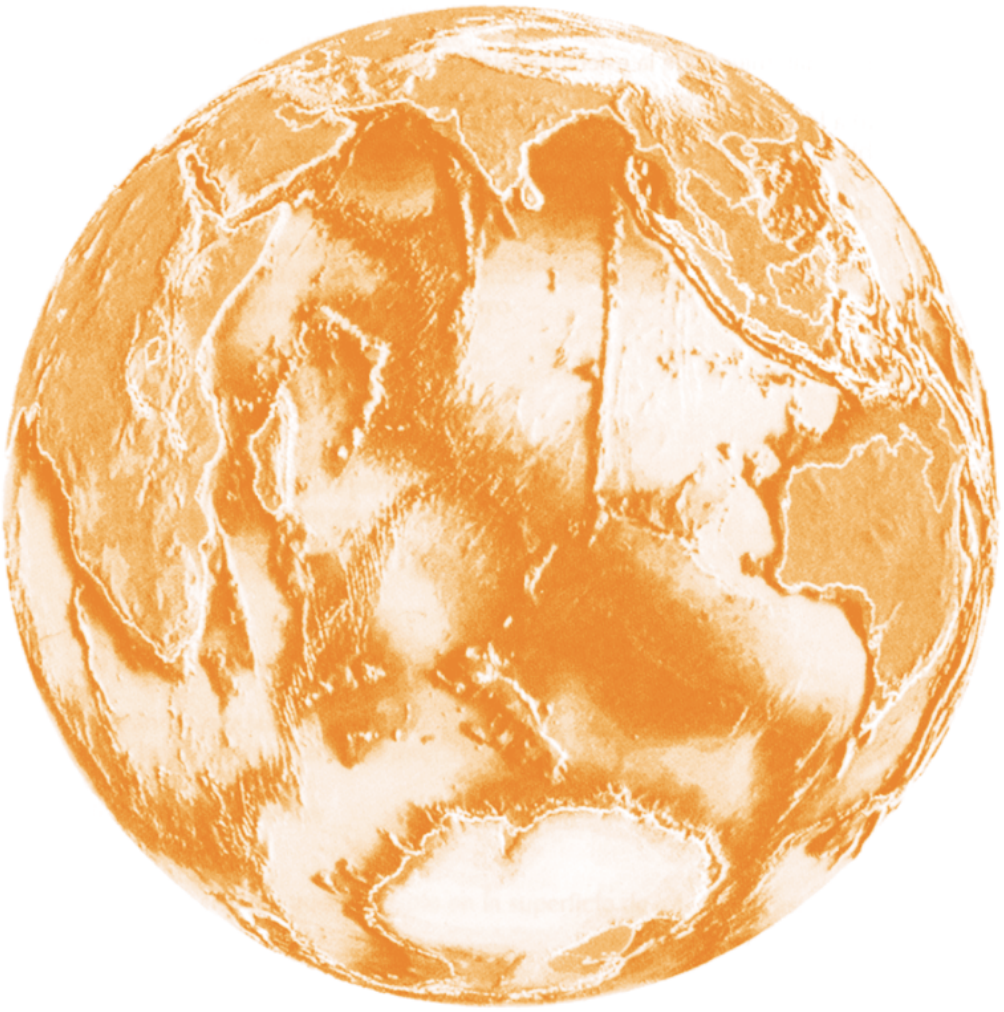


CHAPTER 2

THE EARTH'S CRUST ON THE MOVE

This is how eastern Africa, the Red Sea, and Arabia look from a satellite circling the earth. imagine that you could remove the Red Sea and rotate Arabia toward Africa. Surprisingly enough, these land masses would fit together rather well. By the time you finish this chapter you will know why.

This chapter explains some new theories about the earth. Changing old ideas about the nature of the earth's crust took many years. It started with the strange idea that continents might be moving or drifting over the earth. Research in the oceans revealed surprising evidence. Many questions about our earth have not yet been answered, but the new theories furnish the starting point for future research.

CHAPTER OBJECTIVES

1. Explain the meaning of continental drift.

2. List the evidence for sea-floor spreading.

3. Compare three types of plate boundaries.

4. Describe two forces that could cause plates to move.

2.1 THE JIGSAW PUZZLE OF THE CONTINENTS

Many mysteries about our planet have stirred the curiosity of observant people. Earlier in this century, explorers were amazed to find rocks with fossil imprints of ferns in the frozen lands of the Arctic and the Antarctic. How could plants that thrive in warm, moist climates exist in what is now a harsh climate? What changes had taken place? The answers to the following questions are one man's attempt to solve these mysteries:

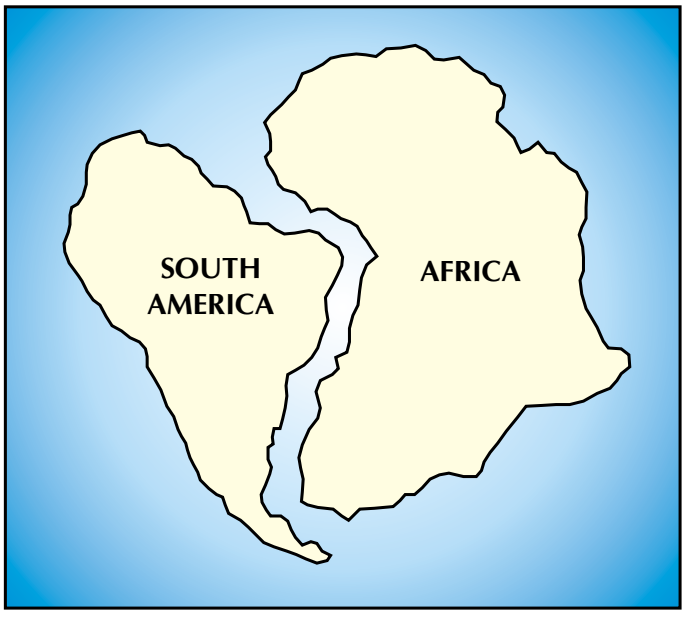
a. What is the theory of Continental Drift?

b. What was the evidence for continental drift?

• THEORY OF CONTINENTAL DRIFT

The first realistic maps of Europe and America were drawn in the 1600s. Since that time many people have wondered about the jigsaw puzzle fit of the Atlantic coastlines of South America and Africa. But they could only guess why these continents looked as if they might fit together. In 1912, Alfred Wegener, a German scientist, published a theory to explain the jigsaw fit in a book titled "The Genesis of the Continents and the Oceans". He stated that all the continents were once joined. The map below shows the joined continents Wegener called Pangaea, which means "all the land" in Greek.

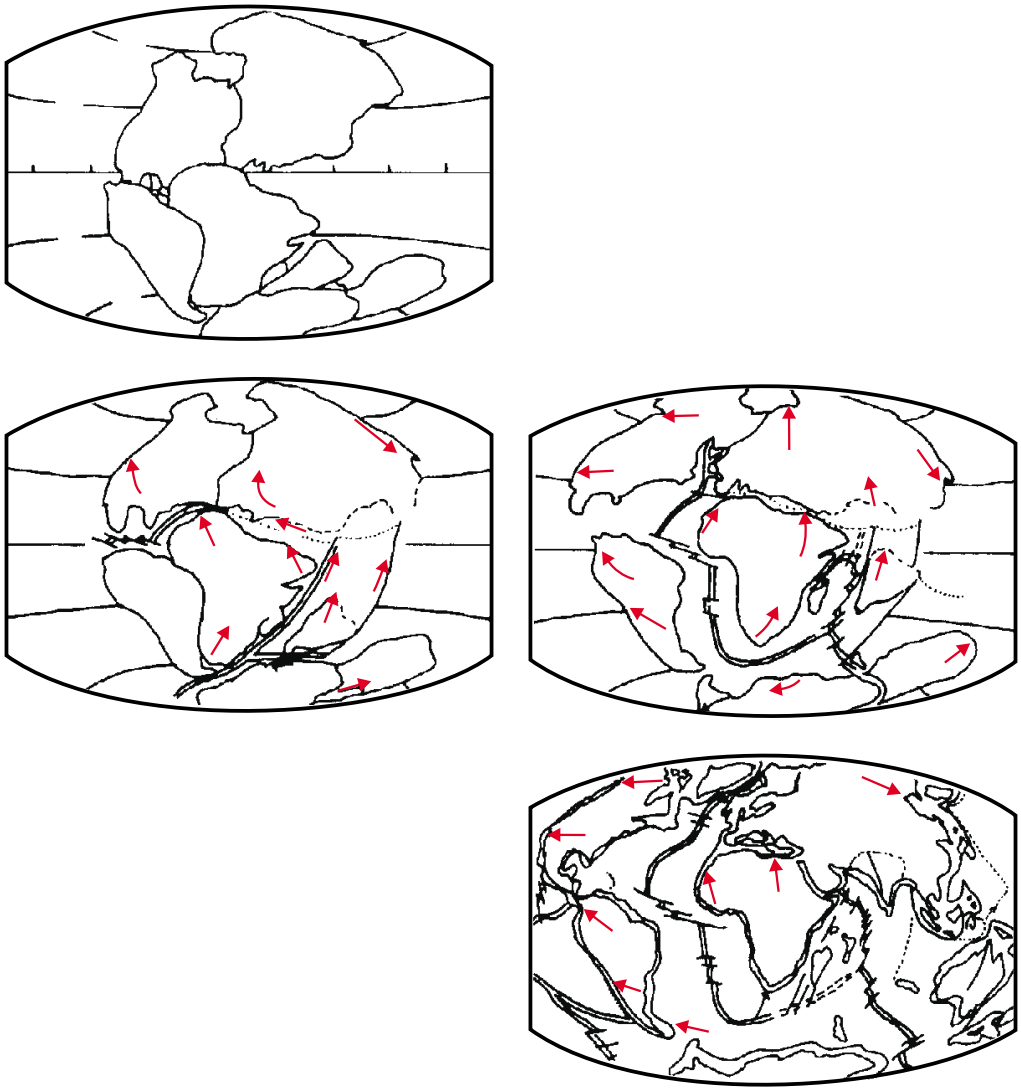
Wegener believed that Pangaea began breaking up and drifting apart many millions of years ago. He insisted that the jigsaw fit of the continents was not an accident, but the result of the splitting of Pangaea. He said that the continents slowly drifted over the ocean floor until they reached their present positions.



