EARTHQUAKES AND TSUNAMIS

HIGH SCHOOL TEXTBOOK

SERVICIO HIDROGRAFICO Y OCEANOGRAFICO DE LA ARMADA DE CHILE
INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
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ABOUT THE TEXTBOOK

This book is the result of both the implementation of Recommendation ITSU-XIII.3 of the Thirteenth Session of the International Co-ordination Group for the Tsunami Warning System in the Pacific, and the work of several education experts. An ad-hoc Working Group headed by Hugo Gorziglia (Chile), revised the work done by the experts who were partially funded by the Intergovernmental Oceanographic Commission.

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EARTHQUAKES AND TSUNAMIS

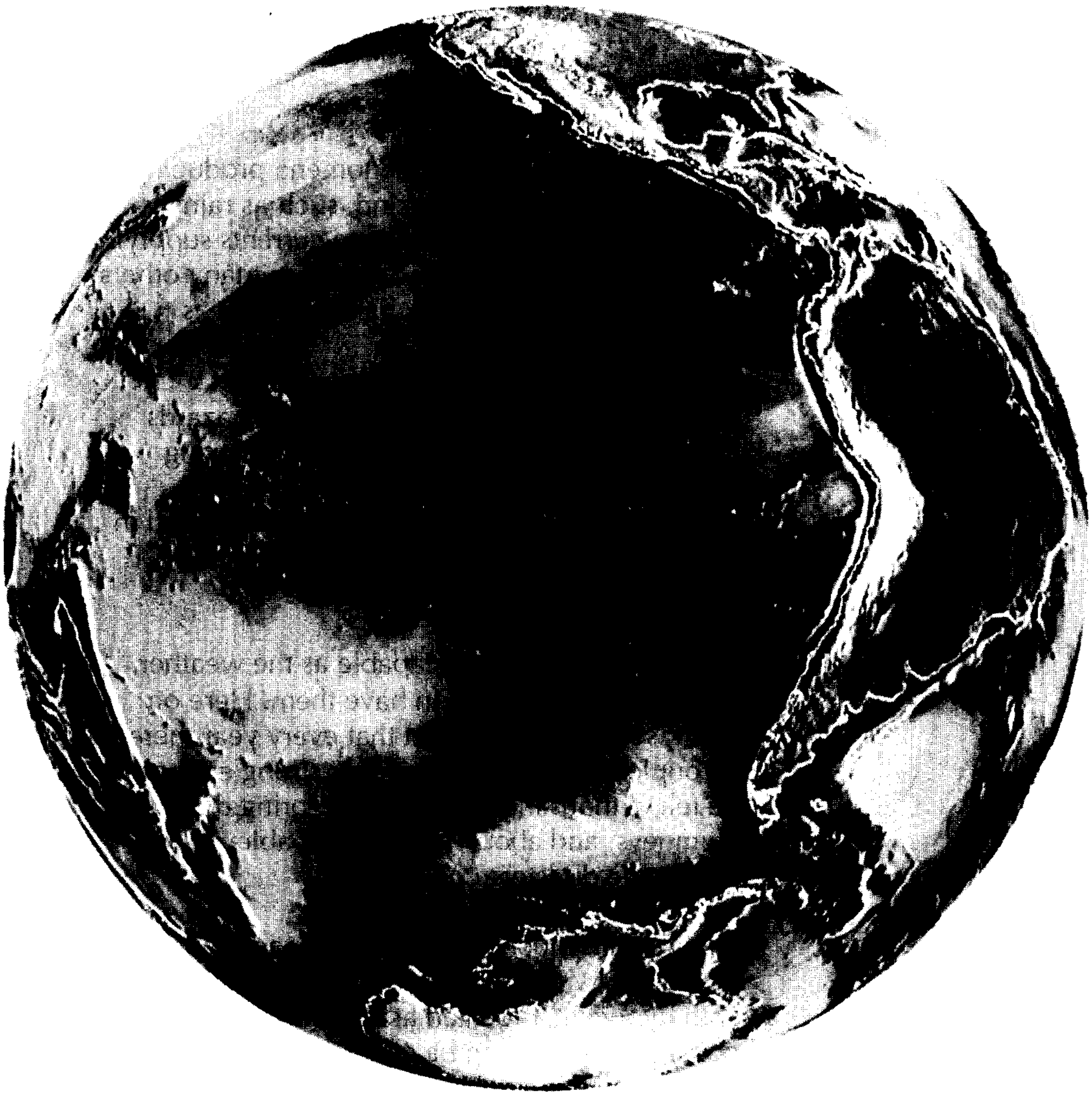
PREFACE

There are many natural phenomena producing beneficial effects for mankind, such as rains for agriculture, and the cold ocean currents supplying abundant fish for food. But there are many others whose effects can be very harmful, such as earthquakes and tsunamis.

It must be acknowledged that natural hazards continue to increase because of the growing exposure which results from expanding populations, many of which are concentrated in big cities of more than 5 million inhabitants (Tokyo, Japan; Lima, Peru).

Earthquakes are as inescapable as the weather. Even Mars and the Moon have them. Here on Earth, seismologists report that every year there are a couple of million earthquakes strong enough to be felt, a thousand or so that can bring down chimneys, and about a dozen capable of producing disasters.

One of consequences of major impact to people is generated by those big magnitude earthquakes with hypocenter located at the sea. When they occur, sea waves can be generated which propagate very quickly across the ocean and produce casualties not only in the source area but along coastlines located thousands of miles away.



CHAPTER 1

OUTSIDE AND INSIDE THE EARTH

The picture shows our earth as it looked to the astronauts who were in space. They noticed how friendly, yet isolated, the earth seemed. This view, plus measurements taken on earth have improved our understanding of our planet.

This chapter has many "vital statistics" about the earth. The first section discusses the shape of the earth and the distribution of land and water masses. The chapter ends describing the internal structure of the earth and the formation and propagation of different seismic waves.

CHAPTER OBJECTIVES

1. Describe and identify the shape and dimensions of the earth.
2. Describe and locate the continents and the oceans.
3. List, compare and describe the layers of the earth.
4. Describe the generation and propagation of seismic waves, and their classification.

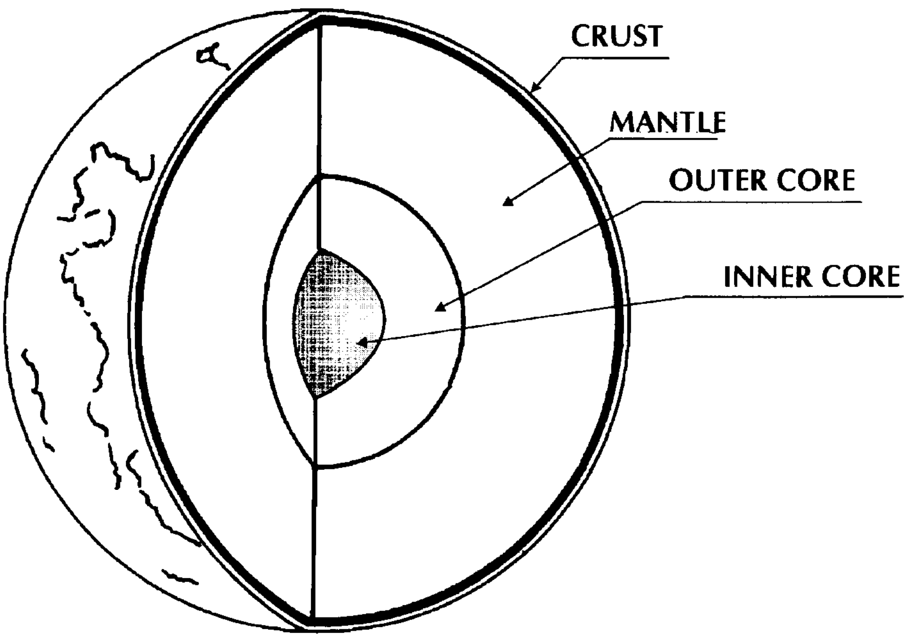
1.1 CHARACTERISTICS OF THE EARTH

- ***SHAPE AND DIMENSIONS***

For a better understanding of natural hazards it is necessary to know some general concepts about the shape, size and internal structure of the planet where we live: the Earth.

As we know, the earth is just one of the millions of bodies in the Universe. However, the earth is not just a planet, but one of the few, or maybe the only one having natural conditions allowing the existence of plant and animal life, and therefore of Man. This is mainly due to the fact that the temperatures on the surface of the earth keeps the water in its liquid phase, which is essential for life. Other planets have very high or very low temperatures, with no liquid water and therefore no possibility to develop any form of life.

The earth's shape is an oblate spheroid, flattened at the poles. To a first approximation the earth is an ellipsoid of revolution (spheroid). Its dimensions are: equatorial radius = 6,378 kilometers; polar radius = 6,356 kilometers; circumference = 40,000 kilometers.

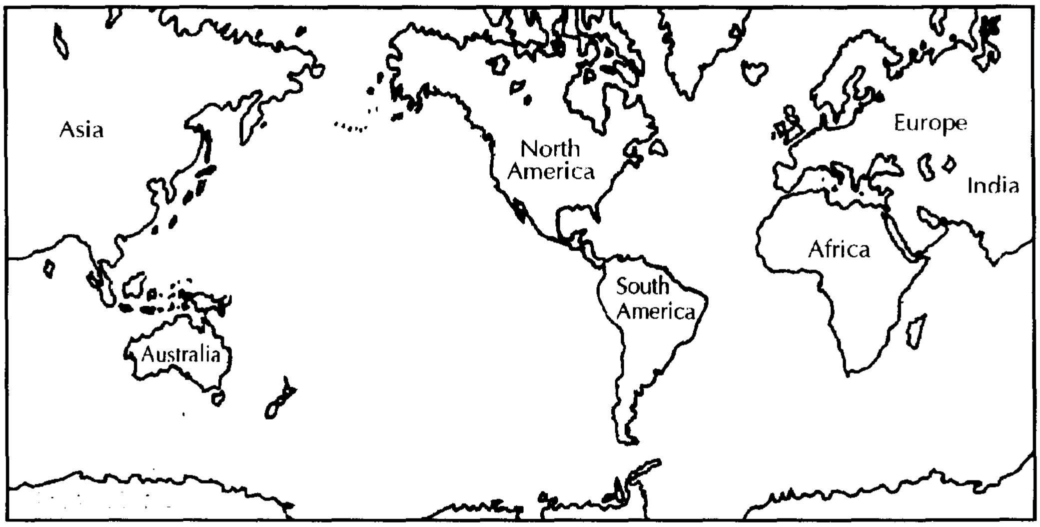


Internal structure of the earth.

The ellipticity of the earth's shape is due to the centrifugal forces produced by its rotation. The resultant forces from rotation have other effects, including the global wind patterns in the atmosphere, the currents in the oceans, and the flow of hot viscous material in its interior.

• *DISTRIBUTION OF OCEANS AND CONTINENTS*

One of the most relevant aspects of its surface is the vast expanse of the oceans. More than 70 % of the surface of our planet is covered by oceans and in the Southern Hemisphere the oceans represent almost 85 % of the total surface as seen in the figure below.



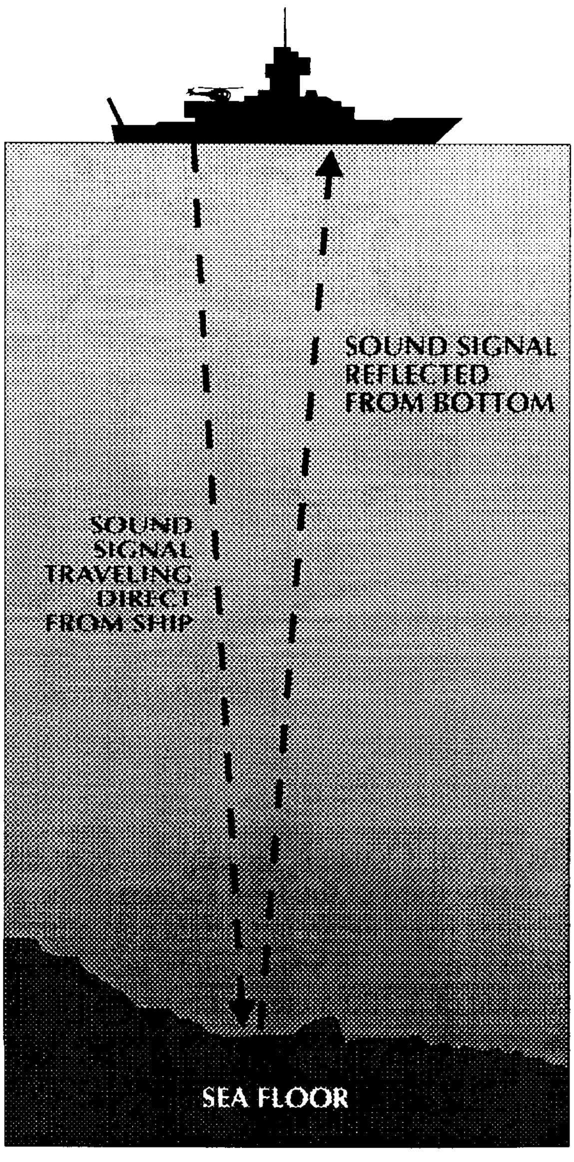
Distribution of oceans and continents.

The Pacific Ocean is the largest ocean on the earth, encompassing more than one third of the total surface of the planet, and its huge marine currents regulate an important part of the world climate. It is also the deepest ocean. Its mean depth is 200 meters greater than the oceanic average of 3,700 meters. It is in the Pacific Ocean, because of its size and the geological structure of the ocean floor, where most of the earthquakes and tsunamis of the world occur.

DO YOU KNOW HOW WATER DEPTH IS MEASURED?

Soundings are measurements of water DEPTH. In the past, sailors took soundings by lowering ropes with weights. When the weight touched the bottom, the length of wet rope showed the depth of the water. In deep water, a sounding was inaccurate because of the water's movement.

Today, scientist find the depth of water by using an echo sounder. This device measures depth by bouncing sound waves off the ocean floor. The echo sounder measures how long a sound wave takes to reach the ocean bottom and return to the ship. Since the speed of sound in sea water is known, the sounder can calculate the ocean's depth at that spot.



Echo sounder operation.

DO YOU KNOW?

The Pacific Ocean is so large that all the continents put together could fit into it. It covers 165,200,000 square kilometers.

The Pacific Ocean is surrounded mainly by linear mountain chains, trenches, and island arc systems that in most areas effectively isolate the deep-sea basins from the influences of continental sedimentation.

If all the water was removed from the ocean basins, there would be revealed a pattern of topographic features dominated by a system of ridges and rises encircling the globe with intervening deep-sea basins between the ridges and the continents. The pattern shows that the deepest parts of the oceans do not occur in the middle as one might expect, but close to the continents and island arcs.

Topography of the ocean bottom.

HAVE YOU HEARD?

The deepest spot in all the oceans is Challenger Deep. It is in the Marianas Trench in the western Pacific Ocean. It is more than 11,000 meters deep! This depth is 1,600 meters greater than the height of Mount Everest, the highest mountain on land.

The middle of the ocean is shallower because of the mid-oceanic ridges. This is similar to the patterns of major mountain chains around the earth which, except for the Himalayas and a few other chains, are not located near the middle of continental masses but near the edges facing deep oceanic trenches. Thus, both continental and oceanic areas exhibit greatest vertical change in narrow zones of the earth's crust.

1.2 INTERNAL STRUCTURE OF THE EARTH

Everybody knows what the surface of the earth looks like, since we see it frequently in maps and pictures, and in the landscapes around us, but does the interior of the earth look like?

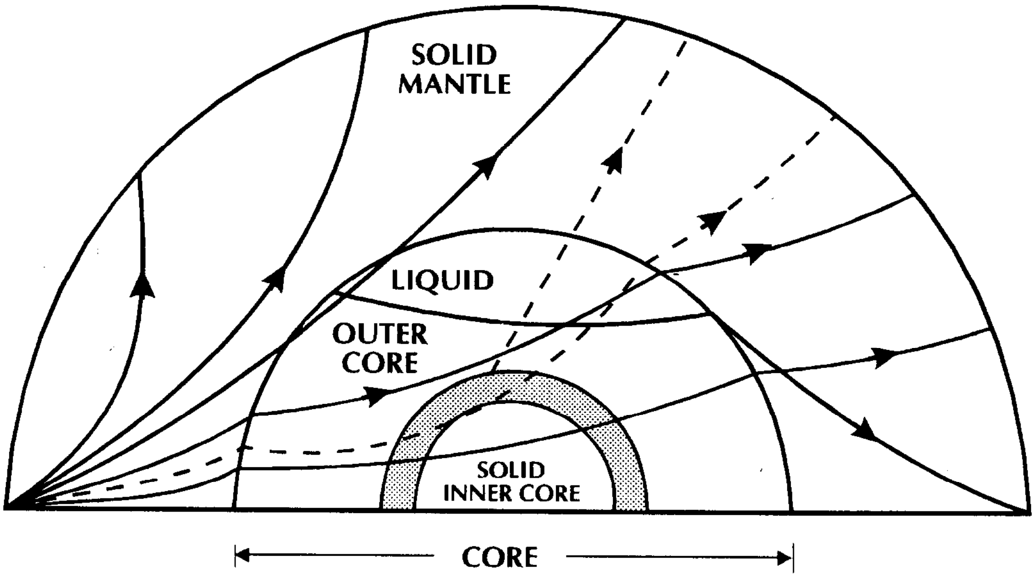
Nobody can make a trip to the center of our planet to discover its internal structure, however, today we know the internal structure thanks to instruments that record the waves produced by earthquakes.

Every year ten or more destructive earthquakes shake our planet. The smallest of this earthquakes release energy almost one thousand times greater than from an atomic bomb. The waves produced by the shocks travel through the interior of the earth and their paths are curved and modified by the different layers of the internal structure of the earth. Thus, the seismic waves show the nature of the areas they pass through, and after being recorded on seismographs we can study them and deduce a picture of the interior. In fact, the seismologist X-ray the earth although some times they see it as through a smoked glass.

Until the beginning of seismology our knowledge about the interior of the earth was based on hypothesis and speculation. Today, thanks to this science we know the structure of the earth scientifically. Combined with the geologic information provided by surface rocks, laboratory experiments with rocks at high pressures, and certain astronomic observations, we have a very good idea of the existing conditions in its interior, its layered structure, the materials, their physical conditions, the pressure, etc.

• SEISMIC WAVES

When you throw a stone into water (e.g. a water well), you see waves spreading from the point where the stone strikes the water; but these waves are also transmitted at depth, diverging from the same point. Something similar to this happens when an earthquake occurs. From the focus or place of the rupture of the crust elastic equilibrium waves are transmitted in all directions in the interior and the surface of the earth.



Propagation of seismic waves within the earth.

DO YOU KNOW?

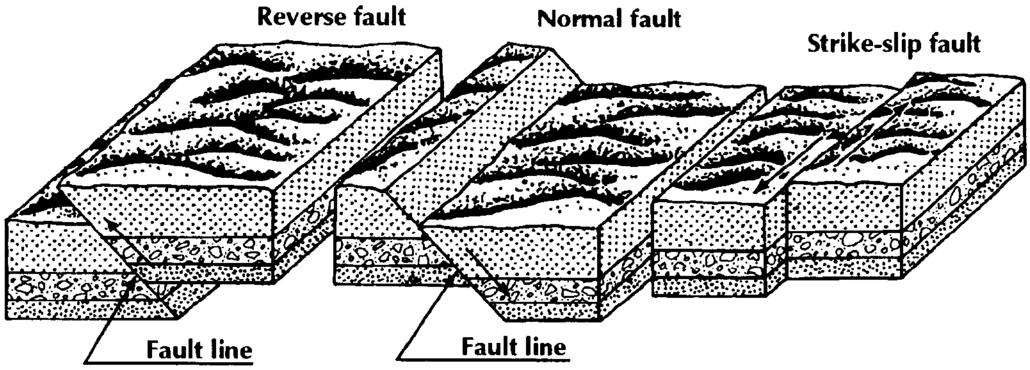
The record of drilling in the exploration of the earth's crust is held by the former Soviet Union with a well 12 kilometers deep drilled in MURSMANK.

HAVE YOU ALSO HEARD?

At a depth of fourteen kilometers the rocks are under a pressure of 4,000 atmospheres and a temperature of 300 degrees Celsius.

For most of the shallow earthquakes (depth of focus = 0 - 70 kilometers), the mechanism for the generation of elastic waves is a fracture or break of the earth's crust in the region. In other words, the stress surpasses the rupture limit of the material in that region, therefore it fractures developing what is commonly known as a "fault" and this "fault" is what generates the seismic waves.

A "fault" can be defined as the relative movement between blocks of the crust, as seen in the picture below.



Once the rupture point of the material of a region has been surpassed (that is, a fault has developed), three fundamental types of seismic waves are generated:

1) ***The compressional-rarefactional wave, P.*** This is analogous to a sound wave and is sometimes called a longitudinal wave. When the compressive phase of such a wave passes a seismograph station, the ground in the immediate area is compressed and the seismograph pier moves slightly in the direction in which the wave is traveling, or away from the epicenter. Conversely, when the rarefactional part of such a wave passes a station, the ground is dilated and the pier moves toward the epicenter. These directions are registered on seismographs. This wave is the fastest of the seismic waves and is therefore designated the first primary tremor, P. This wave, as with sound waves, can be transmitted through rocks and liquids.

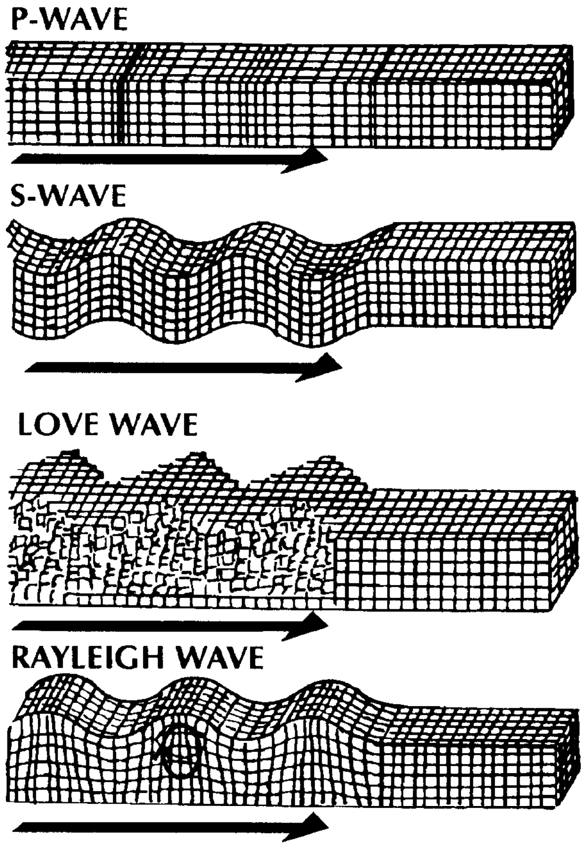
2) ***The transverse, distortional, or shear wave, S.*** This is analogous to a light wave or the transverse vibration of a string. A particle is always displaced in a direction normal or transverse to the direction in which the wave is traveling. Interior transverse waves travel at about 0.6 the speed of compressive P waves and appear as the second most conspicuous

wave group. They have therefore been designated the secondary tremor, S. These waves can not propagate through fluids like liquids and gases.

Speed of the P and S waves depends on the density and elastic properties of the rocks they pass through. Typical P wave velocities in granite rock and in water are respectively, 5.5 and 1.5 kilometers per second (Km/sec), whereas the S wave speed in the same materials is about 3.0 and 0 Km/sec; this last value is due to the fact that liquids have a rigidity modulus equal to 0.

3) ***Surface waves, L.*** These represent by far the greatest amount of wave energy, and they are called surface waves because they propagate close to the surface of the earth.

There are two types of surface waves. The faster of the two is a shear wave designated as either a Love Wave, Lq, after the physicist who developed the theoretical concept, or a G wave, after Gutenberg, the seismologist who discovered and discussed its presence on seismographic records. The motion of a particle is transverse to the direction of propagation and takes place in the horizontal plane only, as seen in the figure below. It has no vertical component. The second type of surface wave is the Rayleigh wave, Lr, also named after the physicist who developed the theoretical concept. It arrives a short time after the surface shear wave since its speed is about 0.92 that of the shear wave. In a Rayleigh wave the earth particle follows a retrograde elliptical orbit in a vertical plane along the direction of propagation, as seen below.



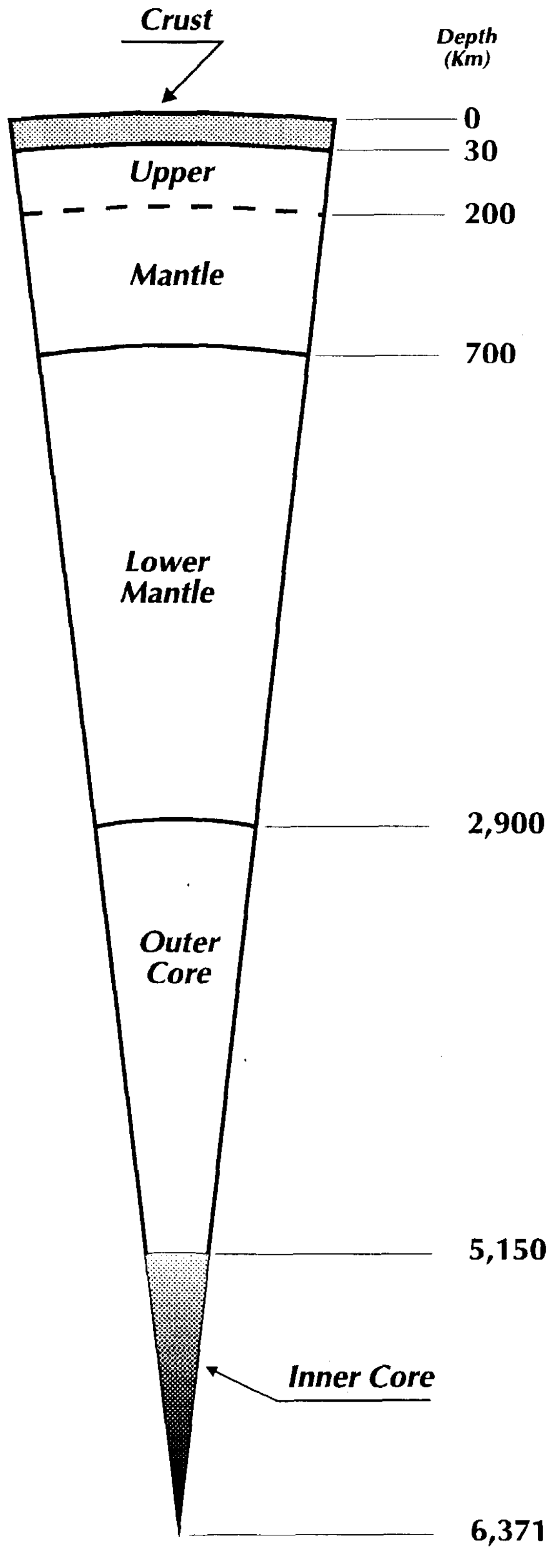
Seismic wave propagation.