Fitting of continents.

• WEGENER'S EVIDENCE FOR CONTINENTAL DRIFT

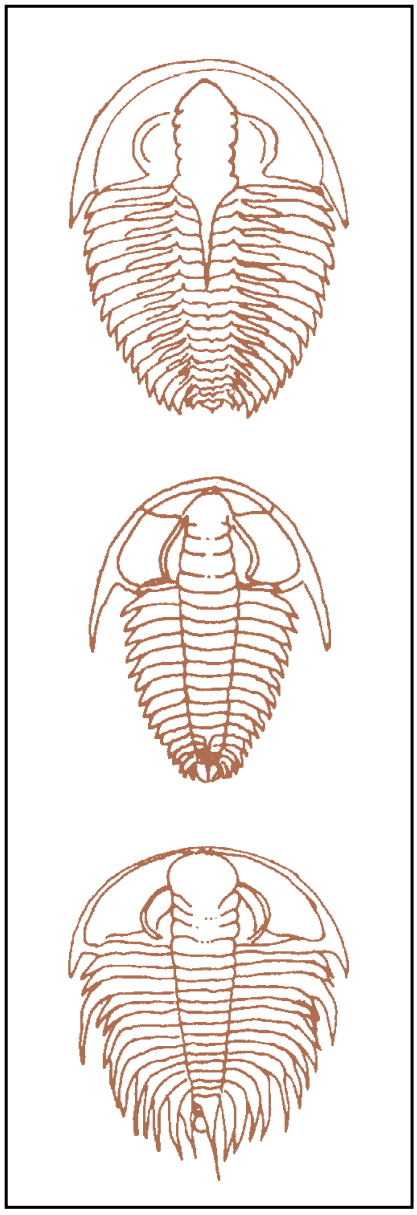
What was Wegener's evidence for continental drift? First, explorers had found fossils and rock layers on the east coast of South America that were similar to those found on the west coast of Africa.



Evolution of continents distribution.

Fossils of the animal shown to the right were discovered in both South America and Africa. These findings convinced Wegener that the continents were once joined. Second, explorers found rocks made of glacial sediments at the equator where no glaciers could exist. How did Wegener explain this finding? He believed that the land mass drifted to a warmer region of the earth.

Wegener's evidence was interesting, but it did not prove that continents moved. Scientists rejected the continental drift theory because Wegener could not explain how or why continents moved. His imaginative theory is not entirely correct, but it set the stage for other bold ideas.



Trilobite
(200 millions years old fosil)

2.2 DISCOVERIES IN THE OCEAN

Scientific breakthroughs in the 1960s sparked interest in Wegener's continental drift theory. Research data suggested that the Atlantic Ocean was growing. How can an ocean grow? Could the crust of the earth be moving? Consider the questions below as you read:

a. What are mid-ocean ridges, and trenches?

b. What is sea-floor spreading?

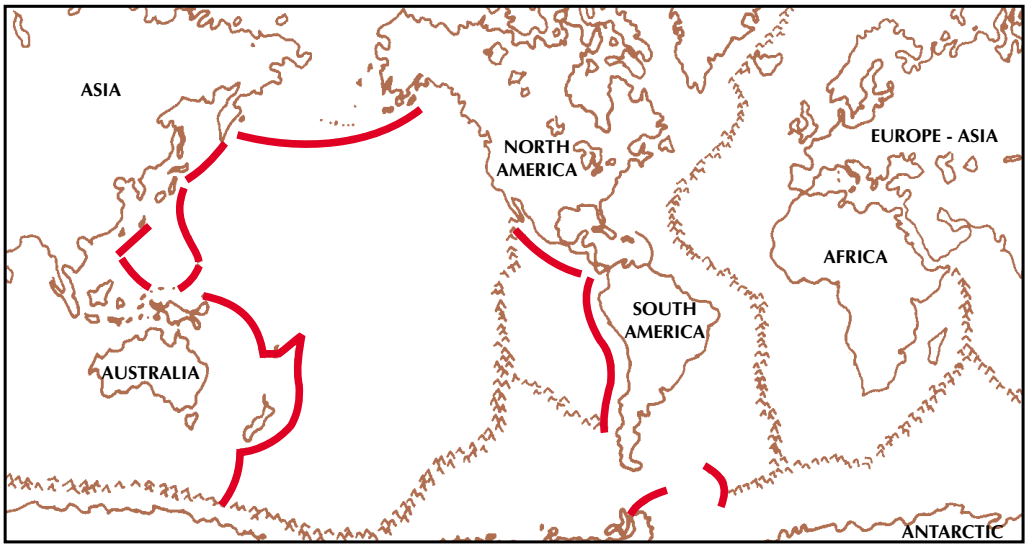
TRENCHES, AND MID-OCEAN RIDGES

Scientists knew very little about the ocean floors when Wegener first discussed continental drift. In the late 1940s, new instruments enabled scientists to map the ocean floors and record earthquakes in the ocean crust.