• LAYERS OF THE EARTH

With all this knowledge Oldham showed, in 1906, that the earth has a central core, and in 1914, Beno Gutenberg located the core's limit at 2,896 kilometers under the earth's surface. Considering that the earth radius is about 6,370 kilometers, the radius of the core is about 3,474 kilometers. Thanks to these and other studies, it can be shown that the earth is divided in four different layers, as seen in the figure:

a) ***The crust***. This is the upper layer, upon which we live, and it is composed of solid rock. Its thickness varies between 5 and 60 kilometers. As a normal average for the whole earth a value of 33 kilometers is used for thickness of the crust and a density of 2.67 grams per cubic centimeter (g/cc). Although this thickness would seem quite large, compared to the mean radius of the earth it is like the eggshell on an egg. The distribution of seismic velocities in the crust is, for the P wave, 6.0 to 6.5 kilometers per second, and for the S waves, 3.5 to 3.7 kilometers per second.

b) ***The mantle***. This layer encompass from the base of the crust to a depth of 2,900 kilometers; the border between the crust and the mantle is known as the Mohorovicic discontinuity (Moho). The mantle is divided in two regions: the upper mantle, from



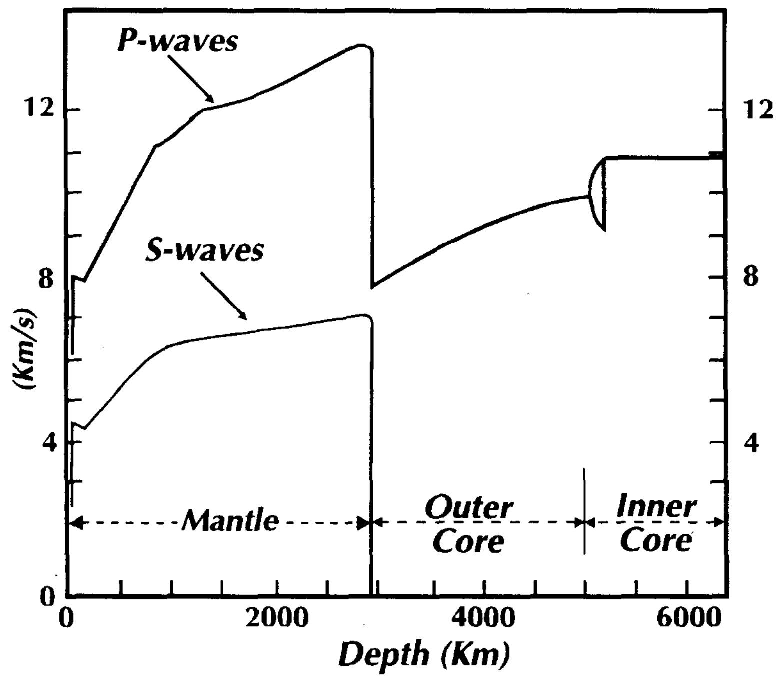
Internal structure of the earth.

the base of the crust to a depth of 700 kilometers, and the lower mantle from this depth to the surface of the core. The first 200 kilometers of the upper mantle is a region of gradual increase of velocity followed probably by a decrease of the S wave velocity. The lower part of the upper mantle, between depths of 300 and 700 kilometers, is characterized by a rapid increase in seismic wave velocities. In the lower mantle, the P and S waves velocities increase more slowly with depth.

c) ***The outer core***, situated between depths of 2,900 and 5,000 kilometers, behaves as a liquid zone, therefore, S shear waves are not propagated through it.

d) ***The inner core***, with a radius of 1,200 kilometers, is considered to be solid and in it the seismic waves velocities increase. Both P and S waves can propagate through the inner core.

The following figure shows the velocity distribution of seismic waves.



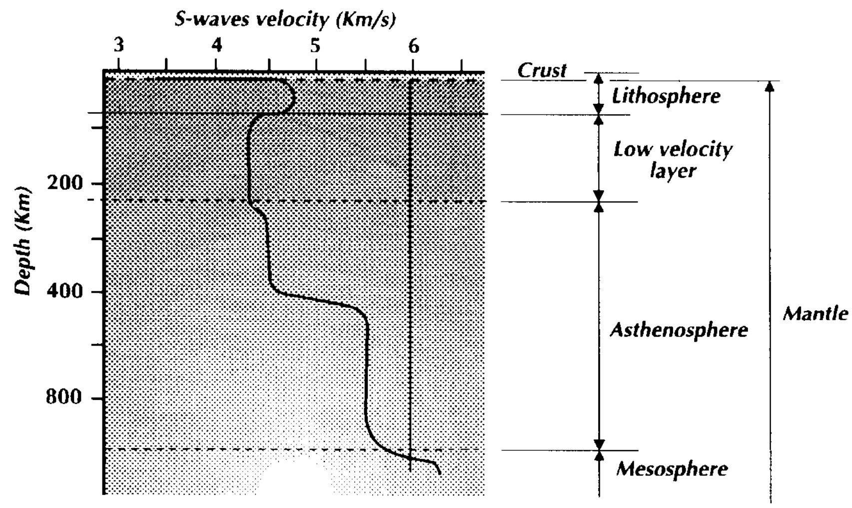
Velocity of seismic waves at different depths.

DO YOU KNOW?

The pressure at the boundary between the inner and outer core is 3.3 million atmospheres and is equivalent to the pressure of a mountain of 3,300 cars piled up over the area of a fingernail.

It was previously stated that the crust, the mantle and the core are distinguished from each other by differing seismic velocities. Another set of terms defining the concentric layering of the earth is based on strength and viscosity. These are the lithosphere, asthenosphere, and mesosphere. The lithosphere is the outermost shell of the earth (about 100 km thick) and includes the crust and the uppermost mantle. It is distinguished by its ability to support large surface loads, like volcanoes, without yielding. It is cool and therefore rigid. The lithosphere is underlayed (to an approximate depth of 700 km) by the asthenosphere (asthenos is Greek for soft). The asthenosphere is near its melting point and because it has little strength, it flows when stress is applied over time. The next layer is the mesosphere. The mesosphere is more rigid than the asthenosphere, but more viscous than the lithosphere. The mesosphere extends to the core and thus incorporates most of the mantle.

These concentric layers and their relationship with the layers previously defined are shown in the next drawing.



Internal structure of the earth according to S-wave velocity.

The mantle is mostly solid. Seismic waves are transmitted at velocities which increase with depth as density increases from 3.3 to 5.5 g/cc. This increase in density occurs progressively in discrete steps. The mantle is complex and shows variations in structure both horizontally and vertically. The most important vertical variation within the upper mantle is the decrease in S- wave velocities from 4.7 to 4.3 km/sec between 75 and 150 kilometers depth. This low velocity layer probably represents the zone of partial melting in the upper mantle which is the source of melts, or magma, that rise to the surface and form igneous and volcanic rocks.

A) REPORTS

- ***ANIMALS PREDICT EARTHQUAKES***

A government agency in China has reported that strange animal behaviors were observed just hours before an earthquake. Cattle, sheep, mules, and horses would not enter corrals. Rats fled their homes. Hibernating snakes left their burrows early. Pigeons flew continuously and did not return to their nests. Rabbits raised their ears, jumped about aimlessly, and bumped into things. Fish jumped above water surfaces.

China was not the only country to report such unusual animal behavior. Late on May 6, 1976, an earthquake shook a town in Italy. Before the earthquake, pet birds flapped their wings and shrieked. Mice and rats ran in circles. Dogs barked and howled. Perhaps the animals sensed the coming earthquake?

For many years farmers throughout the world have told stories about changes in animal's behavior just before an earthquake. Chinese scientists were among the first to believe these stories might have a scientific basis. They have even proposed that zoo animals might forewarn people of a coming earthquake.

Scientists in many countries are interested in finding the causes for the strange behavior. They have suggested that one or more of the following may be possible causes:

1. slight changes in the earth's magnetic field;
2. increased amounts of electricity in the air;
3. very small air pressure changes;
4. changes in noise level;
5. gas escaping from the ground.

When scientists find the causes of the strange animal behavior, they may be able to predict earthquakes within hours.

• *STRANGE FEATURES ON THE OCEAN FLOOR*

Since 1977, divers in research submersibles have made remarkable discoveries at some places on the ocean floor. They found giant cracks in the earth's crust, huge mountain ranges, active volcanoes, and unusual lava formations. But the strangest discoveries were the hot springs near the spreading boundaries in the eastern Pacific Ocean.

These hot springs, also called "black smokers" and "white smokers", spurt hot water from vents in the ocean floor. The water from a black smoker is at least 350^{o}C. It is hot enough to melt the plastic rods that hold the oceanographers' thermometers. The water in the white smokers is not quite as hot.

The hot springs are about 2,500 meters beneath the ocean's surface. Because of the great pressure at these depths, the hot springs' water does not boil.

Geologists believe the hot springs develop when cold ocean water that seeps into the crust is heated by magma rising from the mantle. The heated water dissolves minerals in the magma.

The hot springs erupt into the ocean and are cooled by the ocean water. As the water cools, the minerals in it are deposited around the vents in chimney-like structures. These structures are mounds of valuable mineral deposits that are sometimes 10 meters high.

Many strange organisms, such as giant tubeworms, thrive at the hot springs. These unique animals feed on bacteria that do not depend on energy from the sun. Scientists will continue to study the unusual formations and organisms found near hot springs.

B) CHAPTER SUMMARY

- The earth is shaped almost like a sphere. The distance around the earth is about 40,000 kilometers at the equator.

- Most earthquakes are the result of a movement of rocks along a fault.

- Seismic waves are of three different types: primary or longitudinal, secondary or shear waves and surface waves.

- The layers of the earth, from the outside in, are the crust, the mantle, the outer core and the inner core.

C) QUESTIONS/PROBLEMS

1. Describe the layers of the earth.
2. Explain how the seismic waves are generated.
3. Explain the differences between longitudinal waves and shear waves.
4. Describe how seismic wave velocities vary within the different layers of the earth.
5. Why do scientists think the outer core is liquid?
6. Explain what is meant by a deep focus earthquake?
7. What are some possible causes for strange animal behavior before earthquakes?
8. Why are scientists interested in determining the causes of this behavior?
9. Where are the hot springs?
10. What is a black smoker?

D) EXTRA RESEARCH

1. Calculate what the temperature at the center of the earth would be if the rate of temperature increase of 2°C for each 100 meters from the crust continued through to the center of the earth. The radius of the earth is 6,370 kilometers. Let 15°C be the starting temperature of the crust. Compare your result with the suggested temperature of the earth's core, which is 5,500°C.

2. Using an encyclopedia or other library resource, describe and draw two kinds of seismographs.

3. Find five interesting or unusual facts about famous earthquakes.

4. Find out if there is a technical institute or university in your town which has seismographs and pay a visit to see them working.

E) CHAPTER TEST

A. Vocabulary. Match the definition in Column I with the term it defines in Column II.

		Column I	Column II
( )	1.	the way energy travels through the earth	a. epicenter
( )	2.	instrument to detect seismic waves	b. focus
( )	3.	layer of the earth of 5 to 60 km thickness	c. seismic waves
( )	4.	layer of the earth between the crust and the outer core	d. seismograph
( )	5.	point on the surface of the earth over the focus of an earthquake	e. magnitude
( )	6.	melt rising from the mantle to the surface to form igneous rocks	f. crust
( )	7.	measure of the energy released at the focus of an earthquake	g. fault
( )	8.	outer layer of the earth which includes crust and upper mantle	h. asthenosphere
( )	9.	layer of the earth between depths of 100 and 700 kilometers	j. lithosphere
( )	10.	relative movements between blocks of the crust	k. mesosphere l. intensity

B. Multiple Choice. Choose and mark the letter that best completes the statement or answers the question.

1. The crust of the earth is:

   a) of the same thickness everywhere
   b) thicker under the continents
   c) liquid
   d) very cold in the deeper parts

2. The core of the earth is:

a) uniform
b) immediately under the mantle
c) mainly of iron
d) cold

3. The mantle is:

a) the same everywhere
b) contains the asthenosphere
c) solid rock
d) a thin layer

4. Most earthquakes occur near to:

a) big cities
b) the border of the tectonic plates
c) rivers
d) inland seas

5. A seismic wave traveling only on the earth's surface is:

a) a P wave
b) an S wave
c) a B wave
d) an L wave

6. Scientists use the difference in time between the arrival of P-waves and S-waves to find the location of:

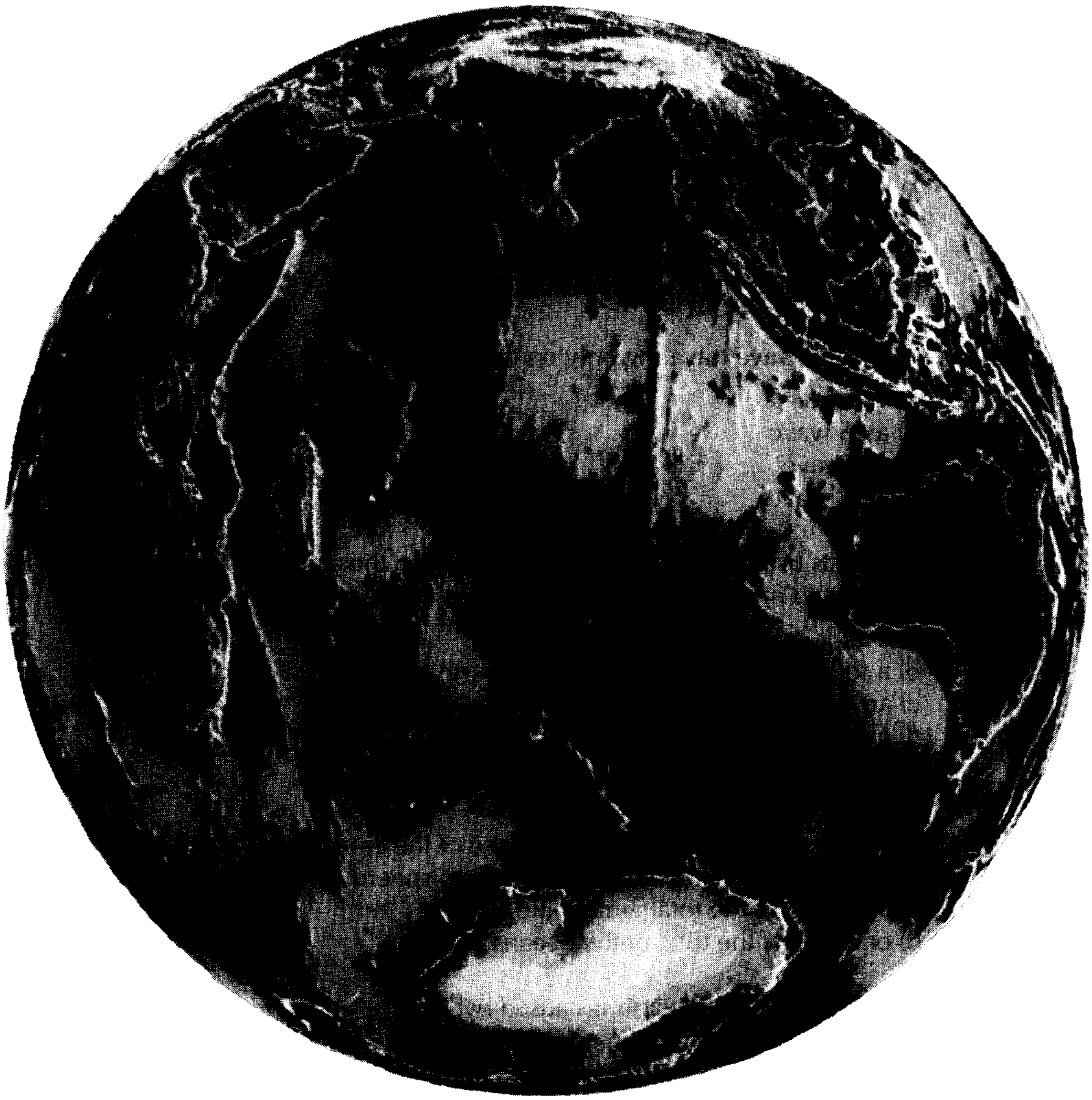
a) a fault
b) a focus
c) an epicenter
d) earth tremors

7. The area of the Pacific Ocean is:

a) 70 % of the total area of the surface of the earth
b) 80 % of the area of the Southern Hemisphere
c) one third of the total area of the earth
d) one fifth of the total of the oceans

8. The flattening of the earth is caused by:

a) the direction of the big ocean currents
b) the flow of hot and viscous material in its interior
c) the centrifugal force generated by rotation
d) the global wind pattern in the atmosphere



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:

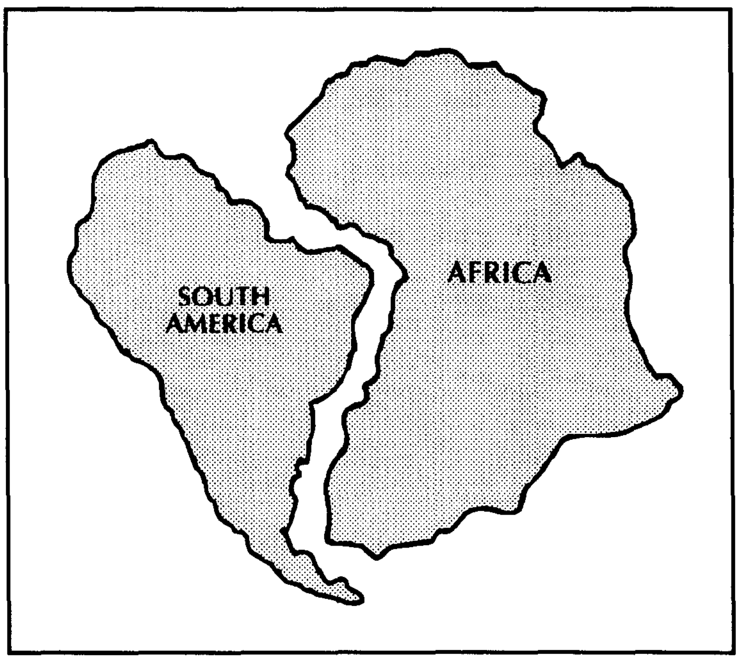
a. What is the theory of Continental Drift?

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.

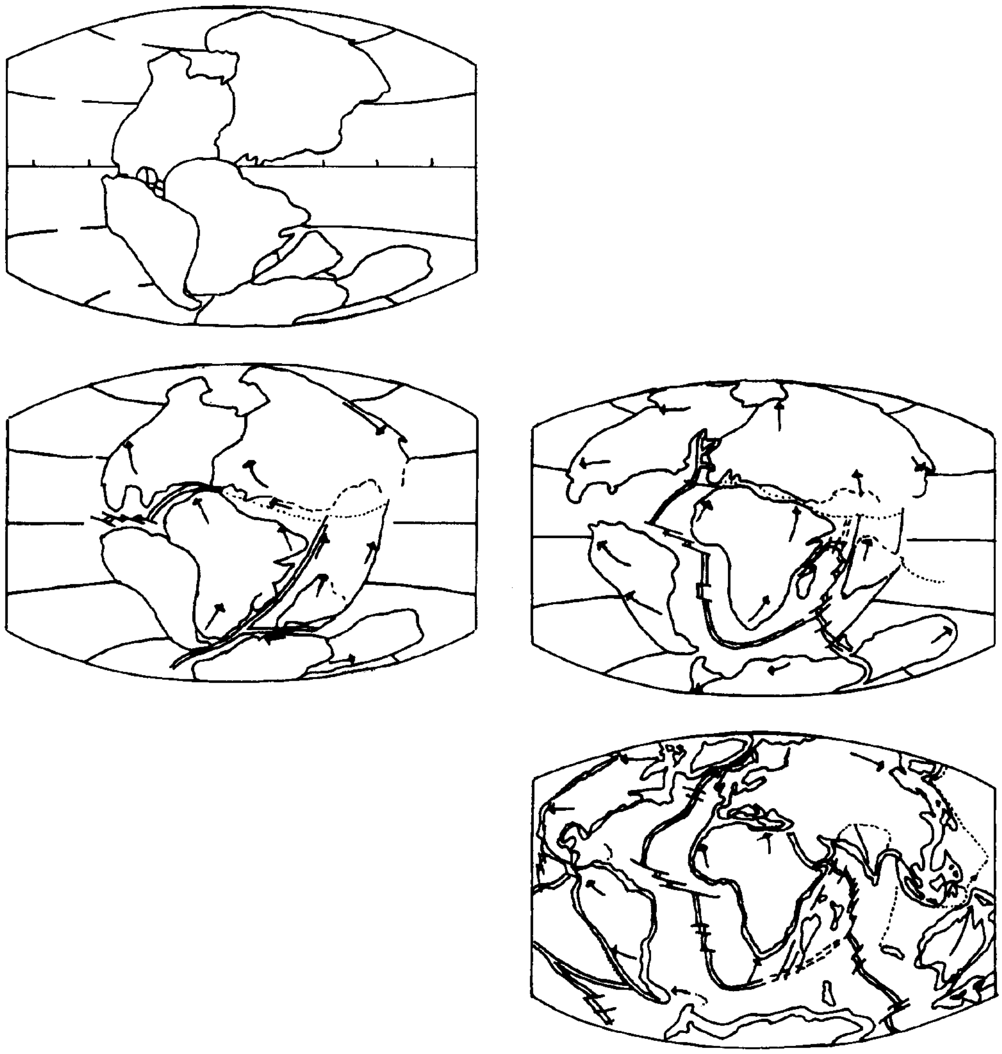
Wegener believed that Pangaea began breaking up and drifting apart many millions of years ago. He insisted that the jigsaw fit of the continents was not an accident, but the result of the splitting of Pangaea. He said that the continents slowly drifted over the ocean floor until they reached their present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



Fitting of continents.

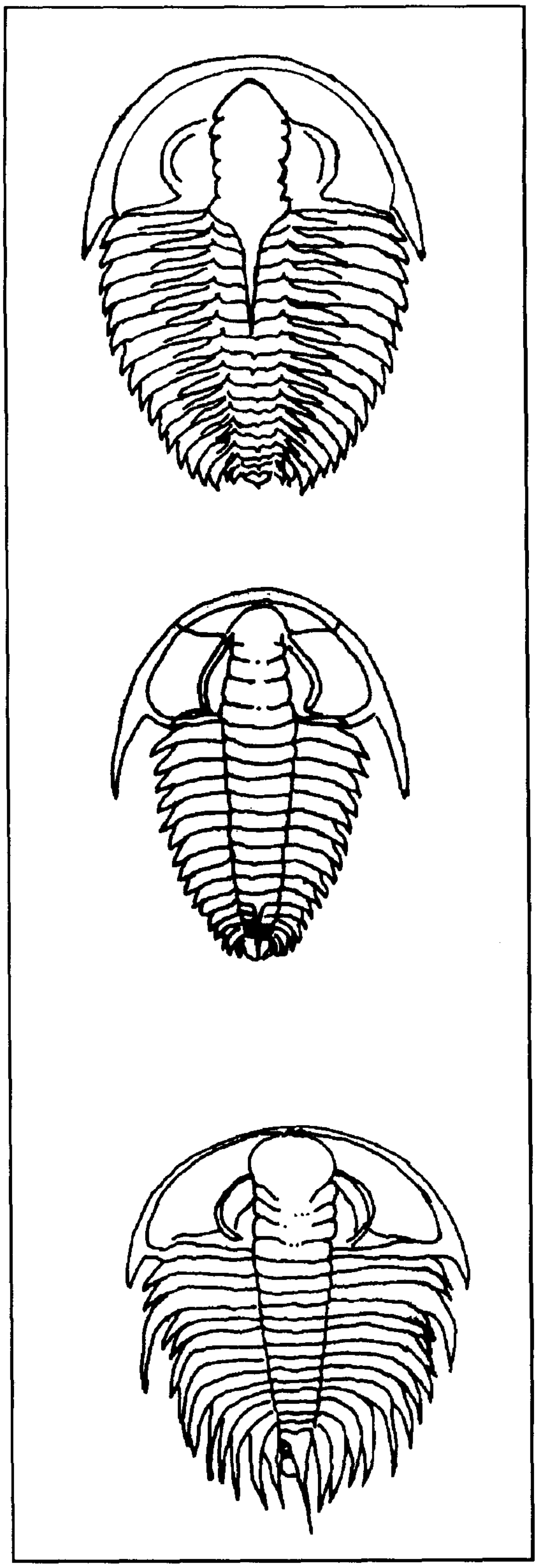
• WEGENER'S EVIDENCE FOR CONTINENTAL DRIFT

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.



Trilobite (200 million years old fosil)

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.

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?

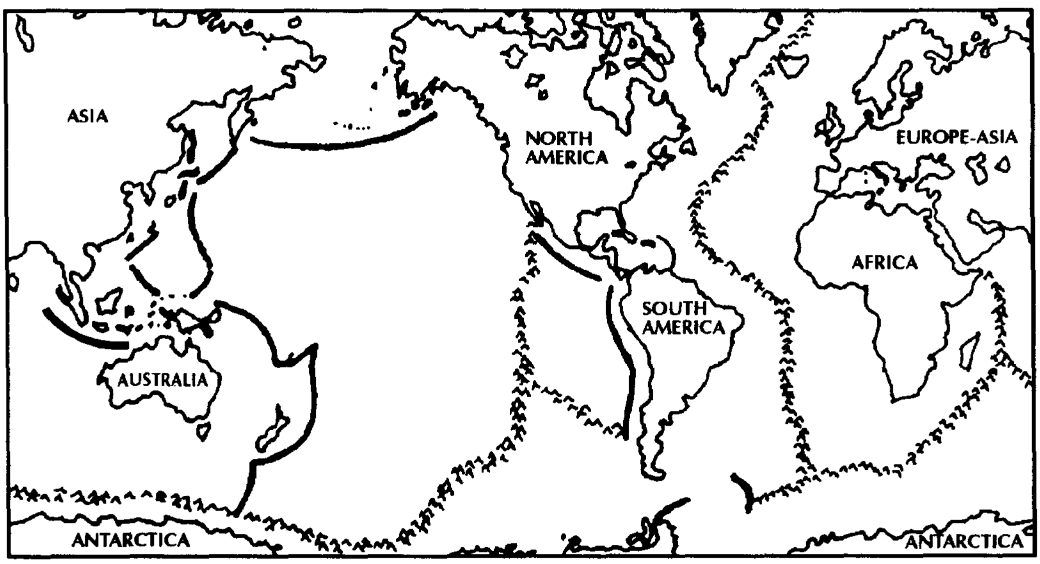
• TRENCHES, AND MID-OCEAN RIDGES

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 oceans.

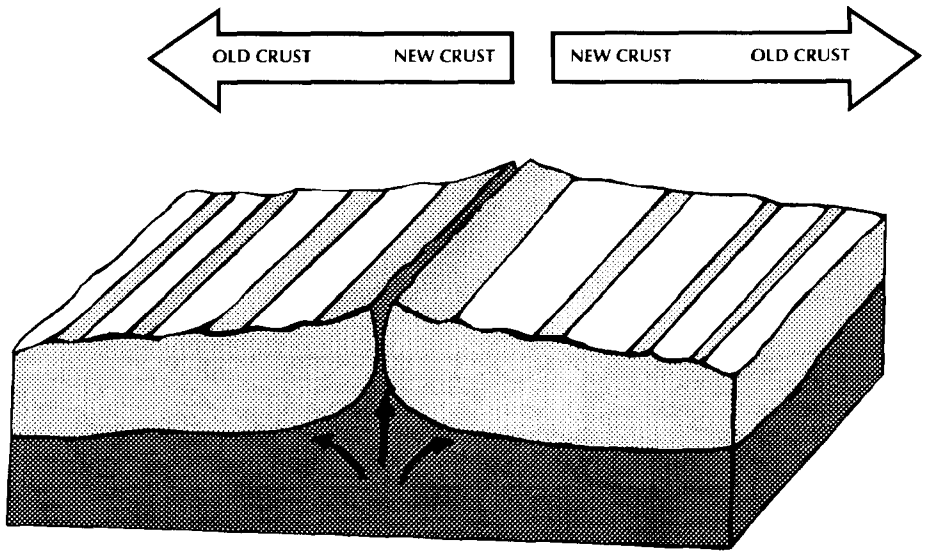
• SEA-FLOOR SPREADING

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

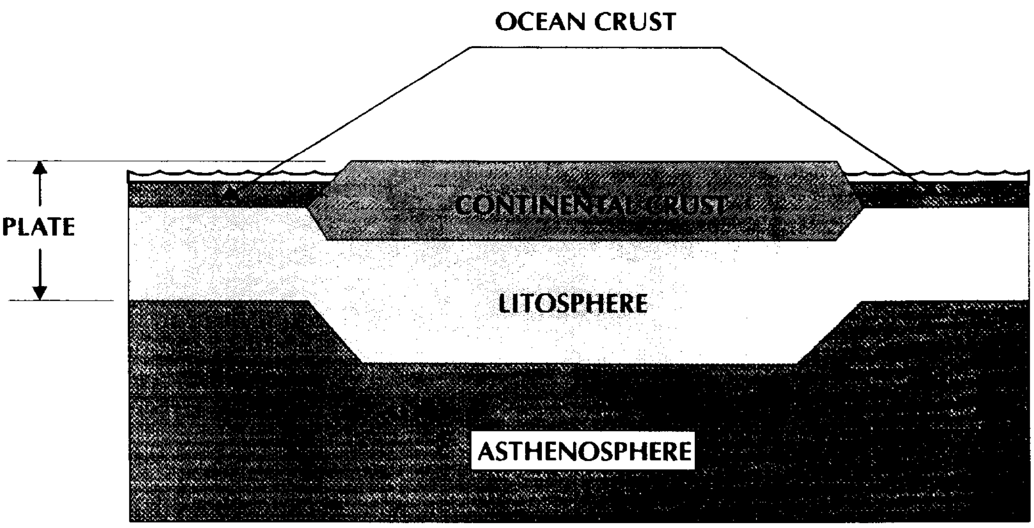
To increase your understanding of any subject, you must add new information to the knowledge you already have. For example, you read and understood numbers long before you learned to tell time. Similarly, earth scientists used the information from sea-floor spreading to develop a broader theory that 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.