For many years sailors knew there were deep places in the oceans. Sea-floor mapping defined the depth and size of the ocean's deepest regions. These deep regions, called trenches, are long and narrow in shape. On the map, note the number of trenches around the border of the Pacific Ocean. Trenches in the Pacific are almost ten kilometers deep in some places.

Mapping the Atlantic Ocean floor revealed huge underwater mountains named the ***Mid-Atlantic Ridge***. A ridge is a long, narrow chain of hills or mountains. The Mid-Atlantic Ridge is now known to be part of an underwater mountain chain that winds 65,000 kilometers around the earth.

The underwater ridges throughout the world vary greatly in size and shape. Many ridges in the Pacific Ocean are flat-topped mountains. In contrast, the ridges in the Atlantic Ocean are two parallel chains of mountains. A valley, 2 to 50 kilometers wide, runs between the mountains. The ridges and trenches in the oceans are shown on the map.



Ridges and trenches in the ocean.

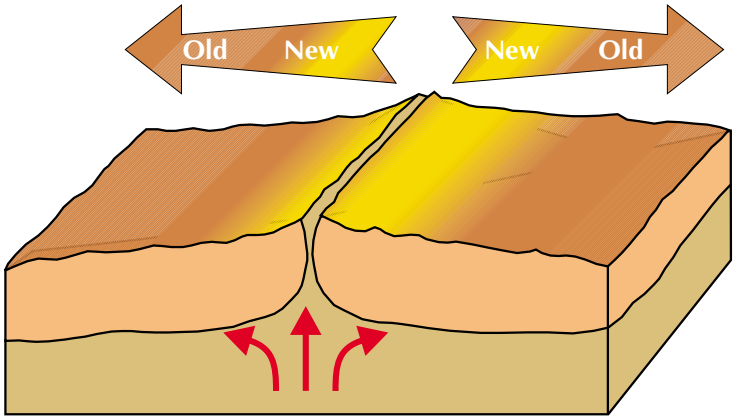
• SEA-FLOOR SPREADING

In 1962 scientists dared to suggest that new crust is forming at the ocean ridges. They found evidence for this outrageous idea on the ocean floor. Scientists found cracks along the middle of mid-ocean ridges where the ocean floor was splitting.

Magma, melted material from the mantle, is rising out of these cracks. It hardens and forms new crust. The new crust is piled high to form the ridges. As more magma comes up, it pushes the newly formed crust away on both sides, carrying the older crust with it.

Ocean sediments, which are particles that settle from water, are thin or missing on the ridges. The sediments gradually become thicker away from the center of the ridges.

The formation of new crust on the ocean floor is called sea-floor spreading. New crust on the ocean bottom suggested that the whole crust is moving - not just the continents.



Formation of new crust on the ocean floor.

DO YOU KNOW?

Sea-floor spreading is so slow that it is not noticeable. Also, because it happens on the ocean floor, we can not see it, except with special instruments. From 2 to 20 centimeters of new crust forms a year in oceans throughout the world.

2.3 PLATE TECTONICS: A NEW THEORY

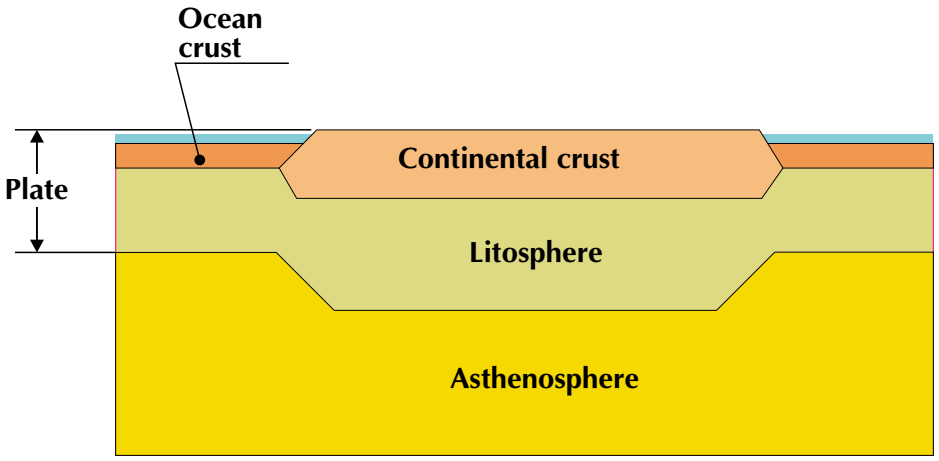
To increase your understanding of any subject, you must add new information to the knowledge you already have. For example, you read and understood numbers long before you learned to tell time. Similarly, earth scientists used the information from sea-floor spreading to develop a broader theory that explains why the earth looks as it does. As you read about this new theory, think about these questions:

a. How did the plate tectonic theory change our thinking about the earth's surface?

b. What are three types of plate boundaries?

• THE PLATE TECTONIC THEORY

According to the plate tectonic theory, the surface of the earth is broken into about 20 large sections called plates. They are about 70 kilometers thick. The diagram shows that the plates are as deep as the lithosphere, which is the solid outer shell of the earth. The lithosphere contains the crust and upper mantle. The plates are rigid and they move over the softer asthenosphere of the mantle. Do you remember the layers of the earth? Revise the corresponding diagrams in Chapter 1.