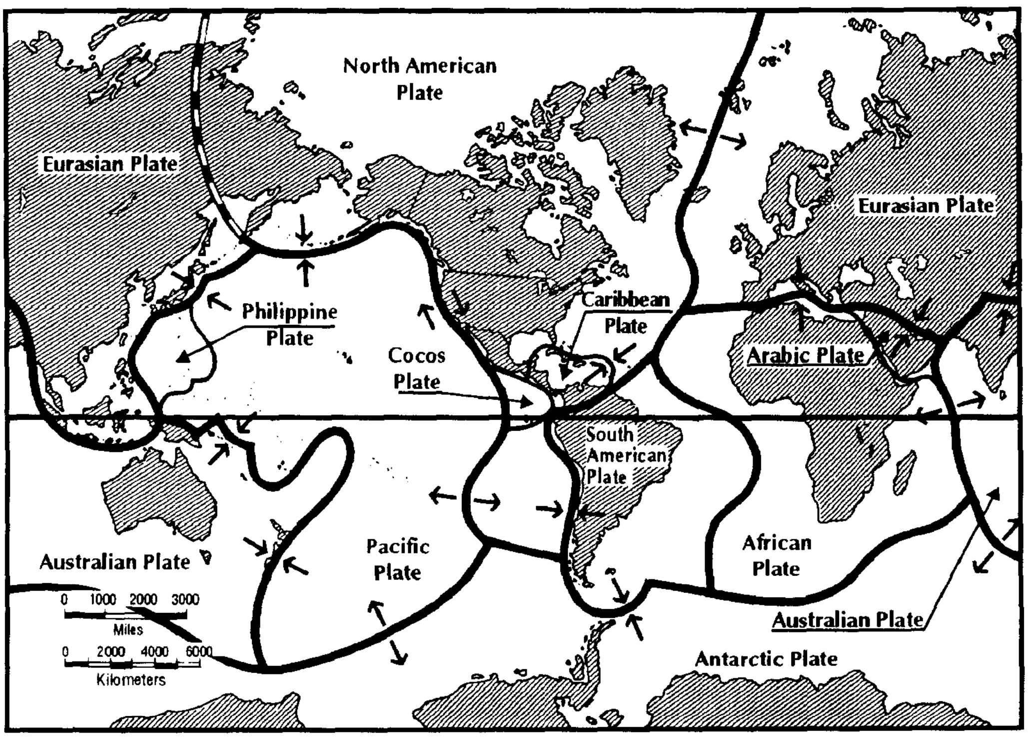


Layers of the earth.

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 Mid-
Atlantic 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.

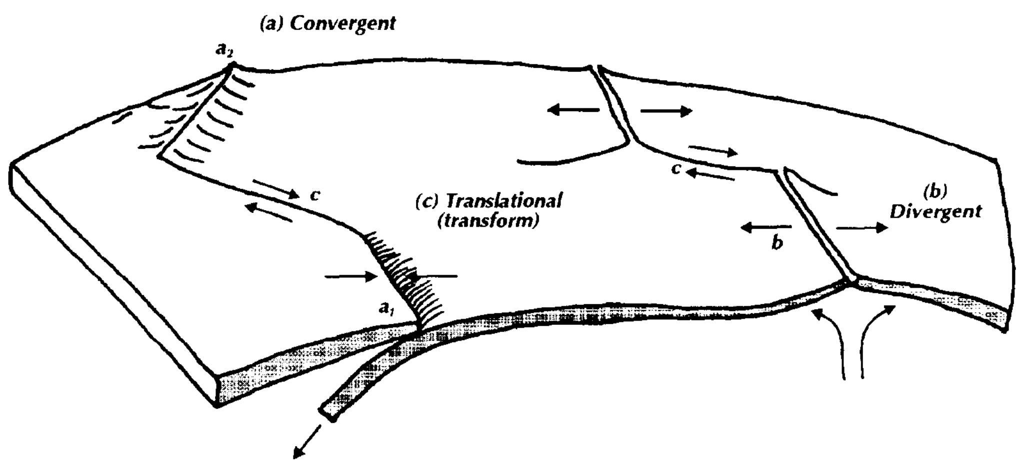


Plate boundaries.

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?

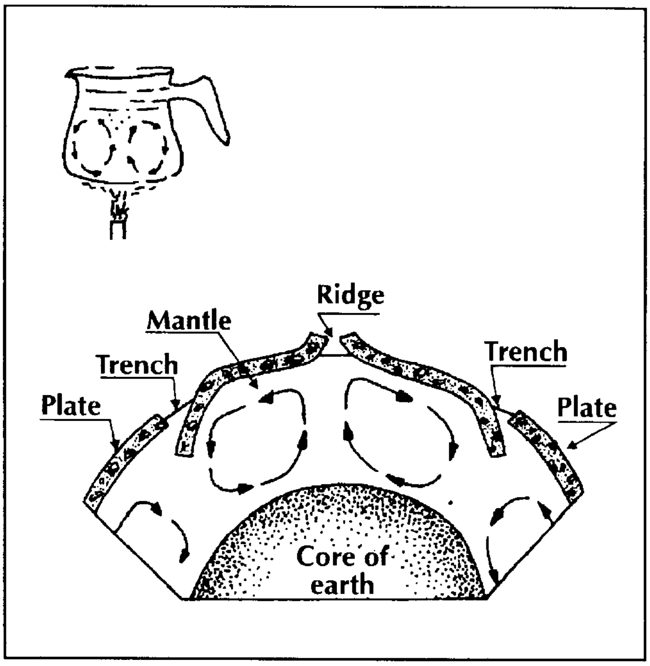
b. How might plumes cause plate movement?

c. What are hot spots?

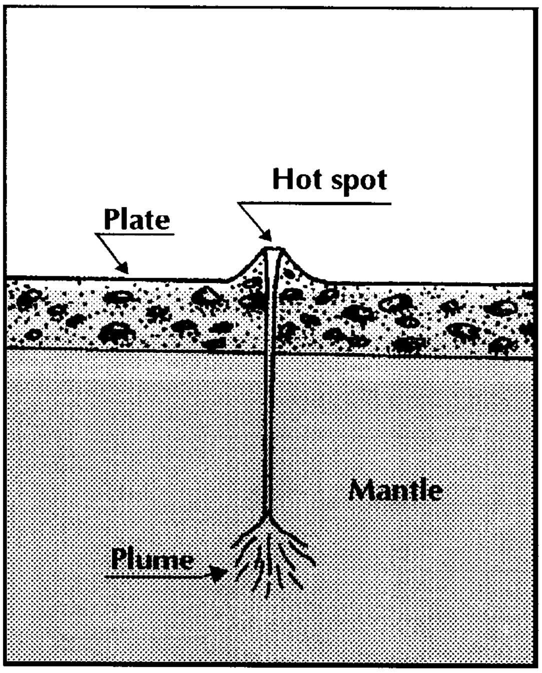
• ONE POSSIBILITY-CONVECTION CURRENTS

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.

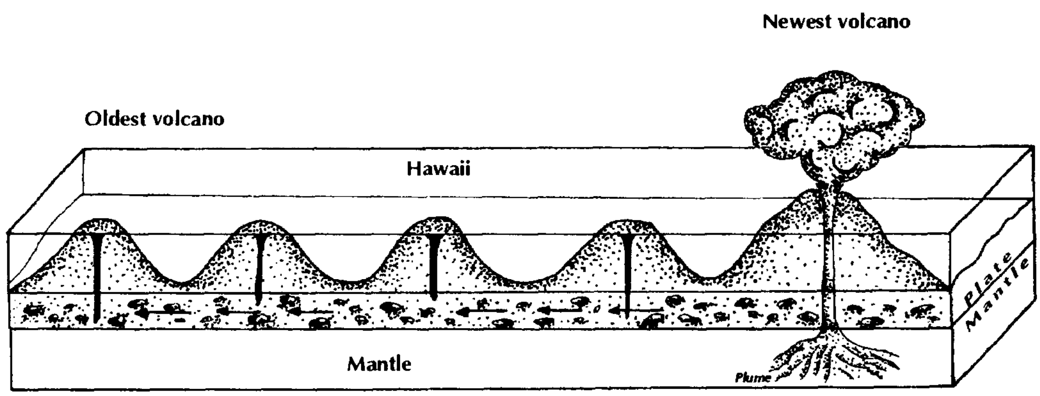
• INVESTIGATING HOT SPOTS

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 Islands 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 be areas where continents are starting to split.

be areas where continents are starting to split.

A) REPORT

• 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, 1755, 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 and 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 earthquakes 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 level in wells, or in the electric and magnetic properties of the ground.

People are indifferent 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 more common and harmful than in many other countries, people have been asked to pay attention to any uncommon behavior 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.

someday it will be possible to forecast earthquakes

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 fault 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 small 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
			e. Pangaea
( )	5.	hot material rises, spreads sideways, and then sinks again	f. plume
( )	6.	a theory that describes the formation of new crust	g. plate tectonics
( )	7.	region on the earth's surface that has a great many volcanoes	h. sea-floor spreading i. trench
( )	8.	a jetlike flow of hot material from deep within the mantle	j. magma
( )	9.	theory that land masses move over the ocean floor	

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.

CHAPTER 3

SEISMICITY OF THE EARTH AND VOLCANOES

In the picture you can see an eruption of a volcano. These eruptions affect the land and the air for kilometers around. Earthquakes, like volcanoes, can cause a great deal of damage.

In this chapter you will read about earthquakes and volcanoes on Earth. This chapter also suggest some "signs" that scientists are using in an effort to predict earthquakes and volcanic eruptions.

CHAPTER OBJECTIVES

1. Explain the relationship between faults, earthquakes, and plate boundaries.
2. Explain how scientists use seismic waves to locate the epicenters of earthquakes.
3. Contrast the formation of intrusive and extrusive rocks.
4. Describe four types of volcanic cones.

3.1 EARTHQUAKES

An earthquake is a trembling or shaking of the earth. What causes an earthquake? Huge explosions can shake the earth, or magma moving up in a volcano may cause an earthquake. Most earthquakes, however, happen because rocks move along a fault. Think about these questions as you read about earthquakes:

a. How are earthquakes related to faults?

b. Where do most earthquakes occur?

c. What does the Richter scale tell you about an earthquake?

d. What are aftershocks?

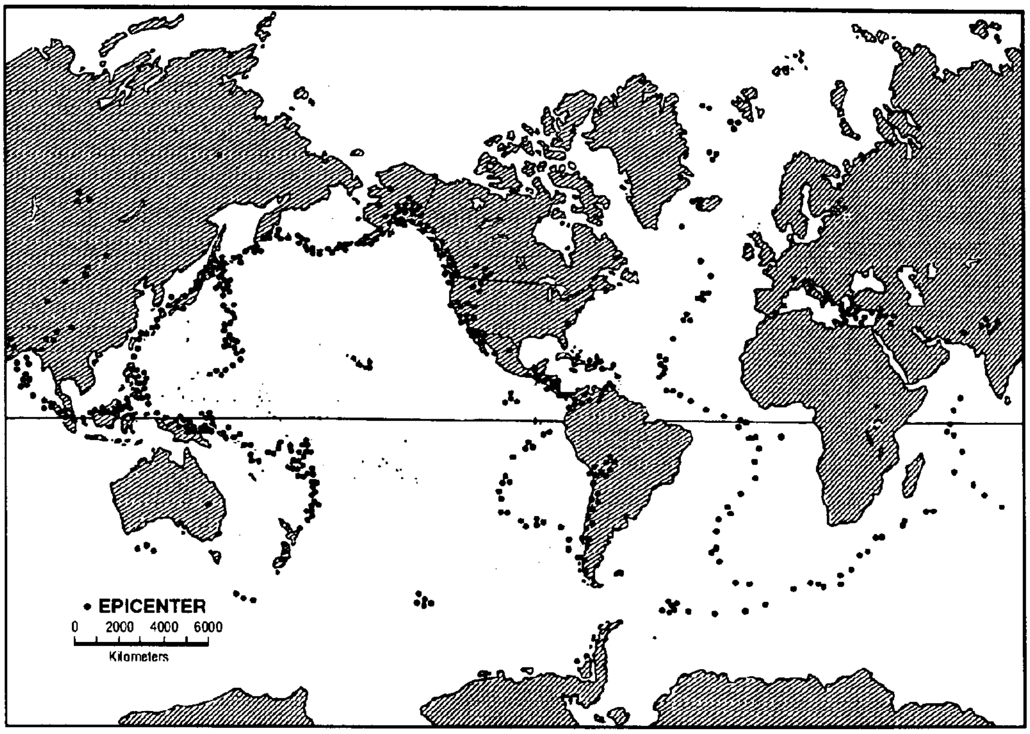
• Earthquakes and Faults

Imagine what happens when you bend a plastic ruler. If you bend it far enough, the ruler breaks. Both pieces snap back to a straight position. Rocks in the earth's crust that are under pressure also bend, break, and snap back. A fault is a break in rocks along which rocks have moved.

When the break occurs, energy is released as seismic waves. This energy makes the earth shake, and we feel an earthquake.

With the installation of highly sensitive seismographs in many locations around the world, it is relatively easy to record the seismic disturbances, even if they are not felt by man. Once seismic waves have been detected and recorded at several seismic stations, it is possible to determine where they were produced. There are several institutions which are dedicated to determining earthquake parameters for all the seismic activity of the world. With this information it is possible to determine the pattern of places of high and low seismicity.

Next diagram shows the world distribution of seismic shocks.



World distribution of earthquakes.

From this diagram it can be concluded that the distribution of seismic events is not homogeneous. There are very well defined seismic areas. In the middle of the oceans seismic events are concentrated along very narrow strips which coincide with the location of the mid-oceanic ridges. Away from these areas, most of the oceanic floor is aseismic.

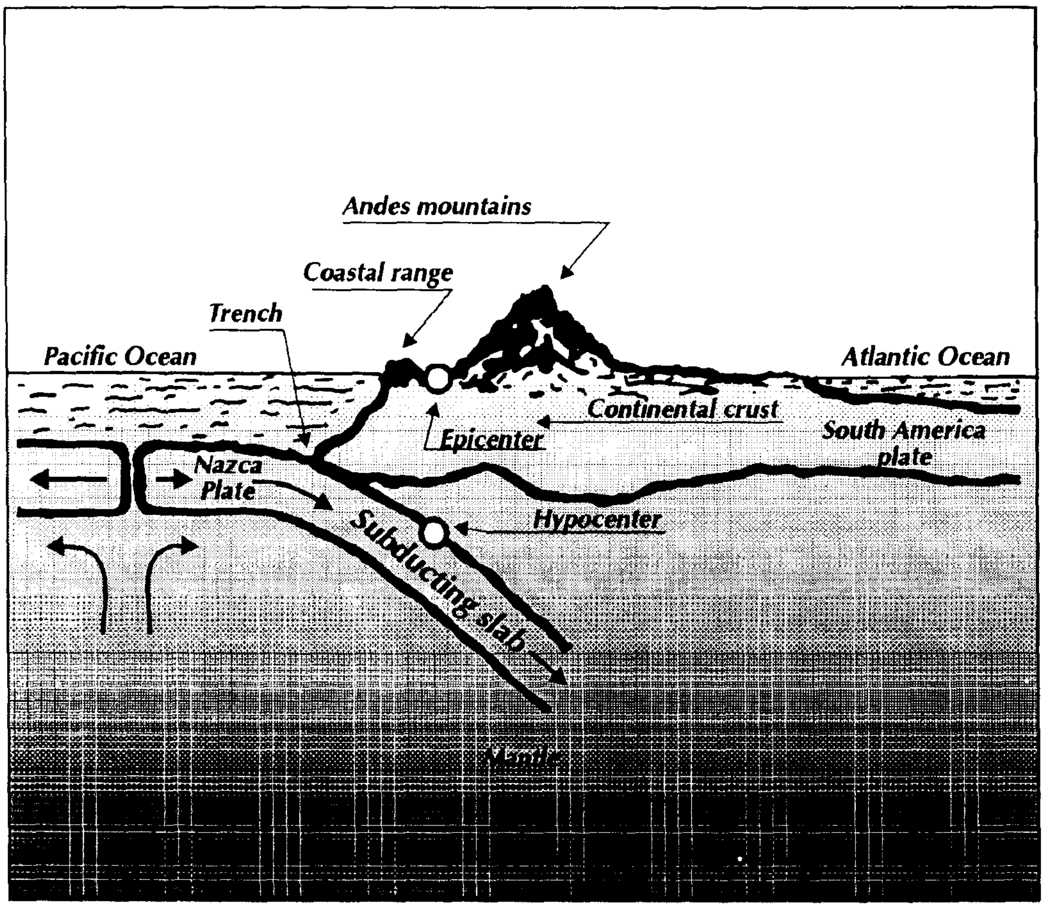
The most important mid-oceanic ridges are: the Mid-Atlantic ridge, the Mid-Indian ridge which divides in two branches to the south, and the East Pacific Rise. The East Pacific Rise starts in the Gulf of California and divides in two at Easter Island (Chile), one going south-west, and one going up to Taitao Peninsula, in continental Chile. Normally all the seismic activity in these areas is shallow and of small magnitude.

Equally concentrated and most numerous are the seismic events located in structures called island arcs. The most important island arcs are located in strips around the Pacific Ocean. The main island arcs are: Alaska-Kodiak Islands, Kamchatka Peninsula, Kuril Islands, Japan, Mariana Islands, Solomon Islands, New Hebrides Islands, Fiji Islands, Phillipines-Sunda-Adaman Islands. In the Atlantic Ocean we find the Lesser Antilles and the South Sandwich Islands. Similar seismic strips are found along the coast of Central and South America. The deepest and largest magnitude earthquakes are all located in these regions. The wider seismic belt along the southern part of Europe, the Himalayas and

South East Asia, is a more complicated area, where earthquakes are more sparse.

Minor seismicity (or almost null) areas are the continental shields, like the Canadian shield in the eastern part of North America, the Brazilian shield in South America, the eastern part of Australia, Central Europe, South Africa and the oceanic floors far from the mid-oceanic ridges.

The point inside the earth where the rock breaks or moves is the focus of the earthquake. The focus of most earthquakes is inside the earth where plates rub; the place on the surface of the earth immediately above the focus is the epicenter of the earthquake. If the focus is at the surface of the earth, the focus and epicenter coincide.



Profile across South America.

If the focus is located at depths between 0 and 60 kilometers, the earthquake is shallow. If the focus is located at depths between 60 and 300 kilometers, the earthquake is of intermediate depth. If the focus is between depths of 300 and 700 kilometers, the earthquake is of deep focus.

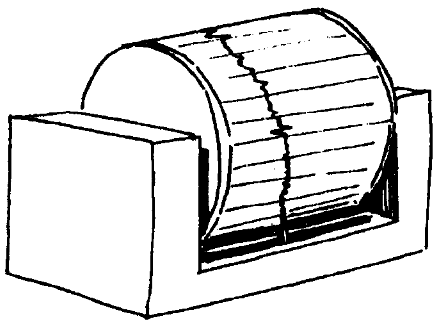
• SIZE OF AN EARTHQUAKE

To measure an earthquake two scales are used to determine intensity and magnitude.

The intensity of an earthquake is the violence with which the earthquake is felt at different locations in the affected area. Its value is determined by assessing the damage produced, the effect on objects, buildings and grounds, and the impact on people. The intensity value of an earthquake is determined according to a previously established intensity scale, which is different for different countries.

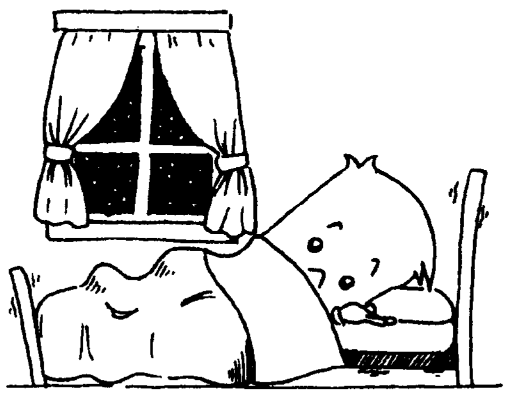
In most countries of America, the scale in use is the Modified Mercalli Intensity Scale which has 12 intensity levels. Following diagrams show the different intensity levels.

INTENSITY I



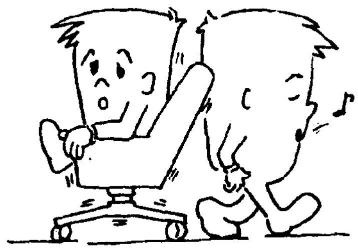
Not felt except by a very few persons under especially favorable circumstances.

INTENSITY II



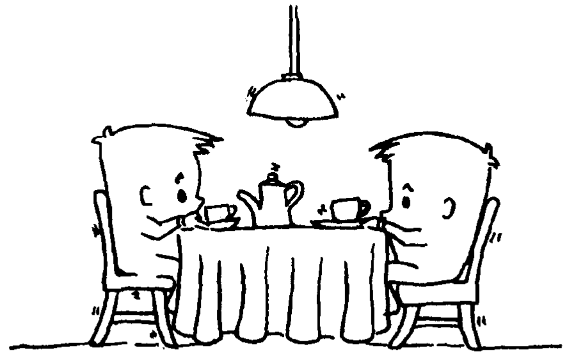
Felt only by a few persons at rest, especially on upper floors of buildings.

INTENSITY III



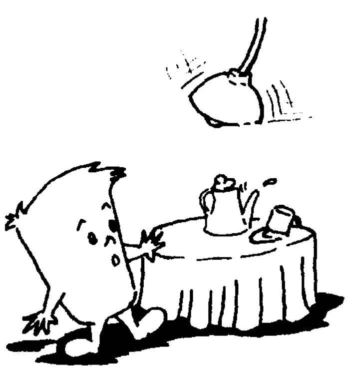
Felt quite noticeable indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake.

INTENSITY IV



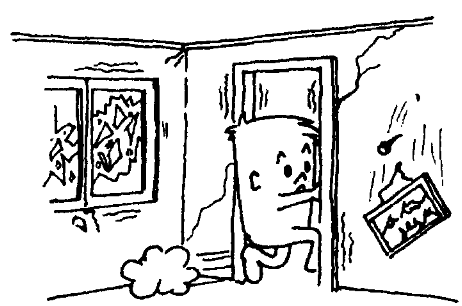
During the day, felt indoors by many people. Dishes, windows and doors, disturbed; walls make cracking sound; liquids in open vessels disturbed.

INTENSITY V



Felt by nearly everyone. Some dishes, windows, etc., broken. Unstable objects overturned.

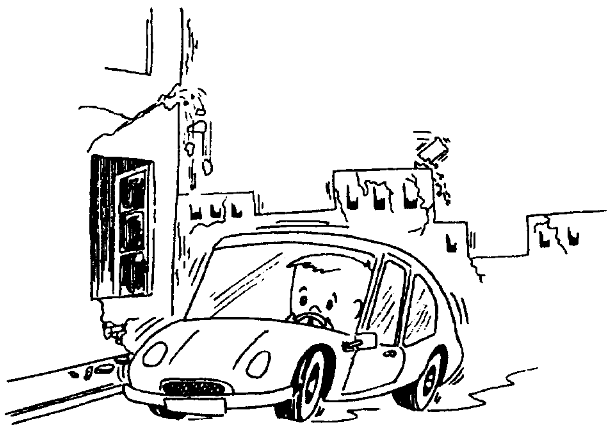
INTENSITY VI



Felt by everyone. Some heavy furniture moved. A few instances of fallen plaster or damaged chimneys.

INTENSITY VII

INTENSITY VIII

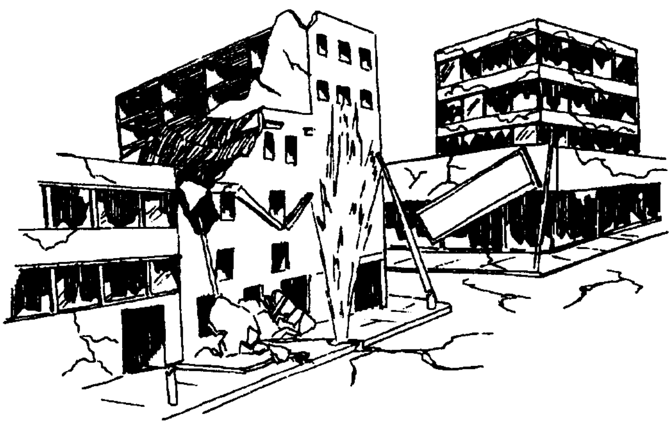


Everyone frightened. Overturned furniture in many instances. Trees and bushes shaken strongly. Noticed by persons driving cars. Cornices, brickwork, tiles and stones dislodged.

Damage slight in specially designed structures. Great in poorly built structures. Chimneys, factory stacks, columns, monuments and walls collapse.

INTENSITY IX

INTENSITY X



Every building damaged and partially collapsed. Ground cracked conspicuously. Underground pipes broken. Several landslides reported.

Some well-built wooden structures destroyed. Most masonry and frame structures destroyed along with their foundations.

INTENSITY XI

INTENSITY XII

Few, if any structures remain standing. Bridges destroyed. Damage great to dams, dikes, and embankments. Rails bent greatly.

Almost everything is destroyed. Objects are thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move.

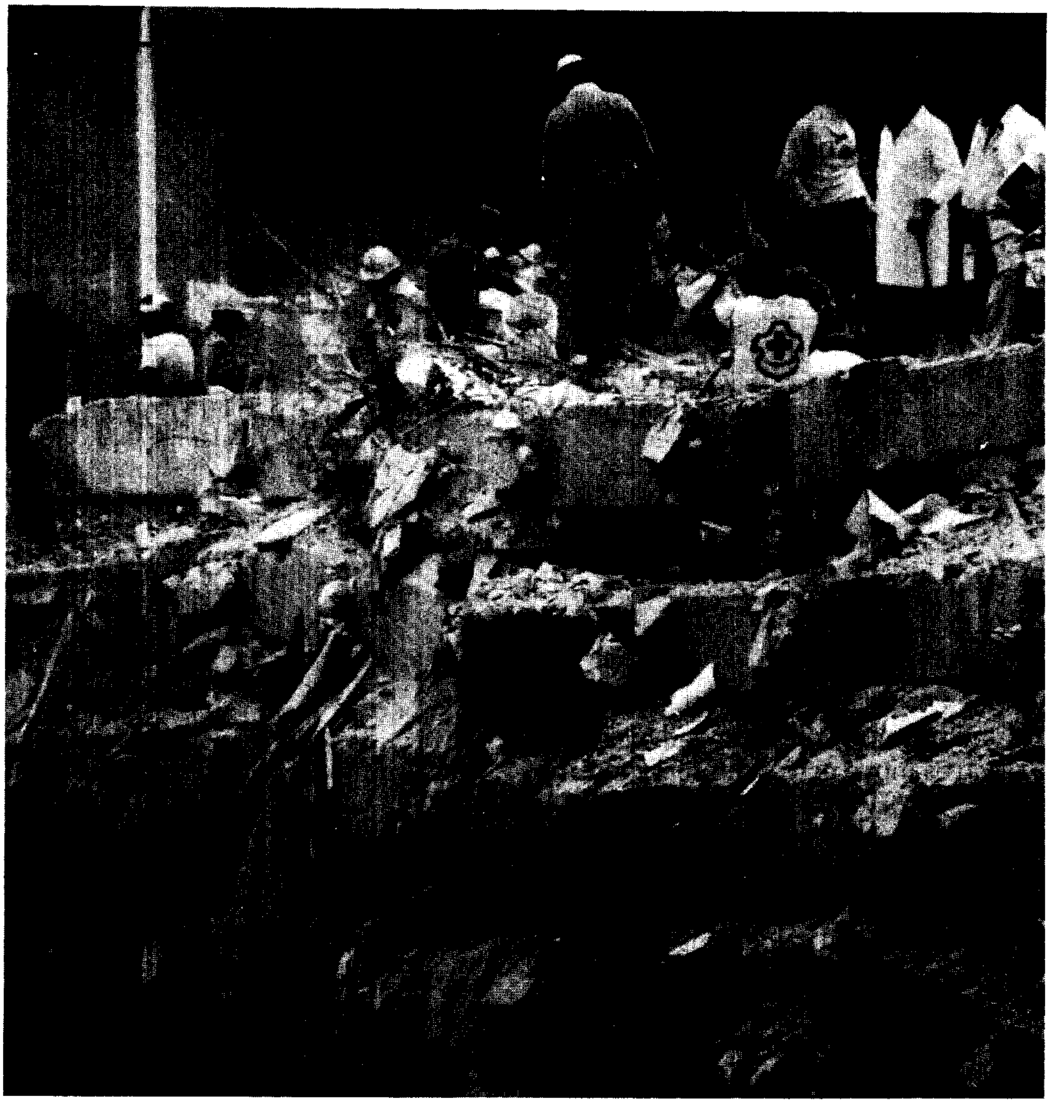
The magnitude of an earthquake is the energy released at the focus of the earthquake. It is measured with the help of an instrument called seismograph. The instrument's reading (amplitude of seismic waves) indicates the amount of strain energy released by an earthquake. The greater the wave amplitude, the greater the magnitude. A magnitude scale was devised by the American seismologist Charles Richter in 1935. It uses Arabic numerals. Richter's scale is logarithmic and open-ended; that is, there is no upper or lower limit to Richter magnitudes. Each whole-number increase in the magnitude of an earthquake represents about a thirty-fold increase in the amount of energy released.