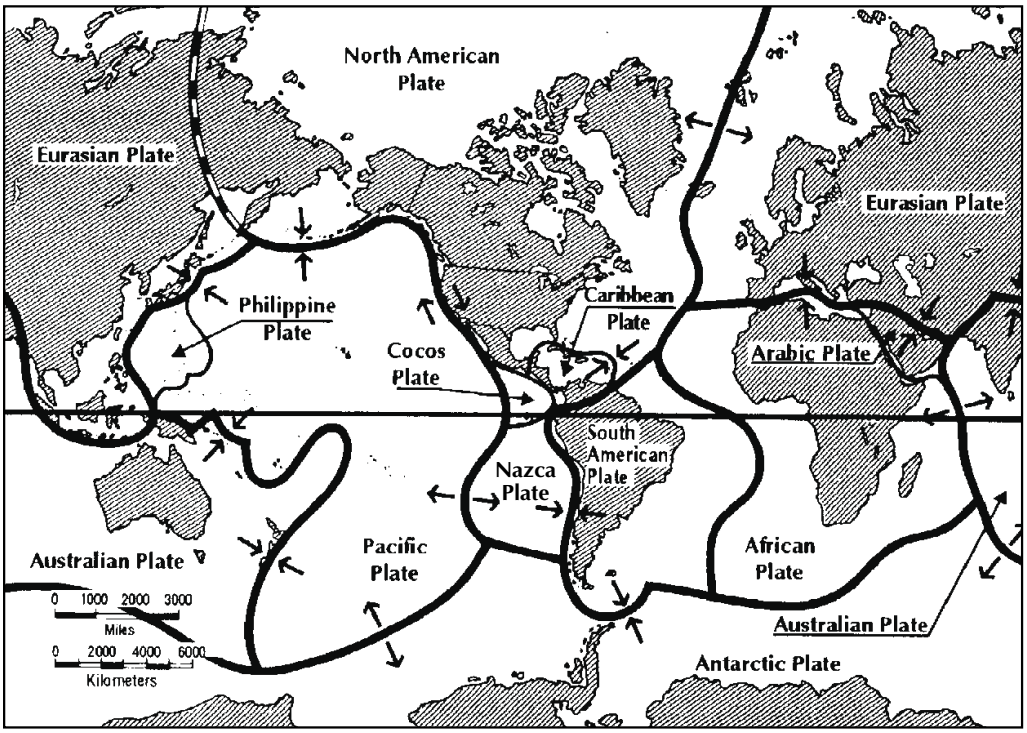


Layers of the earth.

DO YOU KNOW?

Plates move at a rate of 2 to 20 centimeters per year. The Pacific plate is moving about five and a half centimeters per year northward past North America. At this rate, Los Angeles, which is on the Pacific plate, will be next door to San Francisco in 10 million years.

On the map of the plates, notice that one plate can contain both continental crust and ocean crust. The arrows show the directions the plates are moving now. The directions of movement may have been different in the past.



Tectonic plates.

• PLATE BOUNDARIES

The region where plates meet is the plate boundary. How the plates move determines what happens at plate boundaries. The plates may move apart, collide, or slide past each other.

Spreading Boundaries, pictured in the top diagram, are found where plates are moving apart at mid-ocean ridges. New crust forms at spreading boundaries. Iceland, an island in the north Atlantic, emerged at the spreading boundary along the MidAtlantic Ridge. Volcanoes steam and the earth trembles with great regularity along this mid-ocean ridge and at other spreading boundaries. When Pangaea broke, it separated along the Mid-Atlantic Ridge. it took 200 million years for the Atlantic to grow to its present size. Spreading boundaries are also called divergent boundaries.

Colliding Boundaries, shown in the middle diagram, form where two plates bump into each other. The leading edge of one plate sinks into the mantle under the edge of another plate. Where the mantle absorbs the edge of sinking plate, heat and pressure create volcanoes and earthquakes. Pressures along colliding plates may fold rock layers into huge mountain systems, such as the Himalayas in India. Colliding boundaries are also called convergent, consuming or subducting boundaries.

Trenches bordering the Pacific Ocean are regions where the Pacific plate is sinking. The size of the plate slowly decreases as it sinks into the trenches. The Pacific Ocean is shrinking slowly. The loss of crust in the trenches balances the formation of new crust in the mid-ocean ridges.

Sliding Boundaries, shown in the bottom diagram, occur where two plates rub past each other. Faults are cracks in the earth. Earthquakes shake the land when rocks move along a fault. The San Andreas Fault in California, U.S.A., marks the boundary of two plates sliding past one another. People who live near the fault must expect earthquakes. Sliding boundaries are also called translational or transform boundaries.