DO YOU KNOW...?

Many people have reported seeing colored lights or a glow in the sky during earthquakes. Some scientists think that certain rocks in the earth take on an electrical charge when they are shaken violently. This charge causes lightning-like sparks that produce the strange lights.

• Strong Earthquakes and Aftershocks

The strongest recorded earthquakes in history took place in 1964 near the coast of Alaska, and in 1960 off the coast of southern Chile. These earthquakes had values over 8.9 on the Richter scale. Earthquakes of this type produce a lot of damage as seen in the picture below.



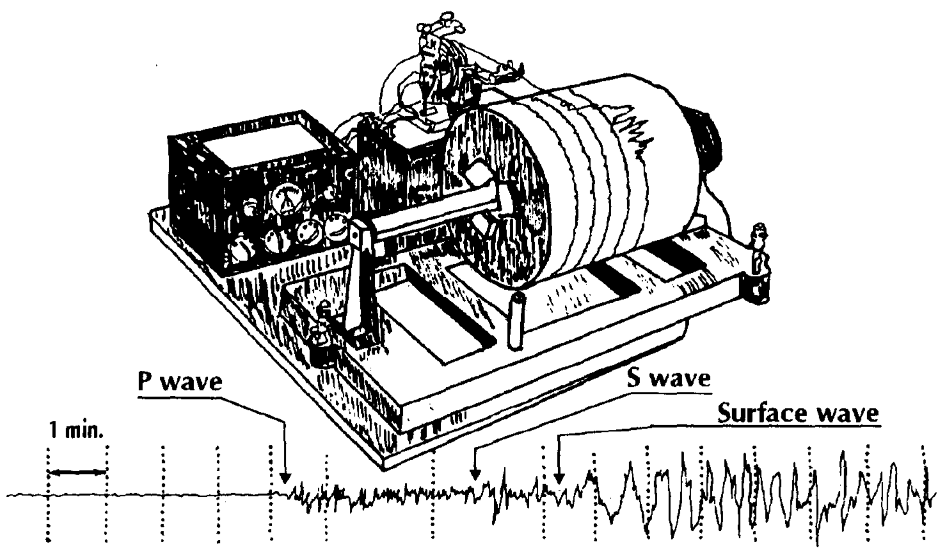
México, earthquake, september 1985.

(From "National Geographic", May 1986)

Many small earthquakes, called aftershocks, usually follow a strong earthquake. The San Fernando, California, U.S.A., earthquake in 1971 registered 6.6 on the Richter scale. Within three days, more than 1,000 aftershocks followed the main earthquake. Some of the aftershocks measured up to 5.0 on the Richter scale.

• Using Seismographs to Find the Epicenter

As explained in Chapter 1, a seismograph is a sensitive instrument that measures and records seismic waves. When a seismic wave shakes the seismograph, the pen marks zigzag lines on a revolving paper roll. The lines are similar to this:



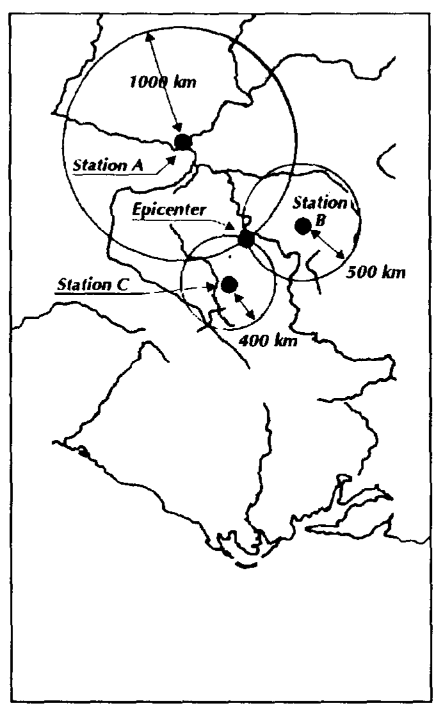
Seismograph and seismogram.

Since P-waves travel fastest, they arrive first at the seismograph, followed by S-waves. L-waves move across the surface of the earth, and arrive last.

Scientists can calculate the distance to the epicenter of an earthquake by reading the seismogram and calculating the time difference between the arrival of the P-waves and the S-waves at the seismograph.

It takes readings from three seismograph stations to locate the epicenter of an earthquake as seen in the diagram.

Assume a scientist finds that the distance from Station A to the epicenter of an earthquake is 1,000 kilometers. The epicenter, therefore, might be at any point on a circle with a radius of 1,000 kilometers around station A on a map.



Epicenter determination.

The scientist draws this circle around Station A on a map. Assume that scientists at Station B and Station C have also read the charts and determined the distances to the epicenter to be 500 kilometers from Station B, and 400 kilometers from Station C. Scientists draw circles around their stations at B and C on maps, using the distance to the epicenter for the radius of each circle as before. The epicenter of the earthquake, shown on the previous diagram, is the point where the three circles intersect on a map.

• Warning *Earthquake Ahead!*

Where and when will the next earthquake happen? How strong will it be? Scientists are trying to answer these questions.

People all over the world who watch faults find that certain "signs" often occur before earthquakes. The ground sometimes bulges or tilts near a fault before a big earthquake. An increasing number of small earthquakes on a fault could mean that a strong earthquake is coming. Also, changes in the water level in a well near a fault is often an earthquake sign.

Using these signs and many others, scientists have been able to correctly predict some big earthquakes. Perhaps in your lifetime earthquake forecasts will become accurate enough to save lives.

ACTIVITY

LOCATING AN EARTHQUAKE

Purpose

To find the epicenter of earthquake X.

Materials

- one sheet of unlined paper
- compass
- metric ruler

Procedure

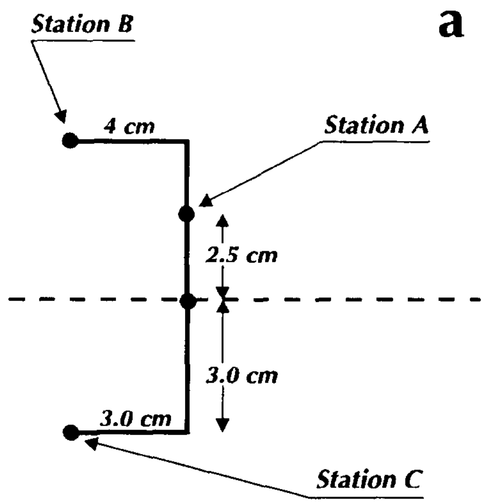
1. Fold the paper in quarters (as shown in a), then unfold it; the intersection of the two folds is your centerpoint.

2. Mark Stations A, B, and C on the paper. Start by marking a point 2.5 cm above the center point on the paper. This is Station A. Draw in B and C using diagram a. You are making a map to find the epicenter.

3. Scientist know how fast P and S waves travel. They can calculate the distance to the epicenter of an earthquake by measuring the difference in arrival time of P-waves and S-waves at their stations. The difference in arrival time of the waves is:

120 seconds at Station A
80 seconds at Station B
80 seconds at Station C

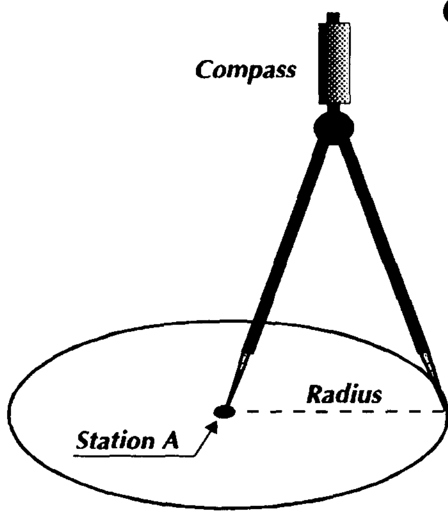
a



b

EPICENTER TABLE	
Distance to epicenter (km)	Difference in arrival time of P and S-wave (in sec)
200	40
300	60
400	80
500	100
600	120

c



Radius= distance in cm from station A to epicenter.

Using the Epicenter Table b, read and record the distance to the epicenter from each station.

4. Convert each distance to cm, so the data can be used on your map. Use the scale 1 cm = 100 km. This data will be the radius of each circle in step 5.

5. On your map draw a circle around Station A, as in c. The radius of the circle is the distance in cm that you recorded in step 4.

6. Repeat step 5 for the other two stations.

7. The location of the epicenter of earthquake X is the point where the three circles intersect. Mark this point with an X.

Analysis

1. When do scientists need to use this method to find the epicenter?

2. Where is the focus of earthquake X?

3. Why is it necessary to draw a circle around each station with the distance to the epicenter as the radius?

4. How could someone predict the approximate location of an epicenter without a seismograph?

3.2 MAGMA AND LAVA

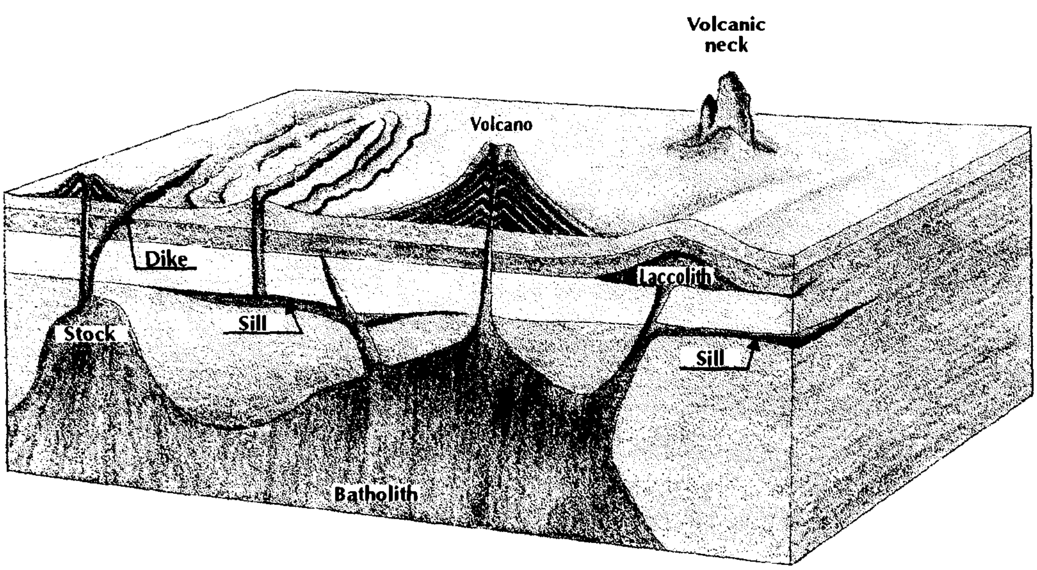
Like an earthquake, the eruption of a volcano means that something is happening inside the earth. Study these questions as you read:

a. What forms when magma is trapped underground?
b. Where does lava reach the surface of the earth?
c. Why is lava important at plate boundaries?
d. How can you classify volcanoes by their activity?
e. How do the shapes of volcanic cones differ?

* Magma Inside the Earth

Rock formed from magma that cools and hardens underground is intrusive rock. You cannot see intrusive rock unless some geologic process exposes the hidden rock. For example, water may wear away the rocks on the surface. Five intrusive structures are illustrated together below, so you can see the shape and relative size of each.

A **batholith**, shown in the diagram, is so large that its bottom is often unknown.



Distribution of intrusive and extrusive rocks.

In fact, the cores of many mountain chains are batholiths. The stock is similar to, but smaller than, a batholith. When magma works its way between rock layers, a sill forms. The mushroom- shaped laccolith forms when magma pushes up on the rock above it. When magma cuts across existing rock layers at an angle, a dike is the result.

• Lava on the Earth's Surface

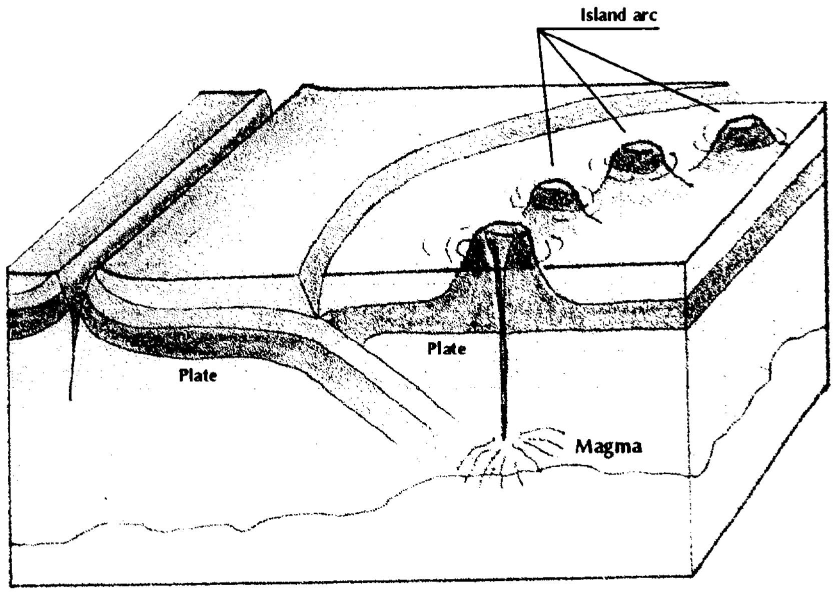
When magma comes out on the surface of the earth, it is called lava. Lava reaches the surface through volcanoes or through cracks in the ground. These cracks are called fissures. Extrusive rocks are hardened lava on the earth's surface.

Lava from large fissures may flood wide areas of land, since they may have been several kilometers long.

• Lava at Plate Boundaries

Most extrusive rocks form where you cannot see them - on the ocean floor. These rocks are the new crust born at mid-ocean ridges. Vast amounts of lava rise through fissures or volcanoes at spreading boundaries. Occasionally volcanoes on the ocean floor grow large enough to become islands.

Many volcanoes are near colliding boundaries. The diagram below shows one ocean plate sinking under another ocean plate. The sinking crust melts in the asthenosphere. Then the magma that forms from the melted crust rises. This magma gives rise to volcanoes on islands called island arcs. The Japanese Islands are an example of an island arc.



Colliding boundary.

Volcanoes may also form on land where an ocean plate sinks under a land plate. This type of boundary produced the Cascade Mountains of Washington and Oregon in the United States of America, as well as the Andes Mountains of South America.

DO YOU KNOW?

Pillow lava is a type of lava that cooled and hardened under water. It is common at spreading boundaries. The strange, rounded lumps of hot lava pop, hiss, and crackle when they meet with cold ocean water.

• Volcanic Activity

Volcanoes differ in appearance and behavior. Some volcanoes explode, shooting out dust, ash and rocks, as well as water vapor and other gases. The 1980 eruption of Mount St. Helens in the United States of America, followed this pattern. Other volcanoes quietly ooze lava.

Why do some volcanoes blow up? Visualize the effects of shaking a warm soda pop. The bottle may explode, releasing the soda and the carbon dioxide, the dissolved gas in the soda. Gases and water vapor, which are under pressure inside a volcano, may also explode.

One of the biggest volcanic explosions that ever took place was the eruption of the volcano Krakatau, a volcanic island in the strait between Java and Sumatra. In 1883 it exploded so violently that people heard the explosion 3,200 kilometers away. Most of the island disappeared. Volcanic dust remained in the air around the world for two years. A giant sea wave created by the explosion killed more than 36,000 people on nearby islands.

Volcanoes often give warnings before they erupt. These warnings include gas and smoke from the volcano. Earthquakes may signal the rise of magma inside the volcano. The ground around or on the volcano may bulge or tilt slightly.

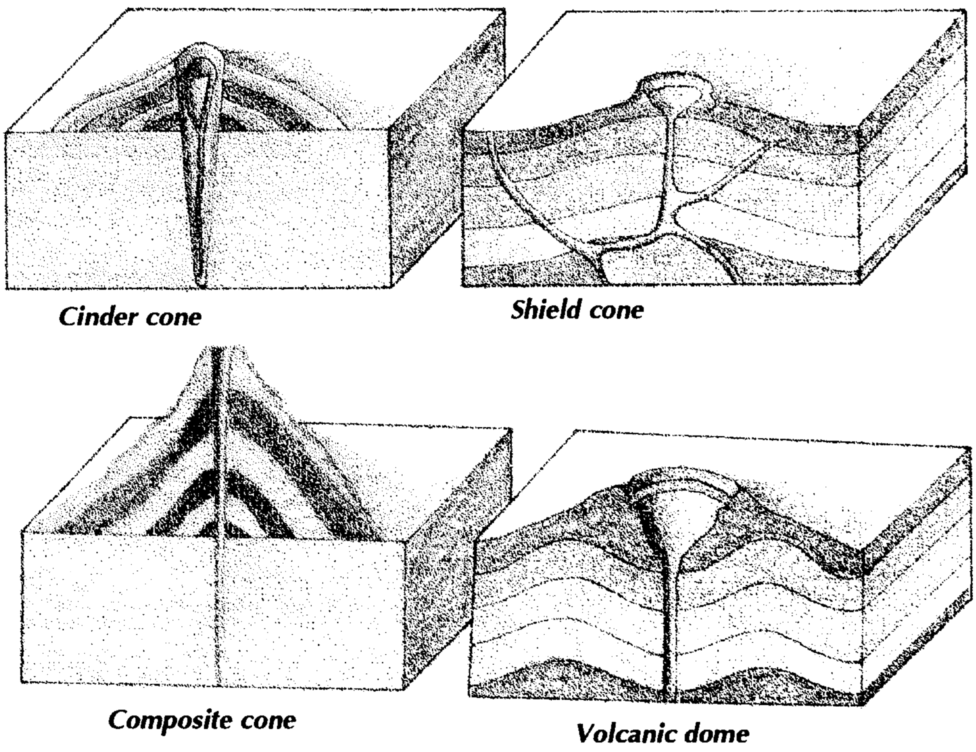
If a volcano has erupted in the recent past, it is called an active volcano. A dormant volcano is one that erupted in the past but has been quiet for many years. An extinct volcano is one that is not expected to erupt again. Most of the volcanoes in the Hawaiian Islands are extinct.

DO YOU KNOW?

Many countries of the world use hot water or steam from the ground to heat their homes or make electricity. Water in the ground is heated by igneous activity. Energy from the heat of the earth is called geothermal energy.

• The volcanic Cone

The mountain built by a number of volcanic eruptions is the volcano's cone. It is made of lava, volcanic ash, and rocks. A cone usually has a central vent. The volcanic materials come up through the vent. The top of the cone ordinarily has a crater, which is a bowl-like depression. The shape of a volcano depends on the way it erupts and the type of volcanic material that leaves the cone.



Types of volcanic cones.

A cinder cone, pictured above, forms when the eruptions throw out mostly rocks and ash but very little lava. Paricutin is a famous cinder cone volcano in Mexico. In 1943, this volcano appeared in a cornfield. In six days the cone was 150 meters high! The volcano reached 400 meters in height before it became dormant.

Non-explosive eruptions with easy flowing lava create shield cones, shown in the diagram. The volcanic islands of Hawaii with their gently sloping surfaces are typical shield volcanoes.

Alternating eruptions of dust, ash, and rocks followed by quiet lava flows build composite cones, shown above.

Volcanic domes result from violent eruptions of lava so thick that it barely flows. As you can see in the diagram, these volcanoes have sloping sides and dome-shaped tops. Mount Pelée is a dome volcano on the Caribbean Sea island of Martinique. It erupted violently and with little warning in 1902. A fiery cloud of gas and ash rolled down the side of the volcano, killing most of the people in the town below.

The effects of volcanic eruptions are far-reaching. Huge amounts of volcanic dust in the air contribute to beautiful sunsets and sunrises. If dense enough, volcanic dust can change the weather. The increased cloud cover from the dust can cause rain, and even cool weather. The fertile soils of the Hawaiian Islands developed from volcanic ash and rocks. Scientists think the gases in the air and the water in the oceans came from ancient volcanic eruptions.

ACTIVITY

EARTHQUAKES AND VOLCANOES

Purpose

To compare the locations of earthquakes and volcanoes around the Pacific.

Materials

* pencil
* outline map of Pacific and countries surrounding it
* globe or map of the world

Procedure

1. Using a globe or world map, locate on your outline map the earthquake areas named in a. Notice that the area names include cities, states, islands, and countries.

2. On your outline map mark with a Q the locations that you found in the step above.

3. Draw a line from one Q to the next nearest Q until all Qs are joined.

4. Using a globe or world map, locate the volcano sites listed on the next page. You will probably not be able to find the volcanoes themselves, but you can find the islands, states, countries, or areas where the volcanoes are located.

5. Mark these locations with a V on your outline map.

6. Repeat step 3 above for all of the Vs.

Analysis

1. Describe the figures that resulted from the joined Qs and the joined Vs.
2. What relationship exists between earthquake zones and volcano zones on your map?
3. How do the earthquake and volcano zones compare with plate boundaries shown on the map in Chapter 2?
4. At which of the three types of plate boundaries are all of the volcanoes and earthquakes located?
5. What other surface feature is likely to be near the volcanoes on your map?
6. Why do you think the area around the Pacific is called "The Ring of Fire"?

a)

Areas of Frequent Earthquakes	Volcanoes
Acapulco, Mexico	Tacora, Chile
Aleutian Islands	Misti, Peru
Anchorage, Alaska	Mt.St. Helens, U.S.A
Concepcion, Chile	Osorno, Chile
Costa Rica	Paricutin, Mexico
Ecuador	Pogromni, Aleutian I
Fiji Islands	Sangay, Ecuador
Los Angeles, California, USA.	Sta.Maria, Guatemala
New Guinea	Ruapehu, New Zealand
Nicaragua	Taal, Philippines
New Zealand	Wrangell, Alaska
Portland, Oregon, USA.	Koryakskaya, Pacific
San Francisco, California, USA.	Coast of Russia
Santiago, Chile	
Yokohama, Japan	

A) REPORT

• ERUPTIONS AND THEIR PRODUCTS

Extracted from "FACING GEOLOGIC AND HYDROLOGIC HAZARDS", U.S. Geological Survey, Professional Paper 1240-B

Volcanic eruptions can be broadly classed as non-explosive or explosive. Nonexplosive eruptions are generally caused by an iron and magnesium-rich magma (molten rock) that is relatively fluid and allows gas to escape readily. Lava flows that are common on the island of Hawaii are the characteristics product of nonexplosive eruptions. Explosive eruptions, in contrast, are violent and are derived from a silica-rich magma that is not very fluid; these eruptions are common at volcanoes in the volcanic chain of Alaska. Explosive eruptions produce large amounts of fragmental debris in the form of airfall ash, pyroclastic flows, and mudflows on and beyond the flanks of the volcanoes.

Tephra is one of the products of an eruption. Tephra is a term used to describe rock fragments of all sizes erupted into the air above a volcano, often in a vertical column that reaches into the outer layer of the stratosphere. Large rock fragments generally fall back onto, or near, the volcano. Small fragments are carried away by wind and fall to the ground at a distance determined by the grain size and density, the height to which the fragments are erupted, and the velocity of the wind. Eruption of a large volume of tephra will cause a distinct layer of ash to accumulate. The spatial distribution of ash accumulation is generally in the form of a lobe which is thickest directly downwind from the volcano and thinnest toward the boundaries; the thickness decreases as distance from the volcano increases. Tephra can endanger lives and damage property at considerable distances from a volcano by forming a blanket at the ground surface and by contaminating the air with abrasive particles and corrosive acids. Close to a volcano, people can be injured or killed by breathing tephra- laden air; damage to property is caused by the weight of tephra and its smothering and abrasive effects.

Hot fragments and gases can be ejected laterally at high speed from explosive volcanoes and can be extremely dangerous. Lateral blasts, the term for the phenomenon, commonly leaves deposits that are no more than 3 to 6 feet thick near their source vent; these deposits thin rapidly as distance from the vent increases. They generally do not extend more than several kilometers from the vent, but occasionally a blast can reach as far as about 25 kilometers. Lateral blasts endanger people chiefly because of their heat, rock fragments carried, and high speed which may not allow sufficient time for them to escape or to find adequate cover. Damage to structures results chiefly from impact and high-speed "wind". Lateral blast phenomenon can grade outward to pyroclastic flows that move down slopes. The effects of the two events are similar.

Pyroclastic flows are masses of hot dry rock debris that move like a fluid. They owe their mobility to hot air and other gases mixed with the debris. They often form when large masses of hot rock fragments are suddenly erupted onto a volcano's flanks. Pyroclastic flows can move downslope at speeds of as much as 160 kilometers per hour and tend to follow and bury valley floors. Clouds of hot dust generally rise from the basal coarse part of the flow and may blanket adjacent areas, especially downwind. Because of their great mobility, pyroclastic flows can affect areas 25 kilometers or more from a volcano. The principal losses from a pyroclastic flow are caused by the swiftly moving basal flow of hotrock debris, which can bury and incinerate everything in its path, and the accompanying cloud of hot dust and gases, which can extend beyond the basal flow and cause asphyxiation and burning of the lungs and skin.

Mudflows are masses of water-saturated rock debris that move down slopes in a manner resembling the flowage of wet concrete. The debris is commonly derived from masses of loose unstable rock deposited on the flanks of a volcano by explosive eruptions; the water may be provided by rain, melting snow, a crater lake, or a lake or reservoir adjacent to the volcano. The speed of mudflows depends mostly on their fluidity and the slope of the terrane; they sometimes move 80 kilometers or more down valley floors at speeds exceeding 35 kilometers per hour. Mudflows may reach even greater distances than pyroclastic flows, about 90 kilometers from their sources. The chief threat to man is burial. Structures can be buried or swept away by the vast carrying power of the mudflow.

Lava flows are generally erupted quietly, although they are often preceded by explosive volcanic activity. Lava flows typically appear only after an eruption has been in progress for hours, days, or a few weeks, rather than at the outset of the eruption. The fronts of lava flows usually advance at speeds ranging from barely perceptible to about as fast as a person can walk. Lava flows typically cause no direct danger to human life, but they generally cause total destruction in the areas they cover. Lava flows that extend into areas of snow may melt it and cause floods and mudflows; lava flows that extend into vegetated areas can start fires. On large central-vent volcanoes lava flows generally are short; therefore, lava-flow hazard zones include only the flanks of the volcano and the nearest 2 to 3 kilometers of adjacent valleys and basins.

Flood-hazard zones extend considerable distances down some valleys. Losses from a volcanic eruption can be reduced in several ways. These include (1) use of knowledge of the past eruptive activity of a volcano to define the potential kinds, scales, locations, extents, effects, and severity of future eruptions and to define hazard zones, (2) establishment of monitoring systems to forecast an impending eruption and to provide warning, (3) disaster preparedness and emergency evacuation, (4) protective measures, (5) risk assessment and land-use planning, (6) insurance, and (7) relief and rehabilitation.

B) CHAPTER SUMMARY

- Most earthquakes are a result of the movement of rocks along a fault.
- Most earthquakes occur near plate boundaries.
- Numbers on the Richter scale indicate the strength of an earthquake.
- P-waves, S-waves, and L-waves carry energy away from the focus of an earthquake.
- Seismographs detect and record seismic waves.
- Rocks form inside the earth and on the surface of the earth because of volcanic activity.
- Most volcanic activity on the earth's surface is near plate boundaries.
- A volcano is called active, dormant, or extinct depending upon its history of eruptive behavior.
- Cinder cones, shield cones, composite cones, and volcanic domes are different types of volcanoes.