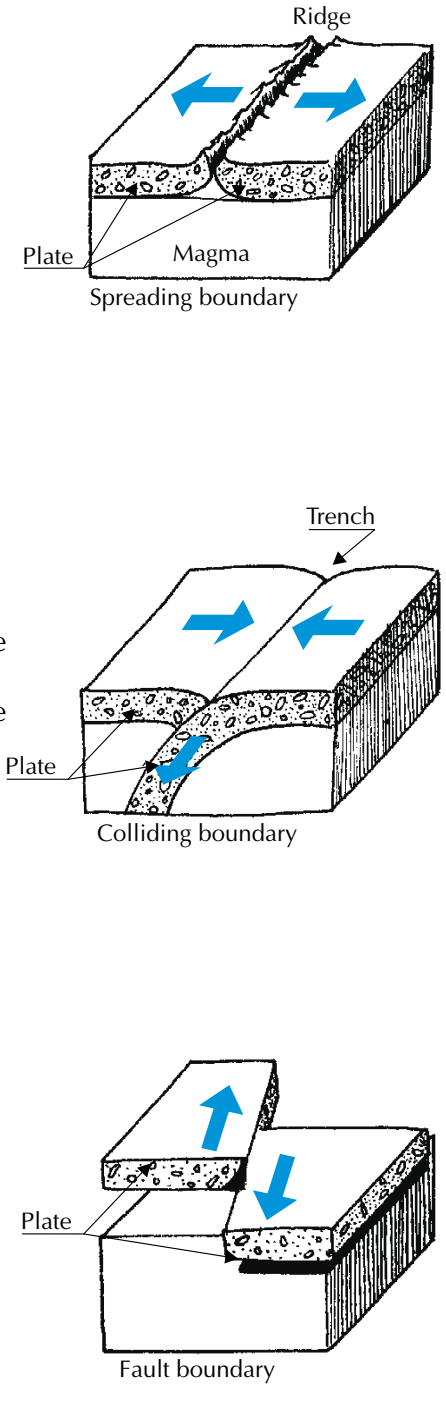


Plate boundaries.

DO YOU KNOW?

if plate tectonic movements continue without change, in 50 million years there will be no Mediterranean Sea; Spain, French Britain and the islands of Great Britain will be united; the Cantabric Sea will disappear; Australia and Indonesia will form one continent; and the Atlantic and the Indian Oceans will grow. Meanwhile, the Pacific Ocean will decrease in size. In the geologic time scale 50 million years is a short time. In the human time scale it is a time frame very difficult to visualize!

2.4 FORCES STRONG ENOUGH TO MOVE PLATES

Excitement among earth scientist grew as the plate tectonic theory developed in the late 1960s. The mechanism that causes the plates to move, however, is still not known. This section presents ideas about forces strong enough to move pieces of the earth's crust. Think about these questions as you read:

a. How could convection currents move plates?

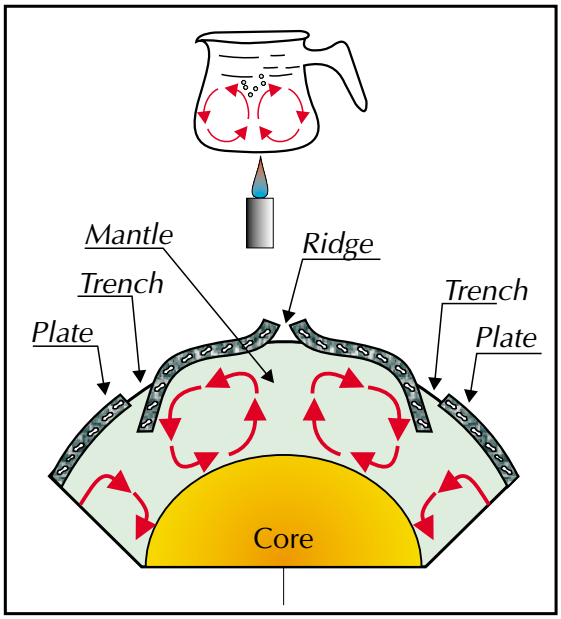
b. How might plumes cause plate movement?

c. What are hot spots?

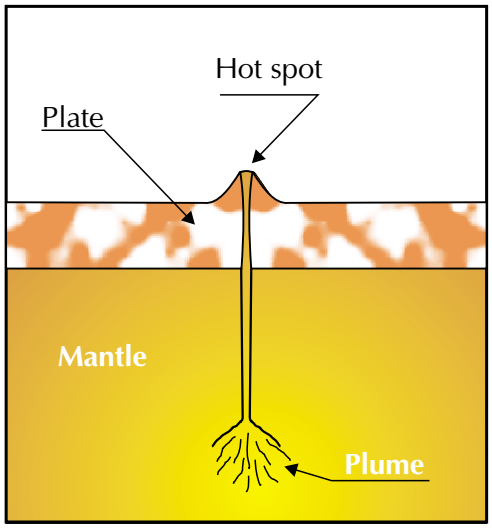
• ONE POSSIBILITY-CONVECTION CURRENTS

Convection currents transfer heat through liquids or gases. The diagram of the coffee pot shows two convection currents in water. Note that the water nearest the flame rises. When it cools near the surface, it sinks.

Some scientists have suggested that convection currents flowing in the mantle may cause the plates to move. Because of the great heat in the mantle, parts of the mantle may flow like a very thick liquid. Compare the diagram of the coffee pot to the diagram of the mantle. A plate might move above a huge convection current like an object riding along on a giant conveyor belt.



Convection currents.



Hot spots origin.

• PLUMES IN THE MANTLE

A plume, pictured on the left, is a narrow, jetlike flow of hot material from a great depth in the mantle. Plumes at spreading boundaries might cause plates to move by adding material to the edges of plates. The added material may push the plates apart.

Scientists do not know whether the force driving the plates is due to convection currents, plumes, a combination of the two, or other unknown factors.

• INVESTIGATING HOT SPOTS

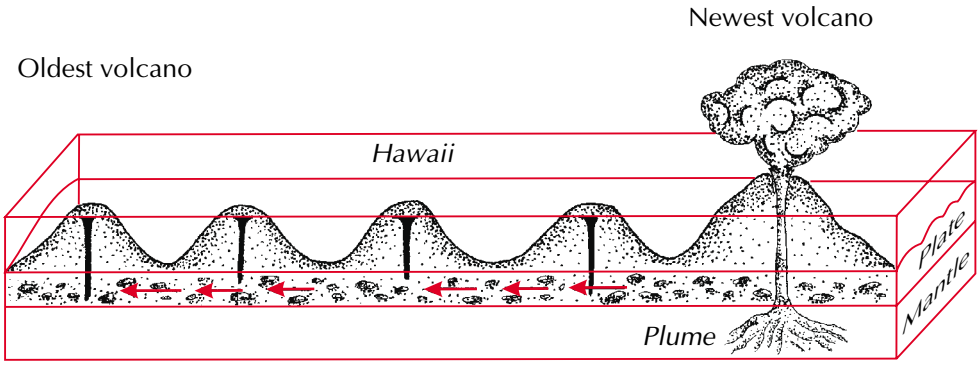
Volcanoes appear where magma from plumes reaches the earth's surface. Places with a great deal of volcanic activity are called **hot spots**. Hot spots are found over plumes in the mantle. Some plumes are located beneath plate boundaries. Earth scientists believe, however, that plumes also occur away from plate

boundaries. For example, hot spots that occur in the middle of a plate are caused by plumes away from plate boundaries.

Hot spots in the middle of the Pacific plate formed the Hawaiian Islands. These volcano-islands are actually huge mountains rising from the ocean floor. Notice in the diagram that the erupting volcano is directly over the plume.

During the past 80 million years, the Pacific plate has been moving to the northwest. The volcanoes move with the plate, but the plume in the mantle does not move. Volcanoes that move away from the plume leave their source of magma. They are inactive.

As the inactive volcanoes move along, new, active volcanoes appear above the plume. Because the plate moves to the northwest, new volcanoes appear to the southeast.



Hawaiian Island origin from a hot spot.

DO YOU KNOW?

Although most hot spots are found in the ocean, some hot spots are on continents. Hot spots on land might by areas where continents are starting to split.

A) REPORT

Someday it wil be possible to forecast earthquakes

TO LUBRICATE THE EARTH

By Isaac Asimov

Once in a while the earth shakes. At the planetary scale it is a very trivial phenomenon, just a short and small shake. At the human scale, by contrast, it is huge; the only natural phenomenon that can kill thousands of people and produce enormous damage in less than 5 minutes.

This shaking is what we call an earthquake.

On January 24, 1556 there was an earthquake in Shensi province, China. This earthquake was reported to have caused 830,000 deaths, the highest death toll to date for this type of disaster. Another earthquake, on December 30, 1703, killed 200,000 people in Tokyo, and on October 11, 1757, 300,000 people died in Calcutta.

On December 1, 1775, Lisbon in Portugal was destroyed by an earthquake and the subsequent tsunami. Sixty thousand people died.

The earthquake's destiny is, with time, to be more and more destructive, because of the simple reason that there are more people over the earth and the works of the human beings are more complex, expensive and numerous.

Let's think, for instance, of the 1906 earthquake that destroyed San Francisco city, killing 700 people, leaving 750,000 people homeless, and producing damage of $ 500 million. If there were such an earthquake today, it is probable that many more people would die, many more would be made homeless, and damage to property would be many times greater.

What can be done? Is it possible to forecast earthquake so that at least people can be evacuated in time?

Perhaps it is possible. There are certain preliminary phenomena which, it seems, foretell a seismic movement: ground uplift or slight cracks in rocks, which cause changes in water lever in wells, or in the electric and magnetic properties of the ground.

People are indiferent to some of the preliminary earthquakes, but animals, who live closer to nature can detect them and show sings of concern. Horses rear and run away, dogs howl and fishes start to jump. Animals which normally stay hidden in holes, like serpents and rats, suddenly come into the open; and the chimpanzees at the zoo are disturbed and spend more time on the ground.

In China, where earthquakes are much common and harmful than in many other countries, people have been asked to pay attention to any uncommon behaviour in animals, any abnormal noise in the ground, any change in the level of water wells or abnormal cracks in paint on walls.

The Chinese say they have forecast some earthquakes and saved many lives in the earthquake of February 4, 1975, in the northeast part of the country. But another earthquake in July 27, 1976 was not forecast and a city was leveled.