C) QUESTION/PROBLEMS

1. What causes earthquakes in the middle of a plate?
2. Explain what is meant by a deep focus earthquake.
3. Why do scientists think that the outer core of the earth is liquid?
4. What causes volcanoes to occur on island arcs?
5. List four signs that might help scientists predict an earthquake.
6. How can you tell that a fault releases energy?
7. Where do most deep focus earthquakes occur?
8. What increase in energy is an increase of one number on the Richter scale?
9. Where did the strongest recorded earthquakes occur?
10. Which two seismic waves move through the earth?
11. Why do scientists need three seismograph readings to find an earthquake?
12. What might the slowing of P-waves indicate?
13. What is a batholith?
14. What is a fissure in the earth?
15. How does an island arc form?
16. What is an extinct volcano?
17. Which of the types of cones is not steep-sided?

D) CHAPTER TEST

A. Vocabulary. Match the definition in Column I with the term it defines in Column II, on the left margin between the brackets.

	Column I	Column II
( )	1. a volcano that has not erupted recently	a. aftershock
R( )	2. a series of small earthquakes that follow a large one	b. batholith
		c. dormant
( )	3. a volcano that is not expected to erupt again	d. epicenter
( )	4. the way in which energy travels through the earth	e. extinct
( )	5. the point on the earth's surface which is above the focus of an earthquake	f. extrusive
		g. seismic wave
( )	6. an instrument that detects seismic waves from distant earthquakes	h. focus
		i. laccolith
( )	7. volcanic activity that takes place at the surface of the earth	j. seismograph

B. Multiple Choice. Choose the letter that best completes the statement or answers the question, and write it on the column at the left margin between the brackets.

( ) 1. To locate the epicenter of an earthquake, scientists need at least

a) one seismograph report
b) two seismograph reports
c) three seismograph reports
d) four seismograph reports

( ) 2. A mushroomed-shaped intrusive rock mass is a

a) laccolith
b) stock
c) sill
d) volcanic dome

( ) 3. Most magma reaches the surface at

a) trenches
b) mid-oceanic ridges
c) faults
d) island arcs

( ) 4. When old ocean crust moves under younger ocean crust, the resulting volcanoes are

a) flood basalts
b) continental volcano chains
c) new ocean floors
d) on island arcs

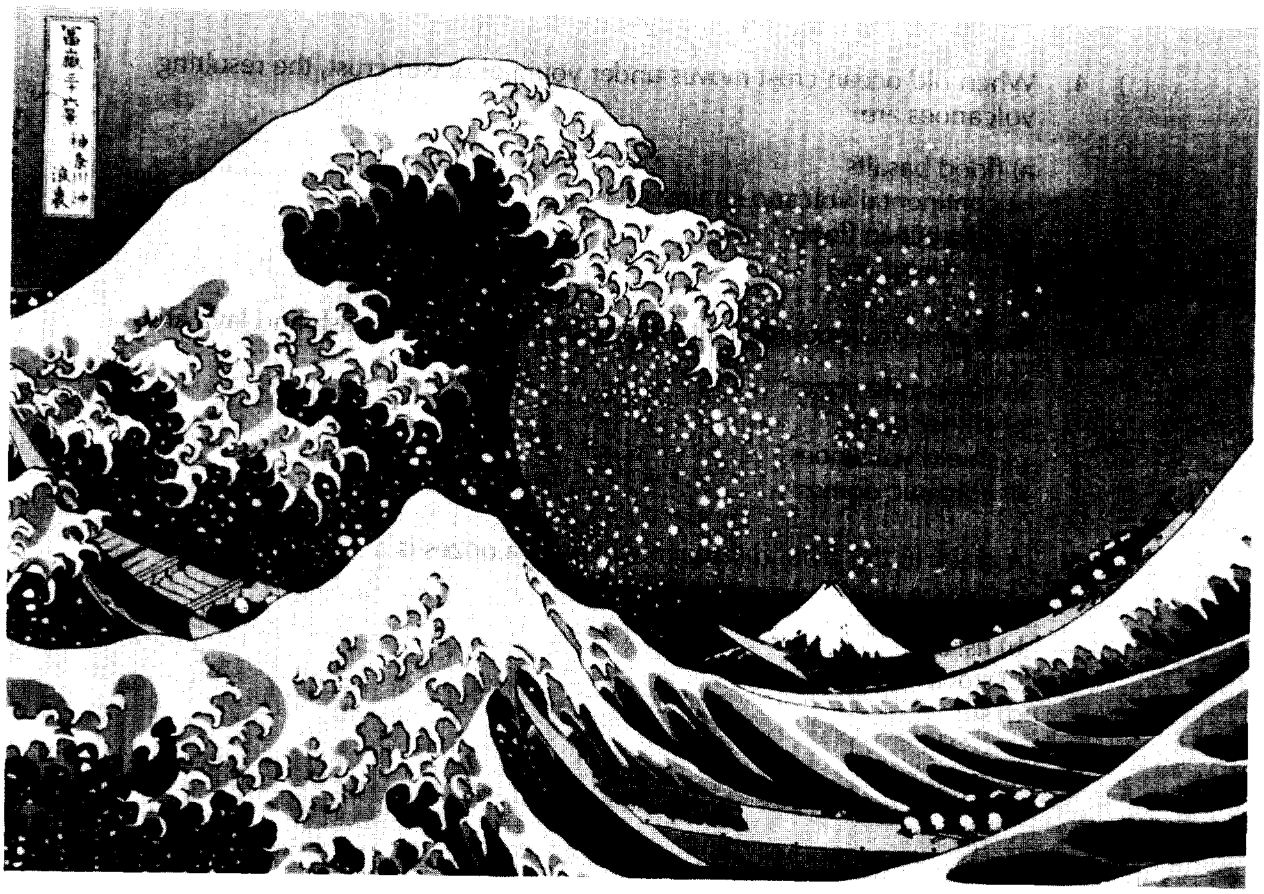
( ) 5. Volcanoes composed of alternating layers of volcanic ash and lava are

a) composite cones
b) cinder cones
c) shield volcanoes
d) volcanic domes

( ) 6. A crack in the ground through which lava oozes is a

a) trench
b) fissure
c) stock
d) sill

TSUNAMI



CHAPTER 4

TSUNAMIS

The earth is covered like an armored reptile with enormous stony slabs which drift on the denser material of the mantle, slabs that are constantly being destroyed and renewed in the processes of "plate tectonics" which we studied in Chapter 2. Nowhere are these processes more in evidence than along the belt of frequent earthquakes and volcanic eruptions that rings the Pacific Ocean.

These earthquakes, the destructive offspring of larger forces shaping and reshaping planet earth, have destructive oceanic offspring of their own - the great waves of the Pacific.

Every island and coastal settlement in the Pacific Ocean area are vulnerable to the onslaught of the great waves.

Some people call them "tidal waves", a name as misleading as it has been persistent. The great waves are not related to the tides. The Japanese, whose islands have felt their destructive power for generations, gave us the name used internationally: tsunami (pronounced " soo-nah'-me")

CHAPTER OBJECTIVES

1. Describe the tsunami waves.
2. Explain the origin of the phenomenon's name.
3. Define the generation mechanisms.
4. Define transformations of a tsunami along its path from the origin area.
5. Describe tsunami effects on the coast.
6. Describe the Tsunami Warning System.

4.1 WHAT IS A TSUNAMI?

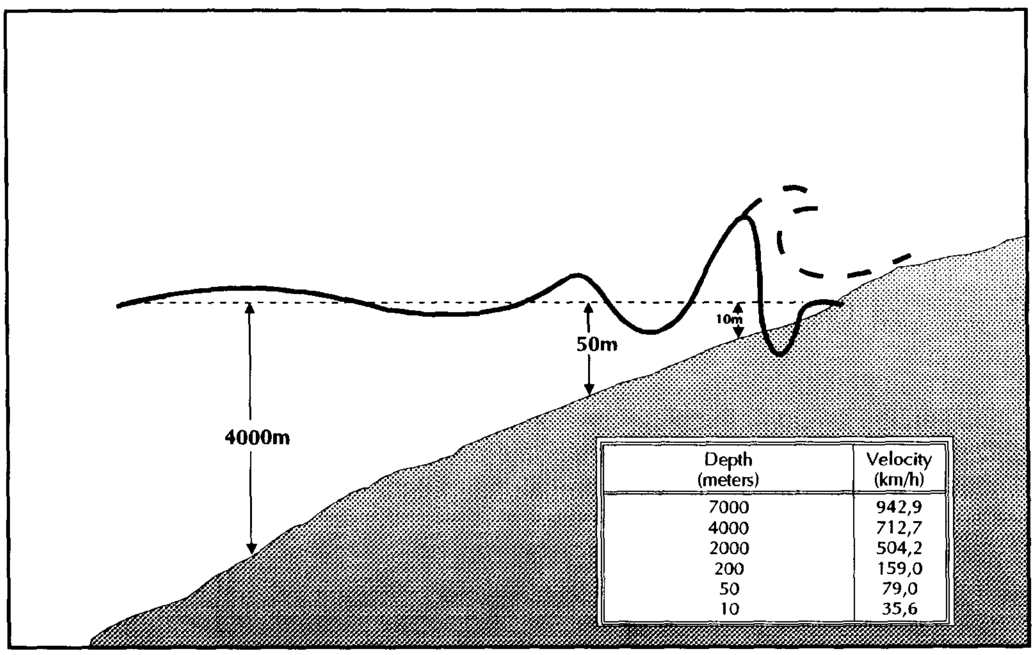
Unlike exaggerated or fictionalized accounts, a tsunami is NOT a single, monstrous wall of water that rises mysteriously out of nowhere to engulf a ship or a coastal community. It is, however, one of nature's most awesome forces - a series of sea waves capable of racing across an entire ocean at speeds up to 900 km per hour.

At sea, tsunami waves are less than 60 cm high - not even perceptible from ships or planes. By contrast, their length is often more than 160 km long, much greater than the water depth over which they travel.

There is no such thing as a typical tsunami. Each one is different. Still, tsunamis are collectively unique in the amount of energy they contain, even when compared to the most powerful, wind-driven waves.

A tsunami "feels the bottom" even in the deepest ocean, and it appears that the progress of this imperceptible series of waves represents the movement of the entire vertical section of ocean through which the tsunami passes.

As the tsunami enters the shoaling water of coastlines in its path, the velocity of its waves diminishes and the wave heights increases as seen in the diagram.



Depth (meters)	Velocity (km/h)
7000	942,9
4000	712,7
2000	504,2
200	159,0
50	79,0
10	35,6

Tsunami wave modifications.

The arrival of a tsunami is often heralded by a gradual recession of coastal water, when the trough precedes the first crest; or by a rise in water level of about one-half the amplitude of the subsequent recession. This is nature's warning that more severe tsunami waves are approaching. It is a warning to be heeded, for tsunami waves can crest to heights of more than 30 meters, and strike with devastating force.

DO YOU KNOW...?

Tsunami is a Japanese word. You say it: soo-nah'-me. Break it in half: "tsu" means harbor and "nami" means wave.

Japanese scientists were the first to conduct specialized studies of tsunamis. Their eastern coast receives the most tsunami activity in the world, and that likely explains why the Japanese word is adopted internationally.

Other lesser used words for tsunami are:

- flutwellen (German)

- vloedgolven (Dutch)

- hai-i (Chinese)

- maremoto (Spanish)

- raz de maree (French)

- vagues sismiques (French)

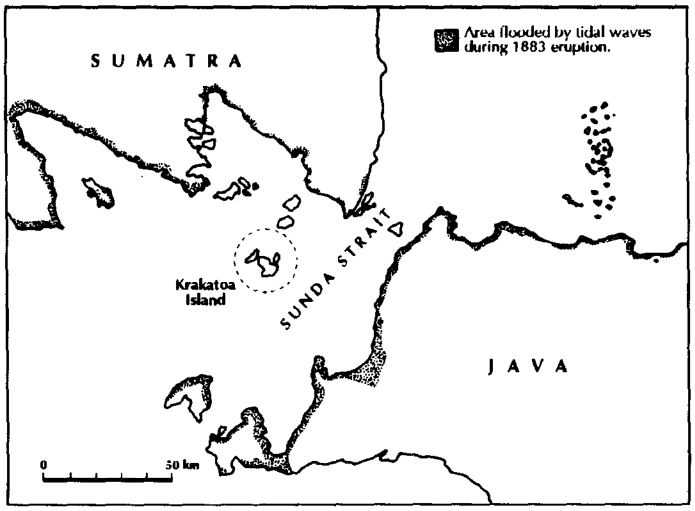
- tidal waves (English)

- seismic sea waves (English)

4.2 WHAT CAUSES A TSUNAMI?

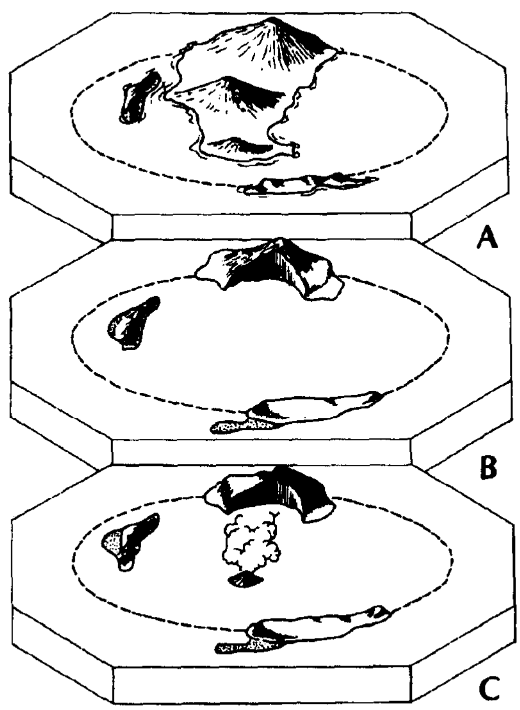
Natural disturbances, like earthquakes, volcanic eruptions and landslides, may cause tsunamis. Man-made disturbances, such as the underwater atomic explosions of 1946, can also set off the powerful waves, but the most frequent cause, by far, is the earthquake.

• VOLCANO-GENERATED TSUNAMI



Krakatoa island place.

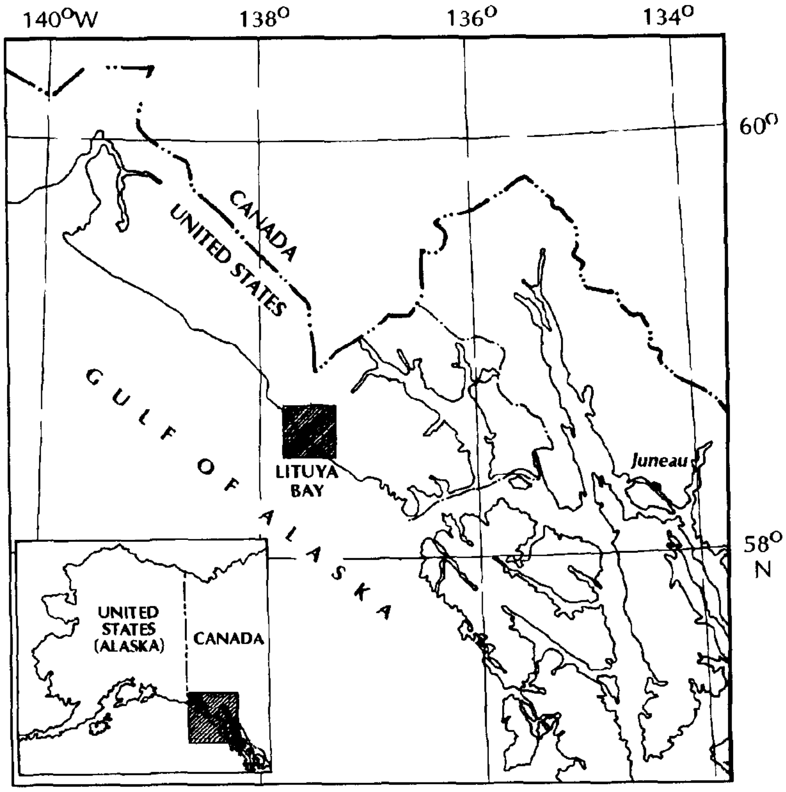
In 1883, a series of volcanic eruptions at Krakatau in Indonesia created a powerful tsunami. As it rushed towards the islands of Java and Sumatra, it sank more than 5,000 boats and washed away many small islands. Waves as high as a 12-story buildings wiped out nearly 300 villages and killed more than 36,000 people. Scientist believe that the seismic waves traveled two or three times around the Earth.



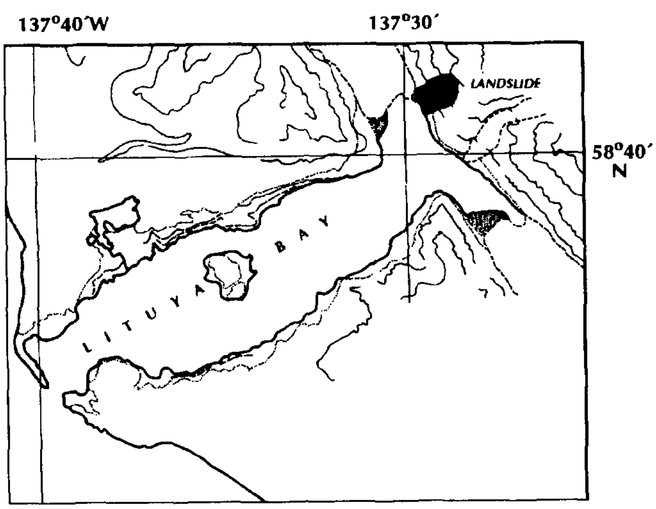
Krakatoa island evolution during 1883 eruption.

• LANDSLIDE-GENERATED TSUNAMI

About 81 million tones of ice and rock crashed into Lituya Bay, Alaska in 1958. An earthquake had shaken the enormous mass loose. The landslide created a tsunami which sped across the bay. Waves splashed up to an astonishing height of 350 to 500 metres - the highest waves ever recorded. They scrubbed the mountain slope clean of all trees and shrubs. Miraculously, only two fishermen were killed.



Lituya bay place.



Lituya bay.

• EARTHQUAKE-GENERATED TSUNAMI

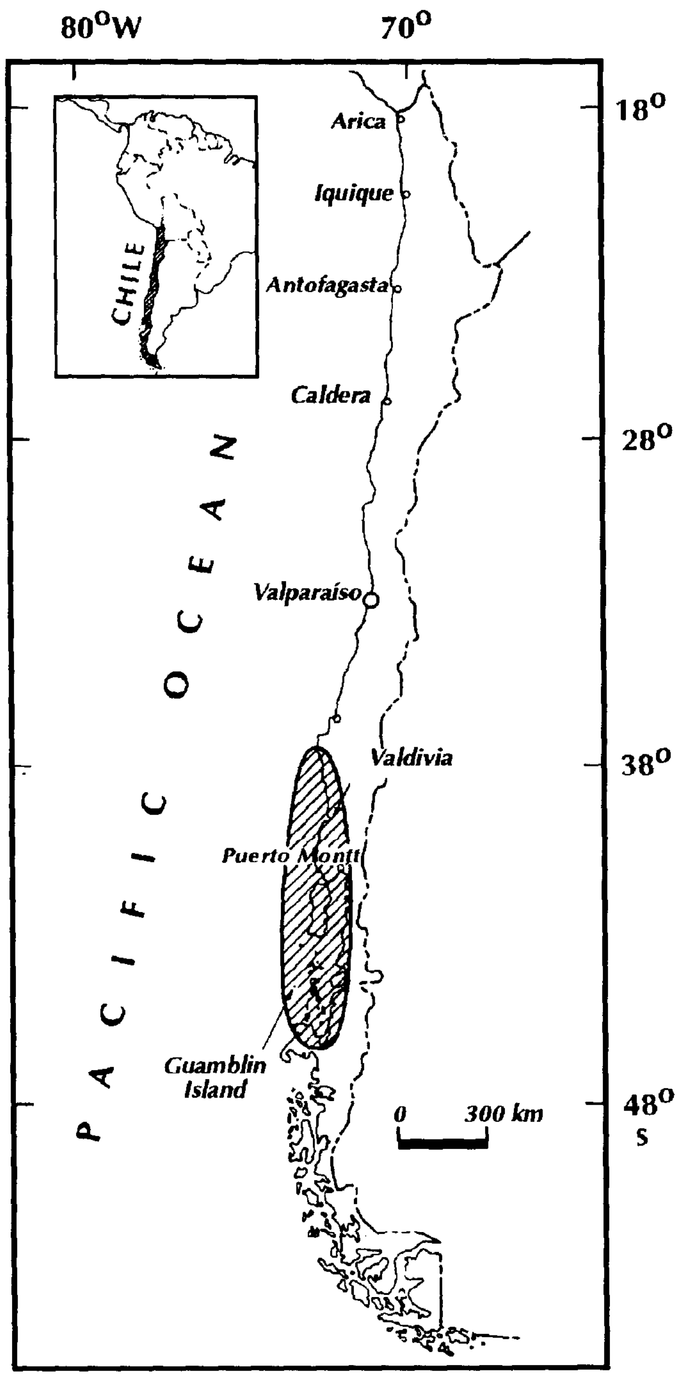
The most destructive tsunami in recent history was generated along Chile's coast by an earthquake in May 22, 1960.

It is not possible to describe in detail the damaged and death related to this tsunami along the coast of Chile, however, every coastal town between latitudes 36S and 44S was destroyed or severely damaged by the action of the tsunami and the earthquake.

In Chile, the double combination of earthquake and tsunami produced more than 2,000 deaths, 3,000 injured, two million homeless, and damage worth $550 million (US). The tsunami caused 61 deaths in Hawaii, 20 in the Philippines, 3 in Okinawa, and more than 100 in Japan.

Estimated damages were $50 million in Japan, $24 million in Hawaii, and $1 million along the coast of the United States.

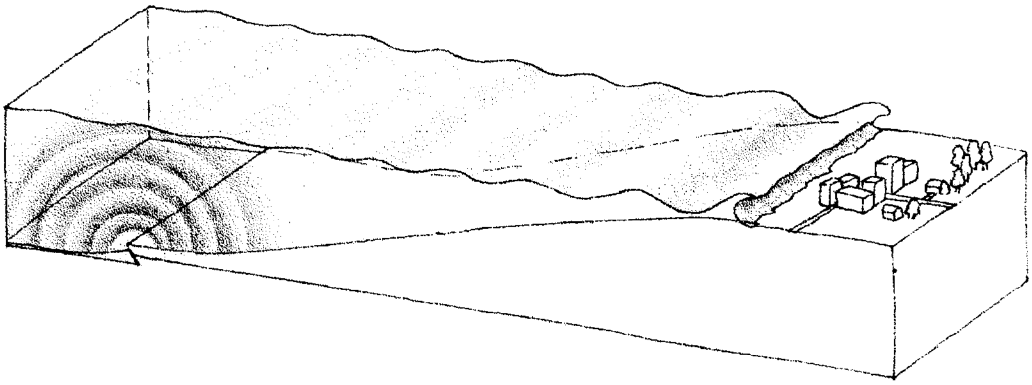
The height of the waves ranged from 13 meters at Pitcairn Islands, 12 meters at Hilo, Hawaii, and 7 meters at several places in Japan, to minor oscillations in other areas.



Area affected by the tsunami of May 22, 1960.

4.3 GENERATION OF TSUNAMIS

Current thinking is that tsunamis are generated by a sudden vertical motion along faults during major earthquakes, as seen in the diagram.



Tsunami generation by vertical movement of the ocean floor.

In the case of submarine earthquakes, the generation mechanism of the tsunami waves is as follows: when the earthquake occurs there is a noticeable displacement of the oceanic crust; a sudden upheaval or subsidence of the ocean floor may be produced; if this happens, the sea surface over the ocean floor deformation area will show a similar deformation, but while the ocean floor deformation is permanent, the sea surface deformation is not.

Although earthquakes that occur along horizontal faults sometimes generate tsunamis, they are local and generally do not propagate long distances. Some scientists pointed out that major earthquakes along horizontal faults near the coast of Alaska and British Columbia generated tsunamis that were observable at distances no greater than 100 km.

As already mentioned, tsunamis usually occur following a large shallow earthquake beneath the ocean. However, there are a number of instances where the earthquake (that produced the tsunami) occurred inland. Hence, one must deduce that tsunamis can be generated either by changes of sea bottom (i.e. faulting) or by the seismic surface waves passing across the shallow continental shelf. The long-period, surface waves (the so-called Rayleigh waves) have a vertical component and transmit a significant portion of the earthquake energy.

The return of the sea level to its normal position generates a series of waves propagating in all directions from the initially deformed area.

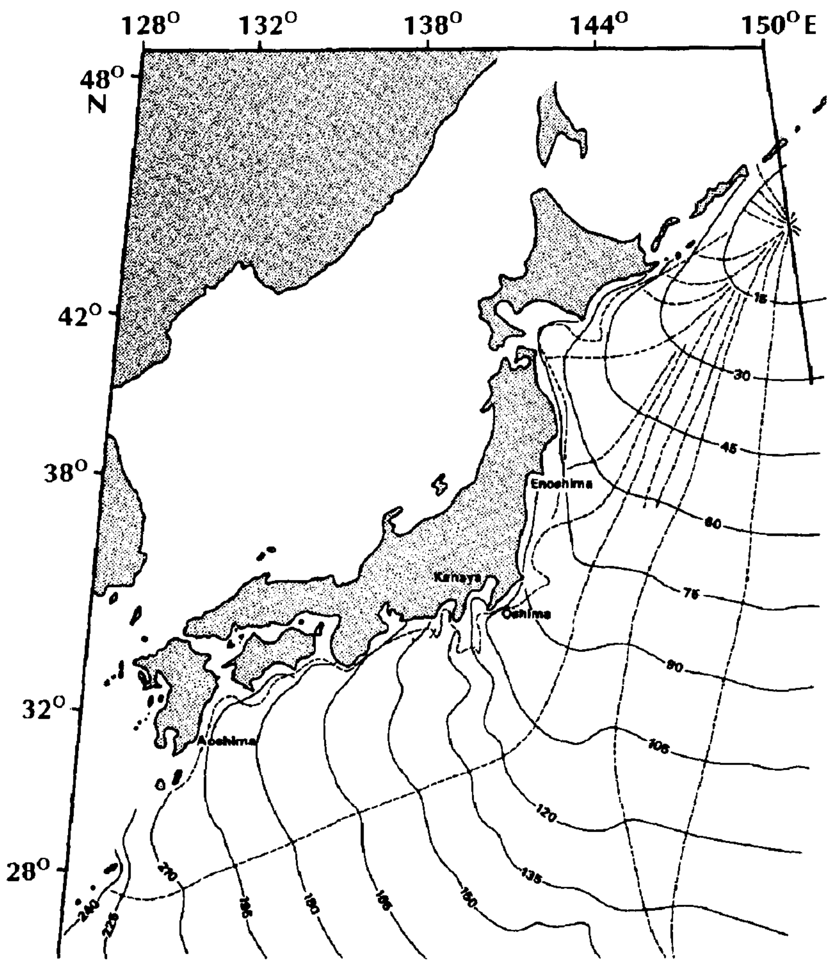
4.4 TSUNAMI PROPAGATION

The speed at which the tsunami travels depends on the water depth. If the water depth decreases, tsunami speed decreases. In the mid-Pacific, where the water depths reach 4.5 kilometers, tsunami speeds can be more than 900 kilometers per hour.

Some general concepts regarding refraction, and diffraction of water waves will be considered. These phenomena are important to the tsunami propagation problem.

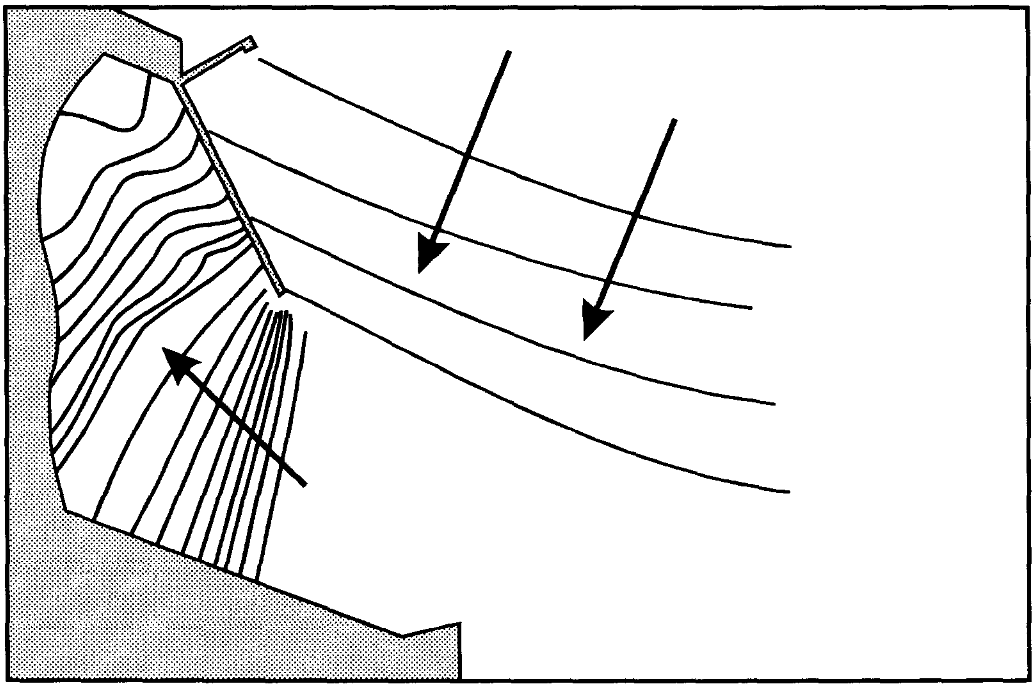
WAVE REFRACTION: Consider progressive waves with wavelengths much larger than the water depths over which they propagate. These are called shallow-water or long waves. Because the waves are long, different parts of the wave might be over widely varying depths (especially in coastal areas) at a given instant.

As depth determines the velocity of long waves, different parts travel with different velocities, causing the waves to bend, and this is called wave refraction.



Examples of refraction of tsunami waves.

DIFFRACTION OF WATER WAVES: Diffraction is a well-known phenomenon, especially concerning optics and acoustics. This phenomenon can be considered as the bending of waves around objects. It is this kind of movement that allows waves to move past barriers into harbors as energy moves laterally along the crest of the wave as shown in the drawing below. This bending is on a much smaller scale and is less easily explained than the bending discussed in refraction which is a simple response to changes in velocity.

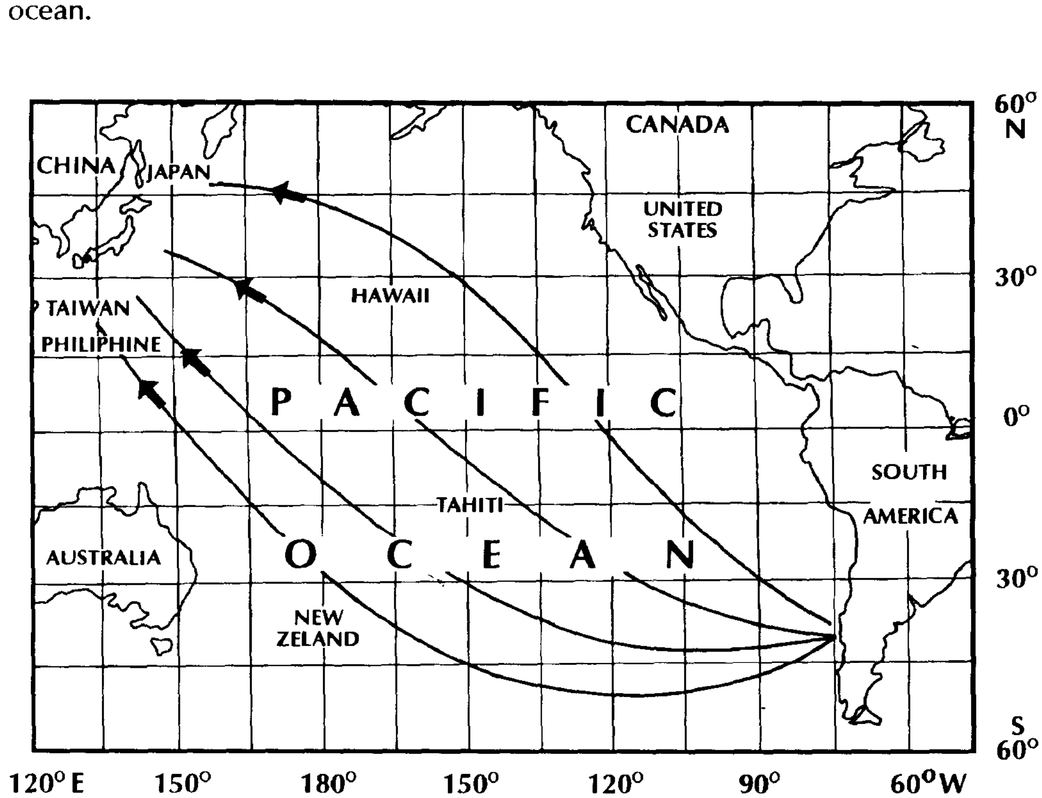


Examples of difraction of waves..

• DISTANTLY GENERATED TSUNAMIS

When a tsunami travels a long distance across the ocean, the sphericity of the Earth must be considered to determine the effects of the tsunami on a distant shoreline. Waves which diverge near their source will converge again at a point on the opposite side of the ocean. An example of this was the 1960 tsunami whose source was on the Chilean coastline, 39.5S., 74.5W. The coast of Japan lies between 30 and 45N. and about 135 to 140 E., a difference of 145 to 150 longitude from the source area. As a result of the convergence of unrefracted wave rays, the coast of Japan suffered substantial damage and many deaths occurred. Next figure illustrates the convergence of the wave rays due to the Earth's sphericity.

Remember that besides the already mentioned effect, the rays of the tsunami waves are also deviated from their natural path along maximum circles, due to refraction of the rays because of depth differences, to paths given by deeper places. The effect of this refraction over long distance generated tsunami waves is that not always the tsunami waves will converge on the other side of the ocean.

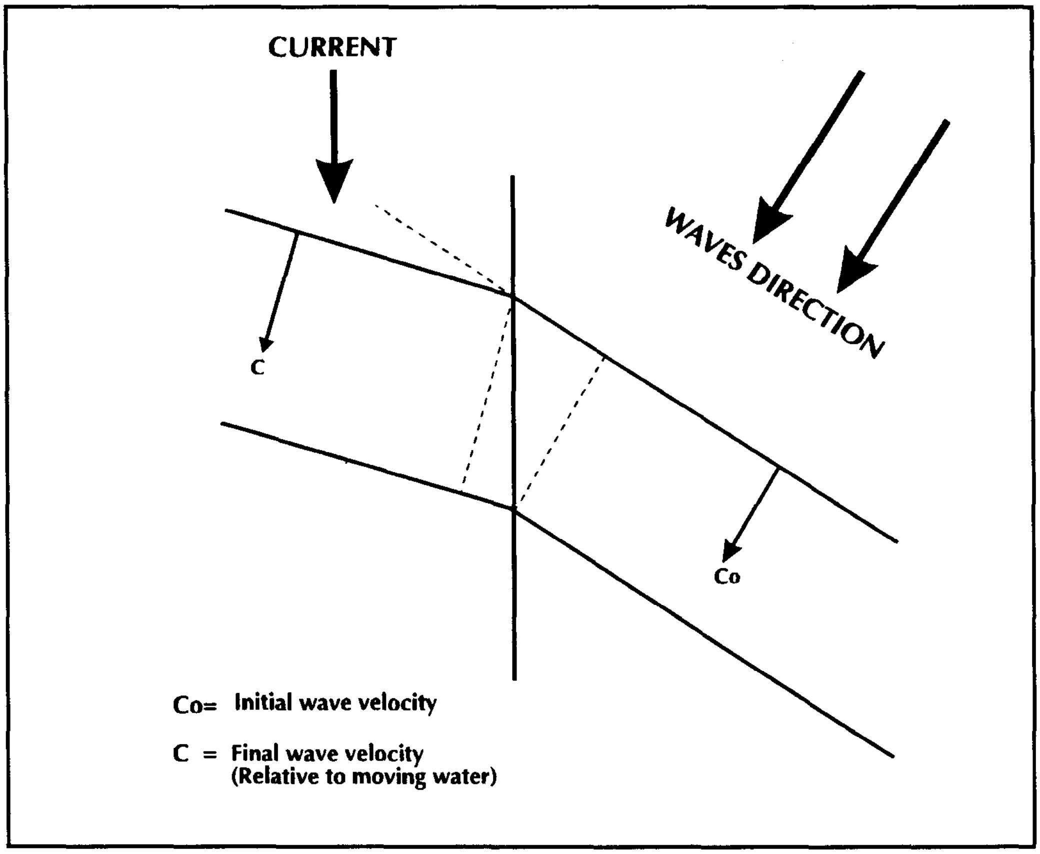


Convergence of tsunami wave rays generated by the 1960 Chilean earthquake.

There are other mechanism that cause refraction of water waves, even in deep water and without topographical irregularities. It has been shown that a current moving obliquely to the waves can change their direction of propagation and wavelength.

As a tsunami approaches a coastline, the waves are modified by the various offshore and coastal features. Submerged ridges and reefs, the continental shelf, headlands, the shapes of bays, and the steepness of the beach slope may modify the wave period and wave height, cause wave resonance, reflect wave energy, and/or cause the waves to form bores which surge onto the shoreline.

Ocean ridges provide very little protection to a coastline. While some amount of the energy in a tsunami might reflect from the ridge, the major part of the energy will be transmitted across the ridge and onto the coastline. The 1960 tsunami which originated along the coast of Chile is an example of this. That tsunami had large wave heights along the entire coast of Japan, including the islands of Shikoku and Kyushu which lie behind the South Honshu Ridge.



Refraction by a current.

• LOCAL TSUNAMIS

When a locally generated tsunami occurs, it impacts coastal areas a very short time after the event which produced the tsunami (earthquake, submarine volcanic eruption or landslide). Lapses as short as two minutes have been observed between the earthquake's occurrence and the tsunami arrival to the closest shore.

Because of this, a tsunami warning system is useless in this type of event and we should not expect instructions from an established system to react and keep us safe from the possible tsunami impact. This operation incapability of the warning systems is further increased by the communications and systems collapse generated by the earthquake. Hence, it is necessary to have prepared a proper response plan in case of a tsunami.

4.5 COASTAL EFFECTS

Tsunami wave action over the shore is variable and mainly dependent of the combination of both submarine and land topography in the area and the orientation of the arriving waves.

• WAVE HEIGHT

The height of the waves is also affected by the shore itself. The funneling effect of a bay, for instance, increases the height of the waves. On the other hand, a shoal or sandbar offshore decreases the height. This explains the wide variation in tsunami heights that usually occur along a single coast.

• TSUNAMI RUNUP ON A SHORELINE

The arrival of a tsunami at a shoreline may cause an increase in water level of 30 meters or more in extreme cases. Increases of 10 meters are not uncommon. This vertical increase in the height of the water level is called the tsunami runup height.

The height of a tsunami will vary from point to point along a coastline. Variations in tsunami height and shoreline topography will actually cause some variation in runup characteristics along any section of coastline.

An example of how extreme this variation can be is given by some scientists; on the island of Kauai, Hawaii, where there was a gentle rise of water level on the western side of the bay, but less than one mile to the east, waves rushed onshore, flattening groves of trees and destroying houses.

It should be noted that the characteristics of the waves may vary from one wave to another at the same coastal point. Some scientists cite a case in Hawaii where the first waves came in so gently that a man was able to wade through chest-high water ahead of the rising water. Later waves were so violent that they destroyed houses and left a line of debris against trees 150 meters inland.

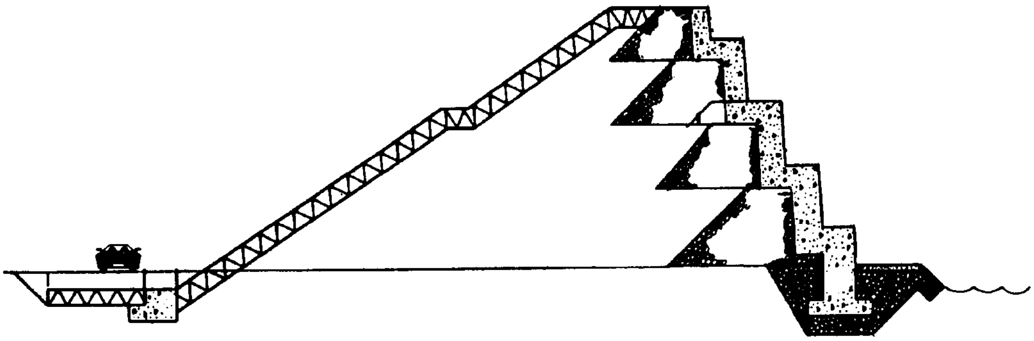
• TSUNAMI IMPACT

The destruction caused by tsunamis stems mainly from the impact of the waves, the flooding, and the erosion of foundations of buildings, bridges and roads. Damage is magnified by floating debris, boats, and cars that crash into buildings. Strong currents, sometimes associated with tsunamis, add to the destruction by freeing log booms, barges and boats at anchor.

Additional damage takes the form of fires from tsunami-related oil spills, and pollution from released sewage and chemicals.

4.6 PROTECTION FROM TSUNAMIS

It is impossible to fully protect any coast from the ravages of tsunamis. Countries have built breakwaters, dikes and various other structures to try to weaken the force of tsunamis and to reduce their height. In Japan, engineers have built broad embankments to protect ports, and breakwaters to narrow harbor mouths in an effort to divert or reduce the energy of the powerful waves.



Type of breakwater designed as protection of low-lying coasts.

But no defense structures have been able to protect the low-lying coasts. In fact, barriers can even add to the destruction if a tsunami breaks through, hurtling chunks of cement about like missiles.

In some instances, trees may offer some protection against a tsunami surge. Groves of trees alone, or as supplements to shore protection structures, may dissipate tsunami energy and reduce surge heights.

4.7 THE TSUNAMI WARNING SYSTEM

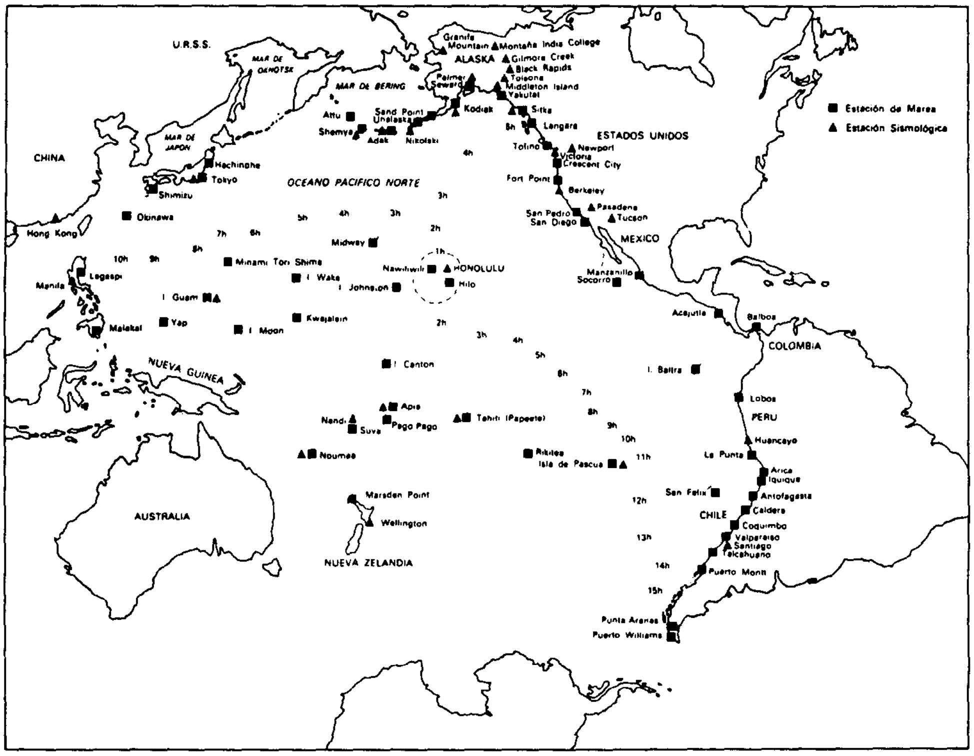
• OBJECTIVE

The operational objective of the Tsunami Warning System (TWS) in the Pacific is to detect and locate major earthquakes in the Pacific Region, to determine whether they have generated tsunamis, and to provide timely and effective tsunami information and warnings to the population of the Pacific to minimize the hazards of tsunamis - especially to human life and well being. To achieve this objective, the TWS continuously monitors the seismic activity and ocean surface level of the Pacific Basin.

• DESCRIPTION

The TWS is an international program requiring the participation of many seismic, tidal, communication, and dissemination facilities operated by most of the nations bordering the Pacific Ocean. Administratively, participating nations are organized under the Intergovernmental Oceanographic Commission as the International Coordination Group for the Tsunami Warning System in the Pacific (ICG/ITSU). The International Tsunami Information Center was established upon request of IOC and serves many roles in assisting ICG/ITSU member nations in mitigating the effects of tsunamis throughout the Pacific. The Pacific Warning Center (PTWC) serves as the operational center for the Tsunami Warning System of the Pacific.

PTWC collects and evaluates data provided by participant countries, and issues appropriate informational bulletins to all participants regarding the occurrence of a major earthquake and possible or confirmed tsunami generation.



Seismic and tide stations of the Tsunami Warning System of the Pacific.

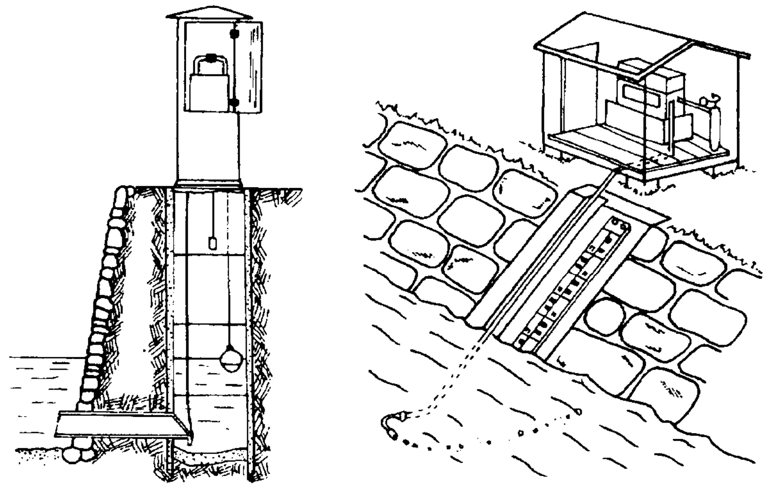
• OPERATIONAL PROCEDURES

The functioning of the System begins with the detection, by any participating seismic observatory, of an earthquake of sufficient size to trigger the alarm attached to the seismograph at that station. Personnel at the station immediately interpret their seismograms and send their readings to PTWC. Upon receipt of a report from one of the participating seismic observatories or as a consequence of the triggering of their own seismic alarm, PTWC send messages requesting data to other observatories in the System.

When sufficient data have been received for PTWC to locate the earthquake and compute its magnitude, a decision is made concerning further action. If the earthquake is strong enough to cause a tsunami and is located in an area where tsunami generation is possible, PTWC will request participating tidal stations located near the epicenter to monitor their gauges for evidence of a tsunami.

Tsunami Warning/Watch Bulletins are issued to the dissemination agencies for earthquakes of magnitude 7.5 or greater (7.0 or greater in the Aleutian Island region), alerting them to the possibility that a tsunami has been generated and providing data that can be relayed to the public so that necessary preliminary precautions can be taken.

Reports received from tidal stations are evaluated; if they show that a tsunami has been generated that poses a threat to the population in part or all of the Pacific, the Tsunami Warning/Watch Bulletin is extended or upgraded to a Warning for the whole Pacific. The dissemination agencies then implement predetermined plans to evacuate people from endangered areas. If the tidal station reports indicate that either a negligible tsunami or no tsunami has been generated, PTWC issues a cancellation of its previously disseminated Tsunami Warning/Watch.



FLOAT TYPE TIDE STATION BUBBLER TYPE TIDE STATIONS

Tide gauges.

In some areas of the Pacific Basin national or regional tsunami warning systems function to provide timely and effective tsunami information and warnings to affected populations. For those coastal areas nearest the tsunami source region, the need for rapid data handling and communications becomes obvious. Because of the time spent in collecting seismic and tidal data, the warnings issued by PTWC cannot protect all areas in the Pacific against tsunamis generated in adjacent waters. To provide some measure of protection within the first hour after generation of a tsunami in the local area, national and regional warnings systems have been established by some countries. Regional systems provide the earliest possible alert to the population within the immediate vicinity of the earthquake epicenter by issuing immediate warnings based on earthquake information without waiting for tsunami confirmation.

To function effectively, these regional systems generally have data from a number of seismic and tidal stations telemetered to a central headquarters. Nearby earthquakes are located, usually in 15 minutes or less, and a warning based on seismological evidence is released to the population of the area. Since the warning is issued on the basis of seismic data alone, one may anticipate that warnings occasionally will be issued when tsunamis have not been generated. Since the warnings are issued only to a restricted area and confirmation of the existence or nonexistence of a tsunami is obtained rapidly, disruptions are minimized while a higher level of protection is obtained.

Among the most sophisticated of the national systems are those of France, Japan, Russia, and the U.S.A. For the United States, PTWC and the Alaska Tsunami Warning Center (ATWC) have responsibility as the U.S. National Tsunami Warning Centers to provide tsunami warning services for any tsunami impacting U.S. national interests. In addition, PTWC acts as the Hawaii Regional Tsunami Warning Center for tsunamis generated within the Hawaiian Islands.

A) REPORTS

• TWO TSUNAMIS OUT OF THE PAST

(Extracted from DISCOVER/August 1983)

Probably the greatest tsunami of all time is shrouded in the myths of antiquity. It was born in about 1450 B.C., at the island of Thera, southeast of Greece. There, a brilliant royal city of the Minoan civilization flourished until one day the volcano on Thera exploded, blasting much of the island into the air. The resulting tsunami, some scholars have speculated, may have inspired the story of Moses' parting of the Red Sea, and the death of Thera may have been the factual basis for the fable of Atlantis related later by Plato.

A giant tsunami accompanied the catastrophic Lisbon earthquake of November 1, 1755. The quake was apparently centered in the ocean floor west of Lisbon. The waves and earthquake killed at least 60,000 people, many of whom were gathered in churches to worship on All Saints' Day. The tragedy evoked intense theological argument about the providence of God, prompted Rousseau to suggest that people would be better off out of doors, and provided a memorable episode in Voltaire's Candide.

• RIDING A TIDAL WAVE

by U.S. Navy Rear Admiral L.G. Billings

(Extracted from THE NATIONAL GEOGRAPHIC MAGAZINE, JANUARY 1915.)

It is the purpose of this article to record a thrilling experience in one of the modern earthquakes, in which a United States man-of-war was carried on the crest of a tidal wave 5 miles down the coast, 2 miles inland, and set down, entirely unharmed, upon the beach, within 100 feet of the Andes.

In 1868 I was attached to the U.S.S. "Wateree," then on duty in the South Pacific - one of a class of boats built at the close of our Civil War to ascend the narrow, tortuous rivers of the South; she was termed a "double tender," having a rudder at each end, and was quite flat-bottomed - a conformation which, while it did not add to her seaworthiness, enabled her to carry a large battery and crew, and eventually saved our lives, in the catastrophe which was soon to come upon us.

August, 1868, found us quietly at anchor off the pretty Peruvian (now Chilean) town of Arica, whiter we had towed the old United States store-ship "Fredonia" to escape the ravages of yellow fever, then desolating Callao and Lima. It was August 8, 1868, that the awful calamity came upon us, like a storm from a cloudless sky, overwhelming us all in one common ruin.

I was sitting in the cabin with our commanding officer, about 4 p.m., when we were startled by a violent trembling of the ship, similar to the effect produced by letting go the anchor. Knowing it could not be that, we ran on deck. Looking shoreward, our attention was instantly arrested by a great cloud of dust rapidly approaching from the southeast, while a terrible rumbling grew in intensity, and before our astonished eyes the hills seemed to nod, and the ground swayed like the short, choppy waves of a troubled sea.

The cloud enveloped Arica. Instantly through its impenetrable veil arose cries for help, the crash of falling houses, and the thousand commingled noises of a great calamity, while the ship was shaken as if grasped by a giant hand; then the cloud passed on.

As the dust slowly settled we rubbed our eyes and looked again and again, believing they must be playing us a trick; for where but a few short moments before was a happy, prosperous city, busy with life and activity, we beheld but a mass of shattered ruins, hardly a house left standing; not one perfect; the streets blocked with debris, through which struggled frantically the least wounded of the unhappy wretches imprisoned in the ruins of their once happy homes; while groans, cries, and shrieks for help rent the air.

Over all this horror the sun shone pitilessly from an unclouded sky; the sea rolled shoreward as steadily as before. How long did it last? No one took any note of time.

With the fresh recollection in our minds of the tidal wave that followed the earthquake at Santa Cruz and stranded one of our proudest sloops-of-war, the "Monongahela," in the streets, we anxiously scanned the sea for any unusual appearance betokening the coming of that dreaded accompaniment; but all was as calm and serene as before.

Our prudent commander, however, gave the necessary orders to prepare for the worst. Additional anchors were let go, hatches battened down, guns secured, life lines rove fore and aft, and for a few moments all was the orderly confusion *of a well- disciplined man-of-war preparing for action. Many hands make short work, and in a few moments we were prepared for any emergency.*

Looking shoreward again, we saw the uninjured thronging the beach and crowding the little pier, crying to the vessels to aid them in digging their loved ones from the ruins and to transport them to the apparent safety of the vessels riding so quietly at anchor. This was more than we could witness unmoved, and orders were given to prepare a landing party of 40 men, duly equipped with shovels, etc. The gig, a large, double-banked whaleboat, with a crew of 13 men, shoved off at once. She reached the shore and landed her crew, leaving only the customary boat-keeper in charge.

Our attention was now distracted from the formation of our working party by a hoarse murmur. Looking shoreward, to our horror we saw vacancy where but a moment before the pier had been black with a mass of humanity - all swallowed up in a moment. Amid the wreckage we saw the gig, bearing a single boat-keeper, borne by an irresistible tide toward the battlements front of the Morro, with the gallant seaman struggling to stem the current. Finding his efforts vain and certain death awaiting him, he laid in his useless oar, and, running aft to the coxswain's seat, grasped the boat flag and waved a last farewell to his shipmates as the boat disappeared forever in the froth of the cruel rock at the foot of the Andes. Thus the "Wateree" lost the only one of her crew of 235 souls on that fateful day.

But our troubles then commenced. We were startled by a terrible noise on shore, as of a tremendous roar of musketry, lasting several minutes. Again the trembling earth waved to and fro, and this time the sea receded until the shipping was left stranded, while as far seaward as our vision could reach, we saw the rocky bottom of the sea, never before exposed to human gaze, with struggling fish and monsters of the deep left high and dry. The round-bottomed ships keeled over on their beam ends, while the "Wateree" rested easily on her floor-like bottom; and when the returning sea, not like a wave, but rather like an enormous tide, came sweeping back, rolling our unfortunate companion ships over and over, leaving some bottom up and others masses of wreckage, the "Wateree" rose easily over the tossing waters, unharmed.

From this moment the sea seemed to defy the laws of nature. Currents ran in contrary directions, and we were borne here and there with a speed we could not have equaled had we been steaming for our lives. At irregular intervals the earthquake shocks recurred, but none of them so violent or long-continued as the first.

Facing the Morro, and a short distance away, a rocky islet rose some feet above the sea. On it the Peruvians had hewn a fort from the solid rock and had mounted therein two 15-inch guns, the garrison numbering some 100 souls. We were but a short distance from this fort and were fearing to be cast against its rocky sides, when suddenly we saw it disappear beneath the waves. Whether it sank or the water rose we could not tell; we only knew it vanished; and when it reappeared, after a few moments, like a huge whale, not only were the unfortunate garrison gone, but the guns and carriages as well. Imagine, if you can, how the water lifted those immense masses of iron, weighing many tons and offering no holding surface from their resting places and tumbled them out of the 8-foot parapet. It is a problem never to be solved.

Before the earthquake Arica had one of the best and most modern machine-shops between Callao and Valparaíso. Many of the machines were ponderous and properly secured on cement foundations. There were also several locomotives, cars, and many heavy castings. These all disappeared; not a vestige was left. It seems impossible they could have been swept out to sea, but assuredly they could not be found on shore.