Evacuation of a city is a big problem and could cause as much disturbance as the disturbance produced by the earthquake itself. Moreover, even if the population is evacuated there is the risk of people losing their property.

Is it possible to both forecast and delay earthquakes?.

Perhaps. The earth's crust is composed of several huge plates that grind against each other when they move. The junction where the plates join (faults) are irregular and uneven, so friction is huge. Rocks on both sides of the fault slide between them. When they jam, pressure is stored up, until finally, when the stress is great enough the faults yields and a sudden movement is produced. Then the process starts again.

Each of these movements produces an earthquake. The more sudden and vast the displacement, the greater the magnitude of the earthquake. Naturally, if the jamming is small and the displacements are frequent, there will be many earthquakes, unable to produce damage. By contrast, if the jamming and the friction are huge and the stress is accumulated over decades, there will finally be a huge earthquake destroying everything in the area.

Is it possible to reduce the friction of the plates and ease the sliding?.

Imagine that we dig very deep wells along a fault and inject water. The liquid would slide among the rocks, lubricating their surface and favoring a gradual slide which would produce a series of small and harmless earthquakes. The dreadful killer earthquakes would never occur again.

B) CHAPTER SUMMARY

- Alfred Wegener proposed that the continents were once joined in a large continent called Pangaea.

- Wegener used rock layers, fossils, and changes of climate as evidence for continental drift.

- The mid-ocean ridge is a mountain chain 65,000 kilometers long in the oceans of the world.

- Magma rises from the mantle creating new ocean crust at the mid-ocean ridges.

- The plate tectonic theory states that the rigid outer part of the earth is broken into a number of pieces called plates. The plates move apart, collide, or slide past one another.

- The flow of material in the mantle by convection and/or plumes may cause plate movement.

- Hot spots are regions on the surface of the earth that lie directly over a plume.

C) QUESTIONS/PROBLEMS

1 . Compare Wegener's continental drift theory to the plate tectonic theory.

2. Imagine a reason, other than continental drift, for identical fossils in South America and Africa.

3. Why is sediment in the center of mid-ocean ridges either thin or absent?

4. What would happen to the crust if there were spreading boundaries but no colliding boundaries?

5. Using the chart on plate movement and trenches in this chapter, explain why so many earthquakes occur in the Philippine Islands.

6. What type of surface feature might occur on a plate where a convection current is sinking the mantle?

7. An active volcano is at the south end of a north-south chain of volcanoes that are no longer active. What direction is the plate moving?

8. List the continents that were part of Pangaea.

9. How would Wegener account for fossil ferns found in the rocks of Antarctica?

10. Describe the Mid-Atlantic Ridge.

11. Where is the youngest rock in a mid-ocean ridge?

12. Describe a segment of the earth called a plate.

13. What caused the trenches around the Pacific Ocean?

14. What is a convection current?

15. in what layer of the earth does a plume originate?

16. If you visit a hot spot, what would you expect to see?

D) CHAPTER TEST

A. Vocabulary. In the brackets of the left margin match the definition in Column I with the term it defines in Column II.

Column I	Column II
1. the name of Wegener's large continent	a. convection current
2. large underwater mountain chain that surrounds the earth	b. continental drift
3. a theory that the earth's surface is broken into many rigid pieces	c. hot spot
4. deepest section in the oceans where a plate is moving under another plate	d. mid-ocean ridge
5. hot material rises, spreads side-ways, and then sinks again	e.Pangaea
6. a theory that describes the formation of new crust	f. plume
7. region on the earth's surface that has great many volcanoes	g. plate tectonics
8. a jetlike flow of hot material from deep within the mantle	h. sea-floor spreading
9. theory that land masses move over the ocean floor	i. trench
	j. magma

B. Multiple Choice. in the brackets at the right choose and mark the letter that best completes the statement or answers the question.

1. Scientists disagreed with Wegener's idea because he could not explain: ( )

   a) similar fossils' in different continents
   b) forces necessary to move continents.
   c) identical rock formations.
   d) climate changes.

2. New ocean crust is produced at: ( )
   a) trenches
   b) mid-ocean ridges
   c) faults
   d) beaches

3. Old ocean crust is being destroyed at: ( )
   a) trenches
   b) ridges
   c) faults
   d) volcanoes

4. If many trenches surround a plate, the plate is probably: ( )
   a) getting larger
   b) getting smaller
   c) remaining the same size
   d) getting thicker

5. Fault boundaries occur where: ( )
   a) one plate sinks under another
   b) plates are no longer moving
   c) two plates are spreading apart
   d) two plates are sliding past one another

6. A possible cause of plate movements is: ( )
   a) convection in the mantle
   b) the earth's rotation
   c) the pull of the moon
   d) the pull of the sun

7. The Hawaiian Island chain was probably created as the Pacific plate passed over a:
   a) fault
   b) plume
   c) trench
   d) mid-ocean ridge

In the following question, mark the INCORRECT or not corresponding alternative.

8. The Mid-Atlantic Ridge ( )
   a) is where two plates collide.
   b) is composed of parallel ridges
   c) is part of the world underwater mountain chain.
   d) is where new crust forms.