It had now been dark for some time and we knew not where we were, the absence of the usual beacon and shore lights adding to our confusion. About 8.30 p.m. the lookout hailed the deck and reported a breaker approaching. Looking seaward, we saw, first, a thin line of phosphorescent light, which loomed higher and higher until it seemed to touch the sky; its crest, crowned with the death light of phosphorescent glow, showing the sullen masses of water below. Heralded by the thundering roar of a thousand breakers combined, the dreaded tidal wave was upon us at last. Of all the horrors of this dreadful time, this seemed the worst. Chained to the spot, helpless to escape, with all the preparations made which human skill could suggest, we could but watch the monster wave approach without the sustaining help of action. That the ship could ride through the masses of water about to overwhelm us seemed impossible. We could only grip the life-line and wait the coming catastrophe.

With a crash our gallant ship was overwhelmed and buried deep beneath a semisolid mass of sand and water. For a breathless eternity we were submerged; then, groaning in every timber, the staunch old "Wateree" struggled again to the surface, with her gasping crew still clinging to the life-lines - some few seriously wounded, bruised, and battered; none killed; not even one missing. A miracle it seemed to us then, and as I look back through the years it seems doubly miraculous now.

Undoubtedly our safety was due to the design of the ship. The ship was swept on rapidly for a time, but after a while the motion ceased, and, lowering a lantern over the side, we found ourselves on shore, but where, we knew not. Smaller waves washed about us for a time, but presently they ceased. For some time we remained at quarters; but as the ship remained stationary, and nothing new occurring, the order was given to "Pipe down," followed by the welcome order, "All hands stand by your hammocks," and such of the crew as were not on watch quietly made their way through the reopened hatches to the sodden berth deck - to sleep.
The morning sun broke on a scene of desolation seldom witnessed. We found ourselves high and dry in a little cove, or

rather indentation in the coast-line. We had been carried some 3 miles up the coast and nearly 2 miles inland. The wave had carried us over the sand dunes bordering the ocean, across a valley, and over the railroad track, leaving us at the foot of the seacoast range of the Andes. On the nearly perpendicular front of the mountain our navigator discovered the marks of the tidal wave, and, by measurements, found it to have been 47 feet high, not including the comb. Had the wave carried us 200 feet further, we would inevitably have been dashed to pieces against the mountain-side.

We found near us the wreck of a large English bark, the "Chanacelia," which had one of her anchor chains wound around her as many times as it would go, thus showing she had been rolled over and over; a little nearer the sea lay the Peruvian ship, the "America," on her bilges; and the sand was strewn with the most heterogeneous mass of plunder that ever gladdened the heart of a wrecker: Grand pianos, bales of silk, casks of brandy, furniture, clothing, hardware; everything imaginable was there.

The earthquake shocks continued at varying intervals, but none of them so violent or long-continued as at first; some of them, however, were severe enough to shake the "Wateree" until she rattled like an old kettle, and caused us to abandon the ship and camp on a considerable plateau, some 100 feet high, and overlooking the ship and wreckage. Here we had an opportunity of seeing the disastrous results of the earthquake on land. We found in some places immense fissures, many of them over 100 feet wide and of unknown depths; others were mere cracks. Some of them proved the graves of the fleeing inhabitants. In one instance, I remember, we found the body of a lady sitting on her horse, both swallowed up while fleeing for their lives. At Arica we found but desolation and death. Where once had stood that pretty little city, a flat, sandy plain stretched before us.

B) CHAPTER SUMMARY

- A tsunami is a series of ocean waves of extremely long length and period, generated by disturbances associated with earthquakes occurring below or near the ocean floor.
- Other causes of tsunamis are submarine volcanic eruptions, landslides and man-made disturbances like underwater atomic explosions.
- The speed of the tsunami waves depends on the water's depth.
- The propagation of tsunami waves is subject to refraction and diffraction.
- Tsunami waves are further modified when approaching a coastline by submerged ridges and reefs, continental shelves, headlands, the shapes of bays, and the steepness of the beach slope.
- The height of a tsunami will vary from point to point along a coastline.
- The sphericity of the Earth causes convergence of the wave rays coming from a distantly generated tsunami.
- The destruction caused by tsunamis stems mainly from the impact of the waves, the flooding and the erosion of foundations of buildings, bridges and roads.
- The operational objective of the Tsunami Warning System in the Pacific is to detect and locate major earthquakes in the Pacific Region, and to determine whether they have generated tsunamis.

C) QUESTIONS/PROBLEMS

1. Describe a tsunami.
2. Explain how a tsunami can be generated.
3. Explain the differences between a landslide-generated tsunami and an earthquake-generated tsunami.
4. Describe the modifications a tsunami wave can have when traveling from its source region.
5. Describe the Tsunami Warning System.

D) CHAPTER TEST

A. Vocabulary. Match the definition in Column I with the term it defines in Column II, on the left margin between the brackets.

Column I	Column II
( ) 1. bending of the ocean waves	a. volcano-generated tsunami
( ) 2. vertical distance between sea-level and flooded height	b. diffraction
( ) 3. long-period surface waves	c. refraction
( ) 4. tsunami produced by a submarine volcanic eruption	d. run-up
( ) 5. bending of waves behind a breakwater	e. Rayleigh waves
	f. flooding

B. Multiple Choice

Choose and mark the letter that best completes the statements or answers the question.

1. A tsunami is:

   a) a sound wave
   b) a wind driven wave
   c) a single mountrous wall of water
   d) several long waves in the ocean

2. The word tsunami means:

   a) sea waves
   b) waves in a harbor
   c) sea tremor
   d) shallow waves

3. A tsunami can be caused by:

   I) big magnitude earthquake
   II) submarine volcanic eruption
   III) landslide close to shore
   IV) atomic explosion

   a) only I and III are correct
   b) only II and IV are correct
   c) I, II, III are correct
   d) all are correct

4. Tsunamis are generally produce at:

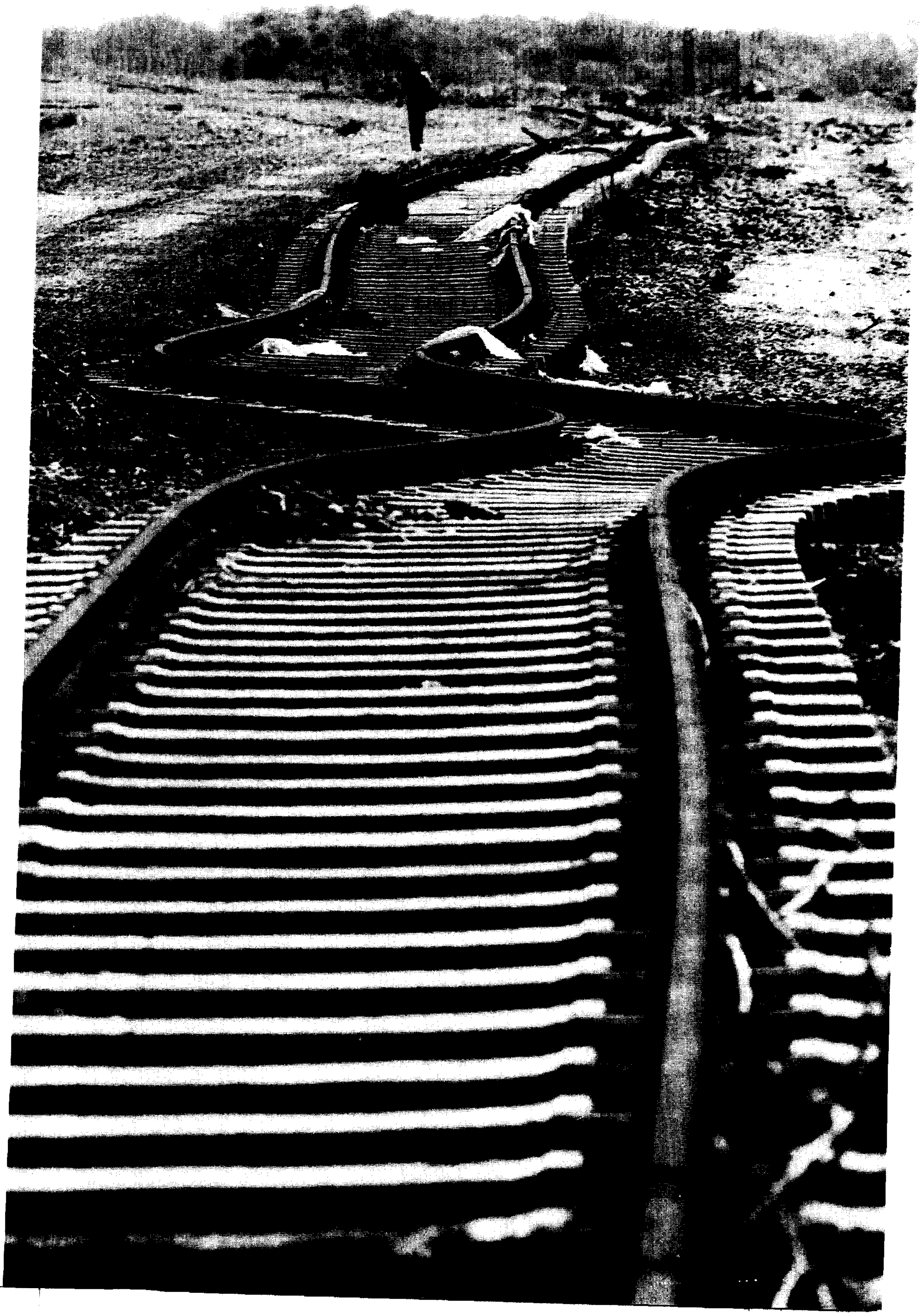
   a) mid-oceanic ridges
   b) colliding plates
   c) hot spots
   d) shield volcanoes

5. Tsunami waves are modified by:
   a) barometric pressure
   b) sea water temperature
   c) refraction
   d) hydrodynamic forces

6. Diffraction of waves is:
   a) an optical and acoustic phenomenon
   b) a change in the wave period
   c) the return of the sea level to its normal position
   d) a sea-bottom deformation

7. Good protection from tsunami impact comes from:
   a) an ocean ridge
   b) barriers
   c) groves of trees
   d) none of the above

8. The Tsunami Warning System issues a Tsunami Warning in case of:
   a) a big earthquake
   b) generation of a tsunami
   c) reports from news media
   d) a hurricane



CHAPTER 5

SEISMICITY OF THE COUNTRY

In any seismic country it is possible to determine differences in the type and frequency of the seismic events occurring in different areas. There areas where there are a lot of earthquakes of small size, and other areas where there are few earthquakes, but they are large.

This chapter describes the variation of seismicity through the country (in this case Chile), providing the main characteristics of the seismic activity in each seismic zone.

CHAPTER OBJECTIVES

1. Describe the characteristic of the earthquake's occurrence in the country.
2. Define the different ways of earthquake's occurrence in different regions of the country.
3. Describe the historical seismic activity of the country.

NOTICE

THIS CHAPTER MUST BE DEVELOPED SEPARATELY BY EVERY COUNTRY, HOWEVER CHILE'S SEISMICITY IS SHOWN AS AN EXAMPLE.

5.1 GENERAL CHARACTERISTICS OF THE SEISMICITY IN CHILE

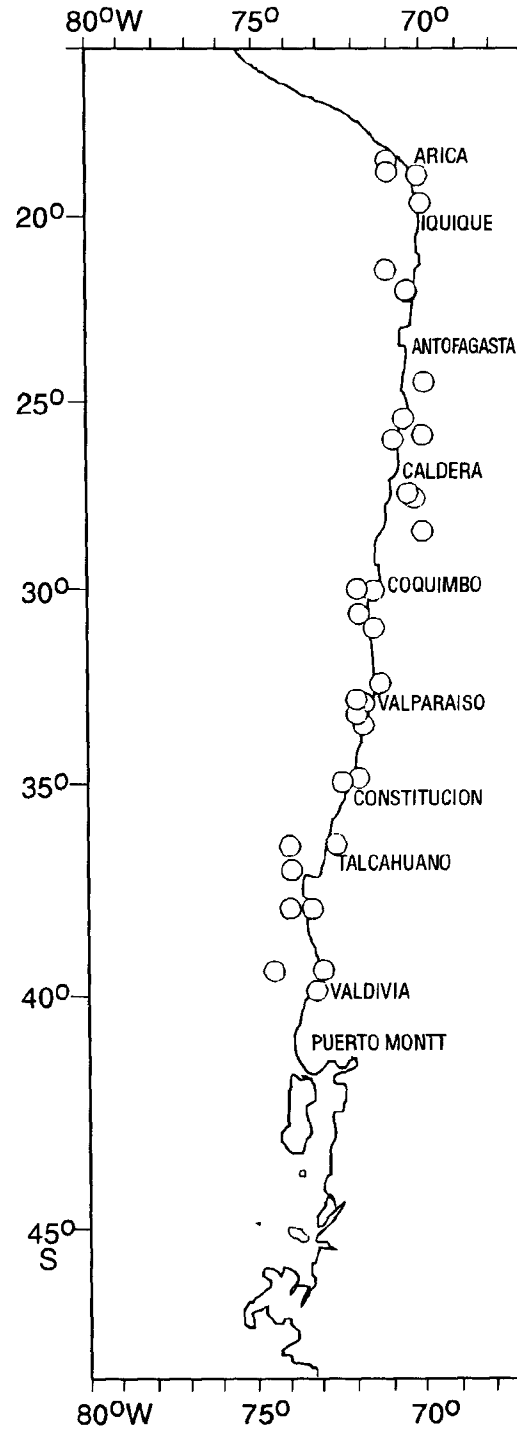
The West coast of South America is outlined by the eastern border of the Nazca tectonic plate and is characterized by its extreme seismicity. There is a very narrow seismic band (100-150 km wide) between the Andes mountain range and the Peru-Chile Trench.

Major differences is seismicity, in morphology of the coast, and in potential for generation of large tsunamis exist along the coastline of Chile.

An outstanding and well-known feature of the spatial distribution of hypocenters along South America is the gap in seismic activity between depths of 320 and 525 kilometers, as shown below.

The deep earthquakes (deeper than 525 km) define two relatively narrow belts of activity, and the number of small-magnitude events relative to the number of large-magnitude events is very low.

The intermediate-depth activity tends to cluster in space. There is a peak in activity between depths of about 100 and 130 km; most of these events occur between about latitudes 17°S. and 24°S. (near the bend in the coastline between Peru and Chile). This is also the region that has lacked large shallow earthquakes for about the past 120 years. The gap in seismic activity at intermediate depths between about latitudes 25.5°S. and 27.0°S. is evident; however, this region has experienced many large shallow events.



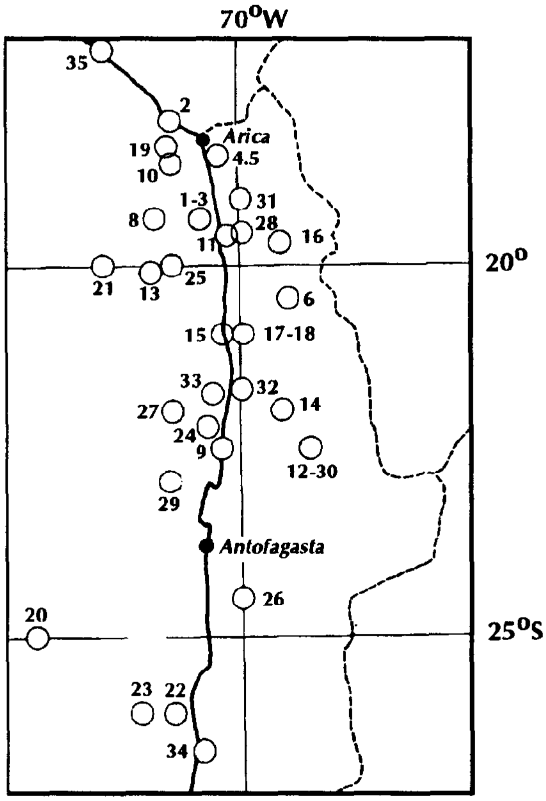
Large earthquakes in Chile.

5.2 SEISMIC ZONING

5.2.1 NORTH CHILE

Northern Chile can be separated into three distinct seismic regions. The northernmost region comprises the area between 18°S. and 20°S. latitude; the second region includes the area between 20°S. and 22°S. latitude; and the third region includes the area between 22°S. and 27°S. latitude.

a) The northernmost region (18°S.-20°S.), sometimes called the "big bend" area in the South American coastline, has a history of destructive earthquakes and tsunamis. Great earthquakes in 1604, 1705, 1868, and 1877 destroyed Arica (located at 18.5°S. latitude) as well as other coastal towns, and generated Pacific-wide tsunamis that were destructive.



Earthquake's location in northern Chile.

b) The second region in North Chile lies between 20°S. and 22°S. latitude. Here, earthquakes have occurred both offshore and inland. The offshore earthquakes have produced several tsunamis, but none has been destructive.

c) The Province of Antofagasta (22°S. - 27°S. latitude) includes much intermediate-depth activity, but lacks major shallow shocks of the type that generates destructive tsunamis. The largest events in this area occurred on Dec. 4,1918, and on Dec. 28, 1966. Both were magnitude 7.8 earthquakes, but only the 1918 event generated a damaging tsunami.

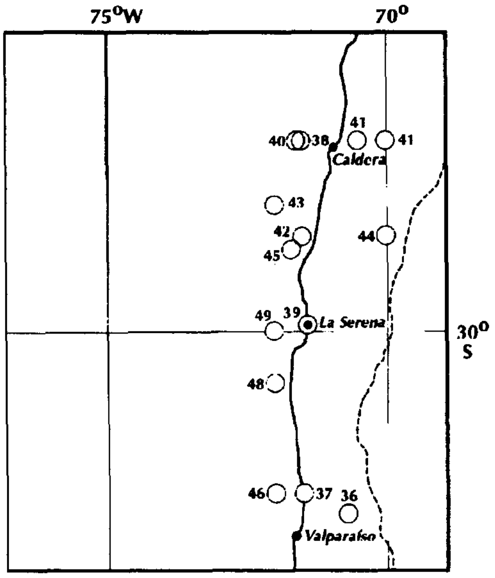
SEISMIC HISTORY OF NORTH CHILE (18°S.- 27°S.)

Event Nº	Date Yr Mo. Day	Lat. S.	Long. W.	Mag.	Effects
1	1543	19.0	70.5	7.7	Max. Mercalli intensity = X
2	1604 11 24	17.9	70.9	8.4	Great tsunami
4	1681 03 10	18.5	70.3	7.5	Max. Mercalli intensity = X
5	1715 08 23	18.5	70.3	7.5	Doubtful tsunami
6	<1768	20.5	69.4	7.7	Max. Mercalli intensity = VII
7	1831 10 09	18.5	71.0	7.0	Max. Mercalli intensity = VII
8	1833 09 18	19.0	71.0	7.4	Max. Mercalli intensity = VII
9	1836 06 03	22.6	70.3	7.5	Local tsunami
10	1868 08 13	18.6	71.0	8.5	Great tsunami
11	1869 08 24	19.6	70.2	7.4	Local tsunami
12	1870 04 22	22.7	68.9	7.5	Max. Mercalli intensity = X
13	1871 10 05	20.1	71.3	7.5	
14	1876 10 26	22.1	69.6	7.2	Max. Mercalli intensity = VII
15	1877 05 10	21.0	70.3	8.8	Great tsunami
16	1878 01 23	19.9	69.5	7.3	
17	1905 04 26	21.0	70.0	7.0	
18	1906 08 30	21.0	70.0	7.2	
19	1906 12 26	18.0	71.0	7.0	
20	1909 06 08	25.0	73.0	7.6	
21	1911 09 15	20.0	72.0	7.3	
22	1918 12 04	26.0	71.0	7.8	Tsunami
23	1925 05 15	26.0	71.5	7.1	
24	1928 11 20	22.5	70.5	7.1	
25	1933 02 23	20.0	71.0	7.6	Small tsunami
26	1936 07 13	24.5	70.0	7.3	Small tsunami
27	1940 10 04	22.0	71.0	7.3	Small tsunami
28	1945 04 19	19.5	70.0	7.2	
29	1947 07 29	23.5	71.0	7.0	
30	1948 12 26	22.5	69.0	7.0	Small tsunami
31	1956 01 08	19.0	70.0	7.1	
32	1967 12 21	21.9	70.1	7.3	Small tsunami
33	1970 06 19	22.2	70.5	7.0	
34	1983 10 04	26.5	70.6	7.4	Small tsunami
35	1988 04 12	17.3	72.4	7.0	

5.2.2 NORTH CENTRAL CHILE (27°S. - 33°S.)

This region is characterized by a shallow dipping seismic zone and by a lack of volcanism. Destructive tsunamis this century have occurred in this area at a rate of about one event every 20 years.

The 1922 and 1943 events, both of magnitude 8.3, demonstrate that this region has a potential for destructive earthquakes. Both the 1955 and 1971 earthquakes did not have large magnitudes, when compared to magnitudes of other earthquakes that generated damaging tsunamis, yet both produced locally damaging tsunamis. The 1730 and 1922 events generated tsunamis that were damaging as far away as Japan, indicating that Japan may be vulnerable to future tsunamis generated in this area of Chile.



Earthquake's location in north-central Chile.

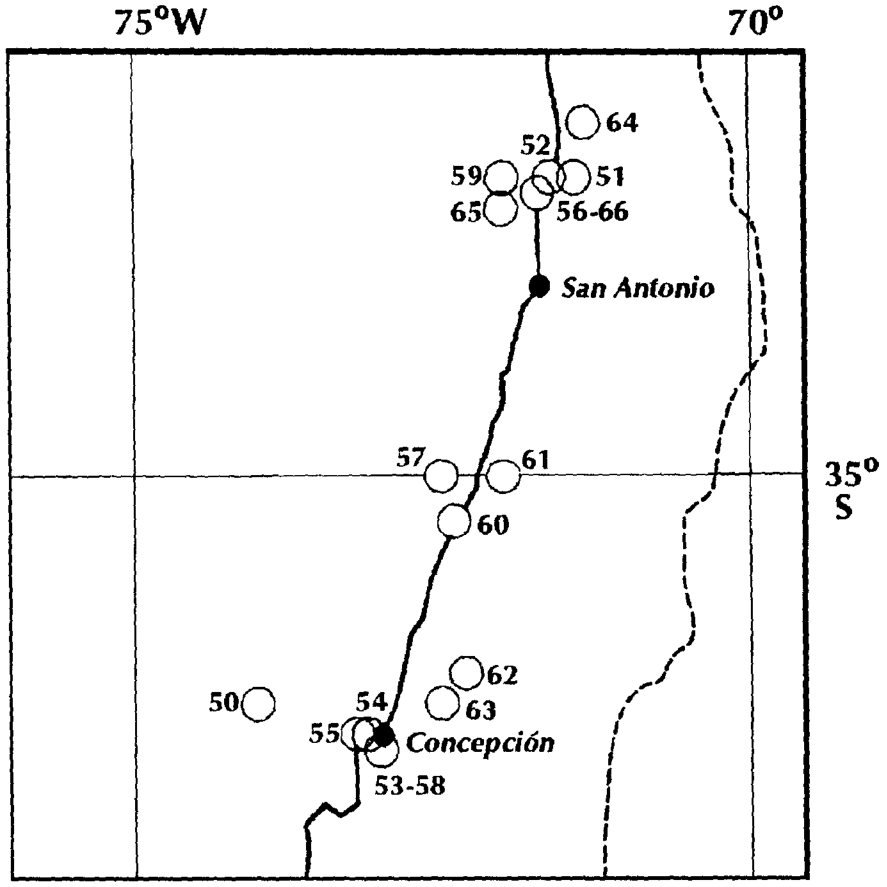
SEISMIC HISTORY OF NORTH-CENTRAL CHILE (27°S-33°S)

Event Nº	Date Yr. Mo. Day	Lat. S	Long. W	Mag.	Effects
36	1687 07 12	32.8	70.7	7.3	
37	1730 07 08	32.5	71.5	8.7	Great tsunami
38	1819 04 11	27.0	71.5	8.5	Big tsunami
39	1849 12 17	29.9	71.4	7.5	Big tsunami
40	1851 05 26	27.0	71.6	7.2	Tsunami
41	1859 10 05	27.0	70.0	7.7	Big tsunami
42	1918 05 20	28.5	71.5	7.9	
43	1922 11 07	28.0	72.0	7.0	
44	1922 11 11	28.5	70.0	8.3	Great tsunami
45	1923 05 04	28.7	71.7	7.0	
46	1931 03 18	32.5	72.0	7.1	
47	1939 04 18	27.0	70.5	7.4	
48	1943 04 06	30.8	72.0	8.3	Small tsunami
49	1955 04 19	30.0	72.0	7.1	Small tsunami

5.2.3 CENTRAL CHILE (33°S. - 37°S.)

Central Chile can be divided in three regions, as shown in the diagram.

a) The region near Valparaiso (33°-34°S.) is marked by the intersection of the Juan Fernandez Ridge with the Peru-Chile Trench, and the abrupt appearance of volcanism to the south. Five tsunamigenic earthquakes have occurred in this area: November 19, 1811; November 19, 1822; October 16, 1868; August 17, 1906 and March 3, 1985. The Nov. 11, 1822, and Aug. 17, 1906, earthquakes were centered almost at the same location. Both had magnitudes of 8.5 or larger and both caused damage.



Earthquake's location in central Chile.

b) South of Valparaiso (34°S.-36°S.), a moderate-size seismic gap exists here, where the potential for future earthquakes is good. Four events having magnitudes of 7.5 or larger have occurred in this area, but none of these generated a destructive tsunami.

c) Concepcion Region (36°S.-37°S.). In the southern part of Central Chile there were two events in 1835 and 1939 with magnitudes higher than 8.0; the first one generated a destructive tsunami. Lower magnitude events occurred in 1751, 1868, 1878, 1953, and 1971.

SEISMIC HISTORY OF CENTRAL CHILE (33°S.- 37°S.)

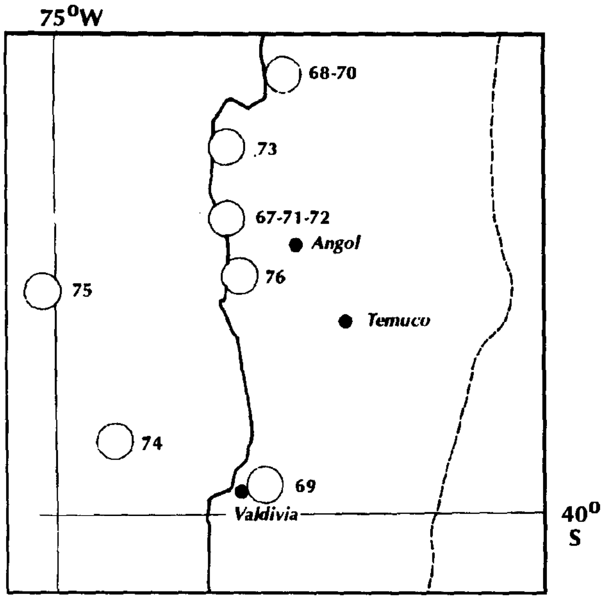
Event Nº	Date Yr Mo. Day	Lat. S	Long. W	Mag.	Effects
50	1751 05 25	36.5	74.0	8.0	Tsunami
51	1811 11 19	33.0	71.4		Small tsunami
52	1822 11 19	33.0	71.6	8.5	Great tsunami
53	1835 02 20	36.8	73.0	8.2	Great tsunami
54	1838 05 07	36.7	73.1		Small tsunami
55	1868 09 14	36.7	73.2		Small tsunami
56	1868 10 16	33.1	71.7		Small tsunami
57	1871 03 25	35.0	72.5	7.5	Small tsunami
58	1878 02 14	36.8	73.0		Small tsunami
59	1906 08 17	33.0	72.0	8.6	Great tsunami
60	1923 02 17	35.3	72.4		Small tsunami
61	1928 12 01	35.0	72,0	8.4	Tsunami
62	1939 01 25	36.3	72.3	8.3	
63	1953 05 06	36.5	72.5	7.6	
64	1971 07 07	32.5	71.2	7.5	
65	1975 05 10	35.7	74.6	7.8	
66	1985 03 03	33.2	72.0	7.8	Small tsunami

DO YOU KNOW....?

The May 22, 1960, earthquake in Southern Chile generated a tsunami that spread out through the entire Pacific Ocean, producing damage in places so far away as Japan, Hawaii and Colombia. There were also deaths in Japan and Hawaii. In this last place the damages were estimated to be $ 75 million (US).

5.2.4 SOUTH CENTRAL CHILE (37°S.-41°S.)

This zone is characterized by a shift of major seismic activity to an offshore structure near the northern boundary of this region, as seen in the diagram.



Earthquake's location in South-Central Chile.

Large earthquakes occurred in this region on October 28, 1562; February 8, 1570; December 16, 1575, March 15, 1657, and May 22, 1960. The 1562, 1570, 1575, and 1960 earthquakes produced destructive tsunamis.

Intervals between the destructive earthquakes of 1575, 1737 (South Chile), 1837 (South Chile), and 1960 (Valdivia area, 40 S. latitude) appear to be larger than those of both the Concepcion and the Valparaiso areas (that is, more than 100 years).

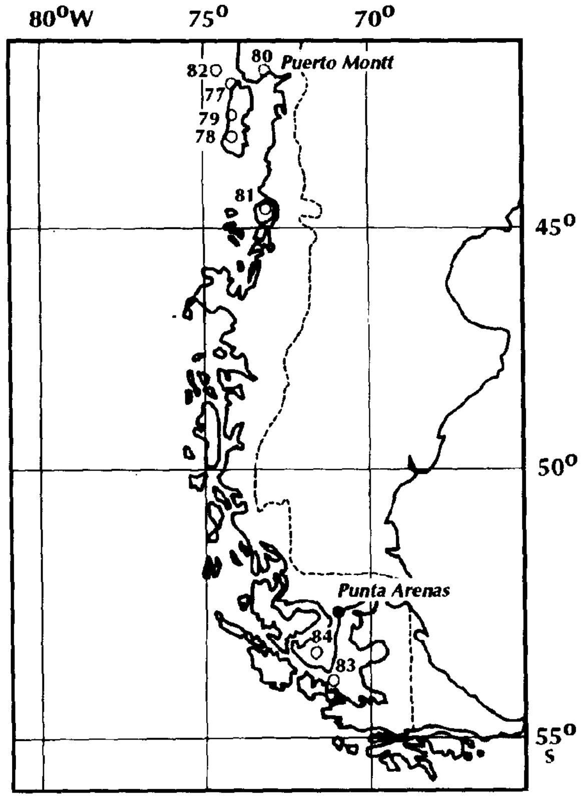
The May 22, 1960, earthquake was the largest seismic event in this region since 1570.

SEISMIC HISTORY OF SOUTH-CENTRAL CHILE (37°S-41°S)

Event Nº	Date Yr Mo. Day	Lat. S	Long. W	Mag.	Effects
67	1562 10 28	38.0	73.5	8.0	Great tsunami
68	1570 02 08	37.0	73.0	8.5	Great tsunami
69	1575 12 16	39.8	73.2	8.5	Great tsunami
70	1657 03 15	37.0	73.0	8,0	Great tsunami
71	1920 08 20	38.0	73.5	7.0	Small tsunami
72	1949 04 20	38.0	73.5	7.3	
73	1960 05 21	37.5	73.5	7.3	Small tsunami
74	1960 05 22	39.5	74.5	8.9	Great tsunami
75	1960 11 01	38.5	75.1	7.4	
76	1974 08 20	38.4	73.4	7.0	

5.2.5 SOUTH CHILE (41°S-60°S)

This zone can be divided in three different seismic regions as seen in the next diagram.



Earthquake's location in south Chile.

a) Region from 41°S - 45°S: The coastline of South America changes dramatically at 41°S. latitude. From this point south, the coastline becomes irregular and has numerous islands, bays, and inlets. This indicates that the collision between the Pacific and South American Plates is not as pronounced in this area, and perhaps that the two plates are not being forced past one another as is occurring along the coast to the north. In the northern part of this region (near 41°S. latitude), earthquakes generated damaging tsunamis in 1633 and 1837. A damaging tsunami occurred at 44.6° S. latitude in 1929.

b) Region from 45°S-53°S: South of the triple junction between the Peru-Chile trench and the Chile Ridge at 46°S. latitude, the oceanic part of the Antarctic Plate is being subducted beneath the South American Plate at a rate of about 2 cm/year.

Magnetic anomalies in the Southeast Pacific indicate that segments of the Chile Ridge collided with the southern part of the South American Continent 26 million years ago. Since that time, there has been a great decrease of volcanic activity on the continent and a cessation of folding in the sedimentary basins.

c) Region from 53°S-60°S: Seismic records are incomplete because of the recent settlements of the South American Continent near 53°S. latitude. Records that do exist, however, indicate that the seismicity is low. The earliest record of earthquake activity is the Magellan Strait earthquake of 1878. Two large earthquakes occurred within a 10- hour period in 1949.

SEISMIC HISTORY OF SOUTH CHILE (41°S-60°S)

Event Nº	Date Yr Mo. Day	Lat. S	Long. W	Mag.	Effects
77	1633 05 14	41.8	74.0		Small tsunami
78	1737 12 24	43.0	74.0	7.5-8.0	
79	1837 11 07	42.5	74.0	8.5	Large tsunami
80	1871 12 28	41.4	73.0		
81	1927 11 21	44.6	73.0	7.1	Tsunami
82	1940 10 11	41.5	74.5	7.0	
83	1949 12 17	54.0	71.0	7.7	Local tsunami
84	1950 01 30	53.5	71.5	7.0	

A) REPORT

REPORT FROM THE PAST

On December 16, 1575 there was a severe earthquake in the South of the country whose characteristics were very similar to the one which occurred several centuries later in the same region (May 22, 1960). Due to this similarity is important to keep a record of the effects of that particular event.

The Indian Territories south of the Bio-Bio River contained five frontier outposts: Imperial, Valdivia, Villarrica, Osorno and Castro. All five were destroyed by the great earthquake of 1575. According to reports by the Commander of Valdivia and the Governor of Chile there were more than twenty deaths in Valdivia, a large number considering the nature and size of the settlement. Cracks and fissures opened in the ground during the main shock and during some of the larger aftershocks. The tsunami reached Valdivia, located on a river of the same name about 25 km upstream from its mouth, shortly after the earthquake, "while the earth still shook", i.e. during the initial aftershocks. The water came rushing upstream, reversing the natural flow of the river. The rising water knocked over houses, poles and uprooted trees. Two galleons, riding at anchor in this port were sunk. After the ebb, the inhabitants had time to flee to higher ground.

The tremors continued for a period of forty days. Sizable cracks appeared in the ground and landslides were also recorded, a river flowing from Lake Riñihue became blocked in its upper reaches. The dam lasted until April of the following year, when after prolonged rains the water level in the lake rose considerably, causing the dam to burst and resulting in much devastation farther downstream; more than 1200 Indians perished and many cattle were lost as well; but the population of Valdivia was saved due to the foresight of its Commander, who had all low- lying houses evacuated well in advance.

The tsunami was highly destructive along the entire coast of southern Chile, up to Concepcion where the amplitudes were too low to cause damage. Nearly 100 Indians were drowned along the coast of La Imperial, north of Valdivia, where Indian settlements exist to this day.

The description and extent of damage due to the earthquake and the tsunami match closely the effects of May 22, 1960.

B) CHAPTER SUMMARY

- Spatial distribution of hypocenters is characterized by the lack of intermediate depth seismic activity between depths of 320 and 525 kilometers.
- Shallow earthquakes are distributed along or close to the coastline everywhere in the country.
- Most intermediate depth earthquakes (between 100 and 130 kilometers deep) occur in Chile from latitude 17°S to latitude 24°S near the bend in the coastline between Chile and Peru.
- Major differences in seismicity exist along the coastline of Chile.
- In the Transverse Valleys Region (27°S-33°S latitude) there is a lack of Neogene volcanism.
- Several seismic events have occurred in different regions of the country which have produced destructive tsunamis.
- No seismicity is recorded presently in South Chile between latitude 45°S and latitude 53°S.

C) QUESTIONS/PROBLEMS

1. What is the characteristic of intermediate depth earthquakes in Chile?
2. List three characteristics of the seismicity of South Chile.
3. What are the largest magnitude events occurred in Chile?
4. In which region have most of the important seismic events occurred?
5. Using books in the library, draw the location of volcanoes over the maps of seismicity for the different regions of the country.

D) CHAPTER TEST

A. Multiple Choice. Choose the letter that best completes the statement or answers the question.

1. Between the Andes and the Peru-Chile trench there is a very active

   a) fault
   b) volcano
   c) seismic belt
   d) tsunami

2. The northern part of North Chile is characterized by

   a) the lack of volcanism
   b) big tsunamis
   c) deep earthquakes
   d) shallow earthquakes

3. The region where the potential for future earthquakes is highest is

   a) South Chile
   b) Central Chile
   c) North Central Chile
   d) North Chile

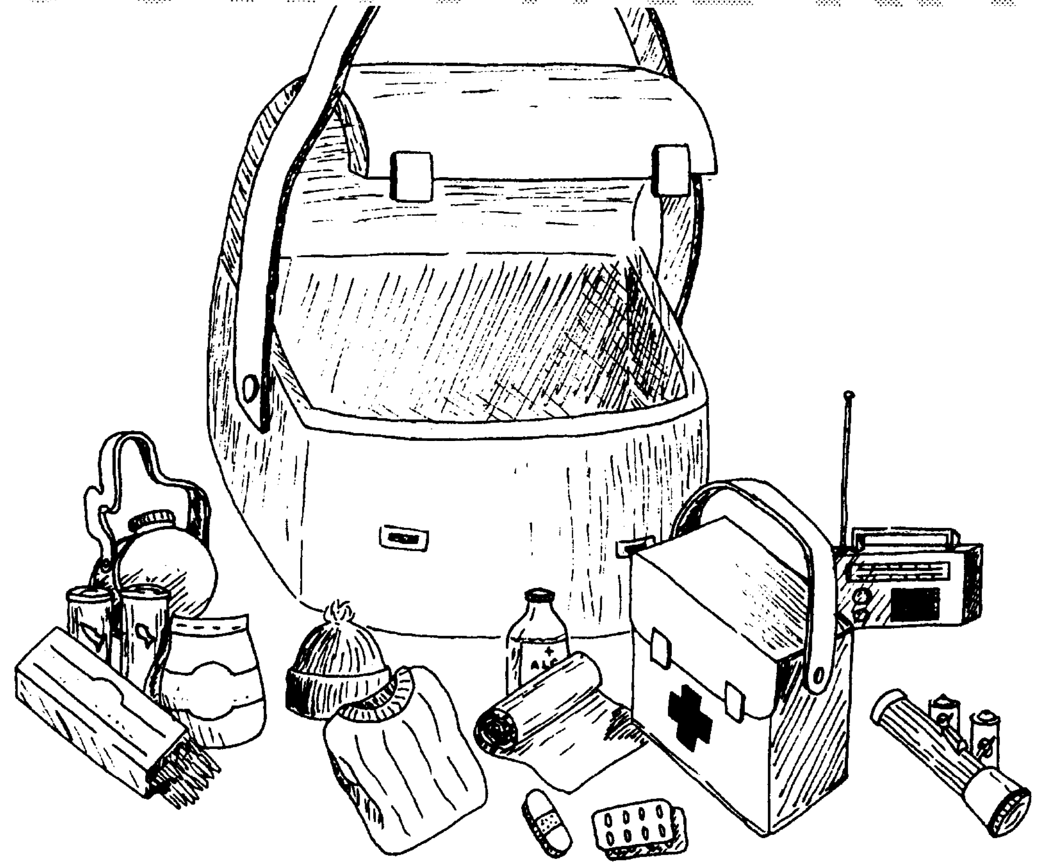
4. The largest magnitude earthquake ever recorded occurred in

   a) South Chile
   b) North Central Chile
   c) Central Chile
   d) South Central Chile

5. The earthquake that occurred in 1575 was very similar to the earthquake of

   a) 1868
   b) 1922
   c) 1960
   d) 1985

SURVIVAL KIT



CHAPTER 6

EARTHQUAKE AND TSUNAMI

PROTECTION MEASURES

- what to do before, during and after

Emergency preparedness is the collection of readiness activities undertaken by a community to maximize efficiency immediately prior to and during the emergency response period.

Because earthquakes strike without warning, it is important to act now. Knowing how to respond, and what to do, could save your life. The real cause of death or injuries during earthquakes is usually not the ground shaking. Most deaths are the result of collapsing buildings, falling debris, and objects like pieces of chimneys or ligths.

In the case of tsunamis, most of the victims arise from not knowing what to do or where to go if a tsunami is known to be coming.

This chapter lists a series of recommendations, for several settings, in case of an earthquakes and/or tsunami.

CHAPTER OBJECTIVES

1. Describe how to be prepared for the occurrence of a big earthquake.
2. Describe the actions to take during an earthquake to be safe from its effects.
3. Describe the actions to take after a big earthquake occurs.
4. Describe the actions to take in case of a tsunami.

6.1 WHAT TO DO BEFORE AN EARTHQUAKE

Unfortunately, earthquakes cannot yet be predicted. We don't know when and where the next one will occur. Because of this, all we can do during a period of quiescense is prepare ourselves by knowing what is expected to happen, and what to do before the earthquake in order to minimize loss of lives and damage to property.

BEFORE THE SHAKING STARTS...
PREPARE YOUR FAMILY!

6.1.1 Hazards most likely to occur:

a) Total or partial collapse of buildings.
b) Injury due to falling objects or debris.
c) Fires breaking out.
d) Electrocution due to breaking of power lines.
e) Gas explosion from gas line leaks.

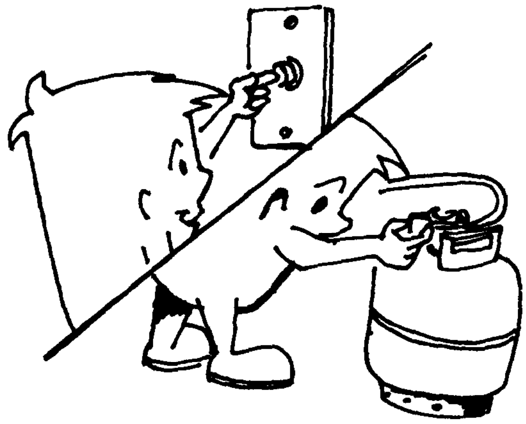
KNOW WHAT YOU HAVE TO DO
BEFORE YOU HAVE TO DO IT!

6.1.2 Actions to Take to Minimize Risk:

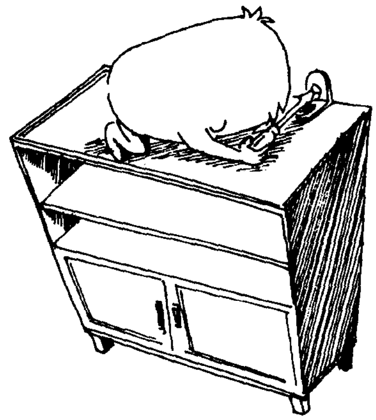
- Know the safe spots in each room:
  - against inside walls
  - under sturdy tables or desks
  - under supported doorways

- Know the danger spots:
  - windows
  - mirrors
  - hanging objects
  - fireplace
  - tall unsecured furniture

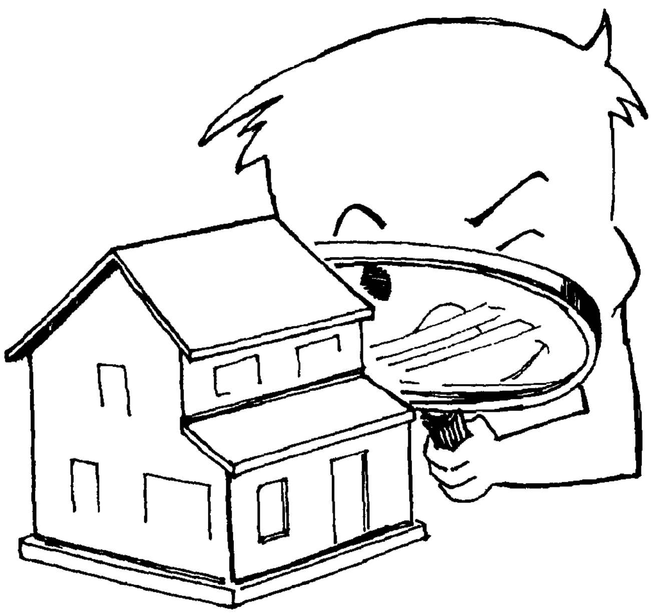
- Practice drills. Physically place yourself in safe locations. This is especially important for children to know and do.
- Learn first aid and cardiopulmonary resuscitation from your local Red Cross chapter or other community organization.
- Keep a list of emergency numbers.
- Learn how to shut off gas, water and electricity.



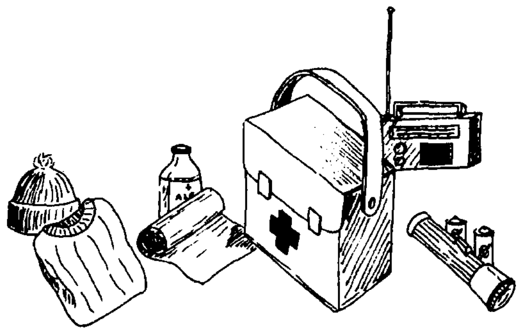
- Keep breakables or heavy objects on bottom shelves.
- Secure tall, heavy furniture which could topple, such as bookcases, china cabinets, or wall units.
- Secure water heater and appliances which could move enough to rupture gas or electricity lines.



- Secure hanging plants and heavy picture frames or mirrors (especially over beds).
- Put latches on cabinets doors to hold them closed during shaking.
- Keep flammable or hazardous liquids such as paints, pest sprays or cleaning products in the garage or outside shed.
- Check chimneys, roofs, walls, and foundation for structural condition.



- Maintain emergency food, water and other supplies, including a flashlight, a portable battery-operated radio, extra batteries, medicines, first aid kit and clothing.



6.1.3 Guidelines for persons responsible for other groups of people.

For school authorities, factory and office heads, etc., the following actions are suggested even before the occurrence of an earthquake:

a) Persons should be assigned to make sure that electric power and gas lines are shut off immediately after the occurrence of an earthquake.

b) Predetermine the procedures to be used in vacating a big building where a large number of people are located.

c) Predetermine an open space where people from buildings should be moved.

d) Marshalls and guides should be assigned and trained to conduct the evacuation of the building.

e) Hospitals and other services especially needed during a disaster should have predetermined plans for establishment of these services outside of the original building in case of an earthquake disaster.

f) Drills should be conducted periodically to test plans and reaction in case of an earthquake.

g) Agencies in the locality needed for rescue or relief should be known beforehand so they may be contacted for assistance.

h) Keep abreast of the government warnings and instructions.

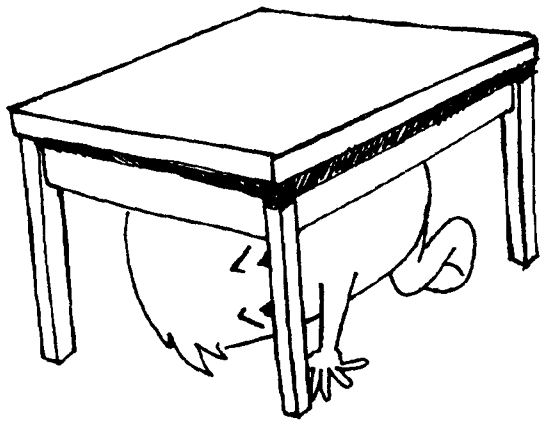
6.2 WHAT TO DO DURING THE SHAKING

DON'T PANIC!

The first thing is to react calmly. Although your reaction must be fast, you don't have to respond in a disorderly manner, because this is how panic is incited. Try to calm other people. Take care of children and elderly persons (some of whom may have physical problems).

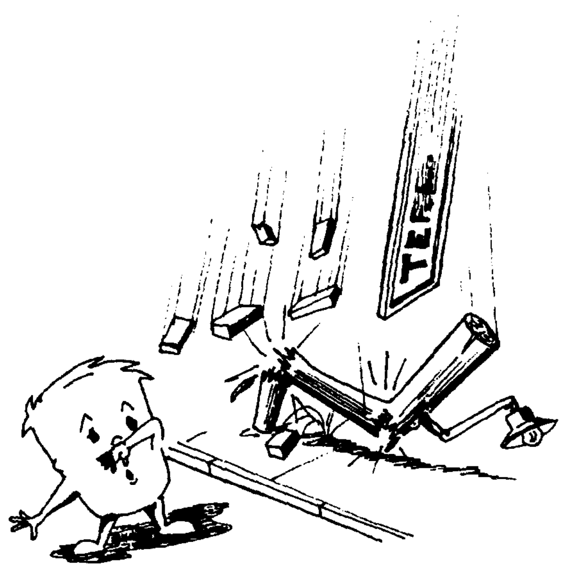
6.2.1 Actions to Take to Minimize Risk:

a) Open space is the safest location during a strong earthquake. Therefore, if open space is accessible within a few seconds, the first reaction is to go to the open. Many believe that the ground will open and swallow people, but this is not true.



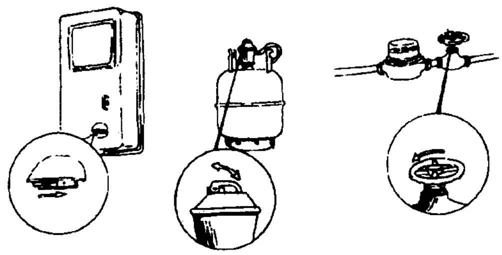
b) If access to the open is impossible within seconds, the next recommendation is to seek shelter under strong objects during the initial shaking. Immediately after the initial shaking, people should go to the open space until the seriousness of the destruction can be more completely evaluated.

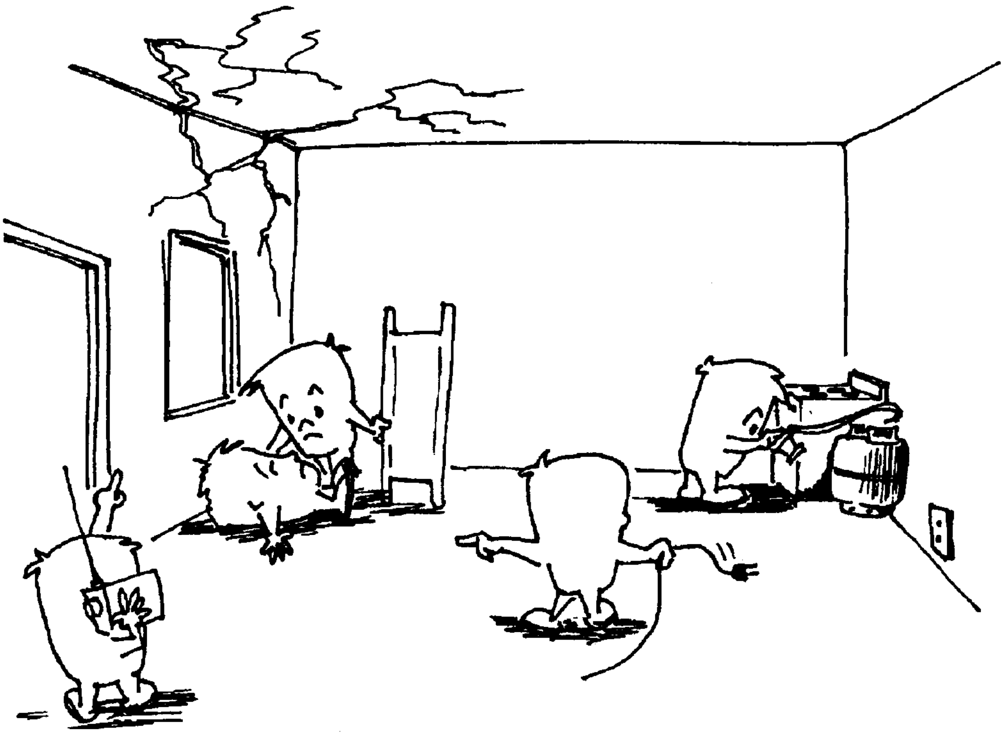
c) If you are in the street, efforts should be taken to keep away from falling debris or other objects such as billboards, street lights, lamp posts, etc.



d) Avoid being caught in narrow alleys, between tall buildings, underneath electric wires, beneath overhanging structures or on steep embankments. There are usually hazards between highrise structures and on the embankments of rivers.

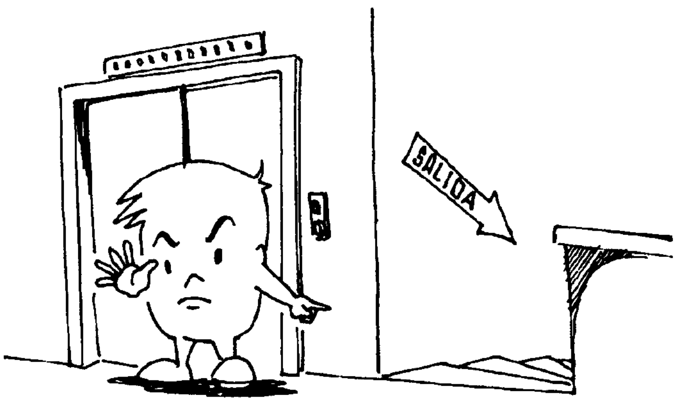
e) Turn off electricity and gas lines. These are potential causes of accidental fires after violent earthquakes.





f) Extinguish fires before you attempt to save lives. If this isn't done, an entire house or block of buildings may burn before anyone can be rescued.

g) Do not use elevators during or after the earhtquake until its safety is ascertained. After the violent shaking, elevators are usually jammed and short circuits may cause electrocution.



6.2.2 General tips for reducing danger in case of earthquakes.

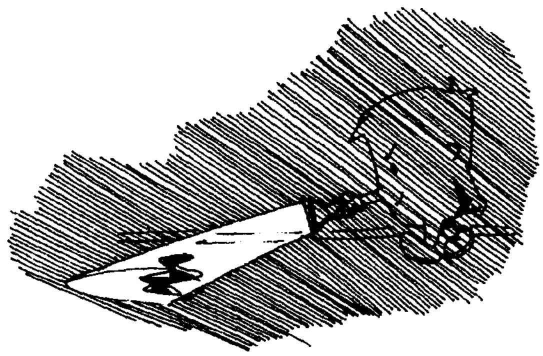
a) Exercise care in the use of oil or kerosene lamps. These should be placed where there is no danger of their falling over and starting fires.

b) Do not sleep where tall, heavy furniture would hit you if it fell over. Any tall, heavy furniture should be anchored or tied down.

c) Do not store heavy objects on high shelves where they might fall and cause injury.

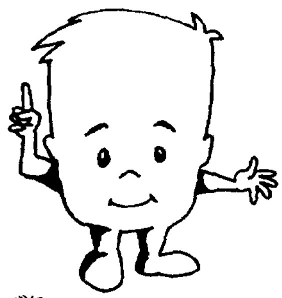
d) Keep flashlights handy for use if disaster occurs at night.

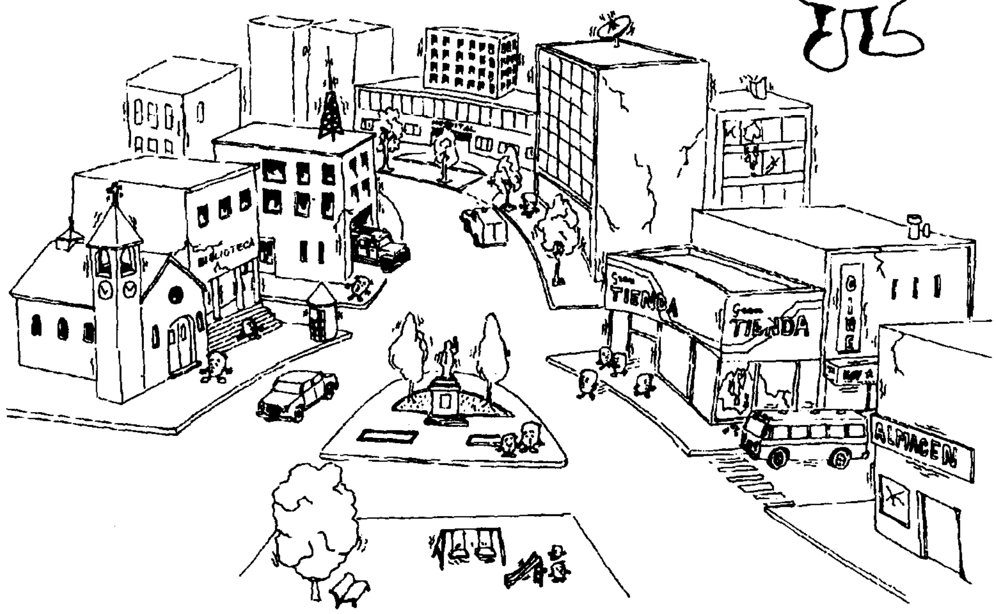
e) Keep an adequate supply of water and food for emergency use.



f) The individual is the final judge as to the most appropriate action for their situation. Each person should have clear in their mind an earthquake action plan, for both self and family, which covers normal situations.

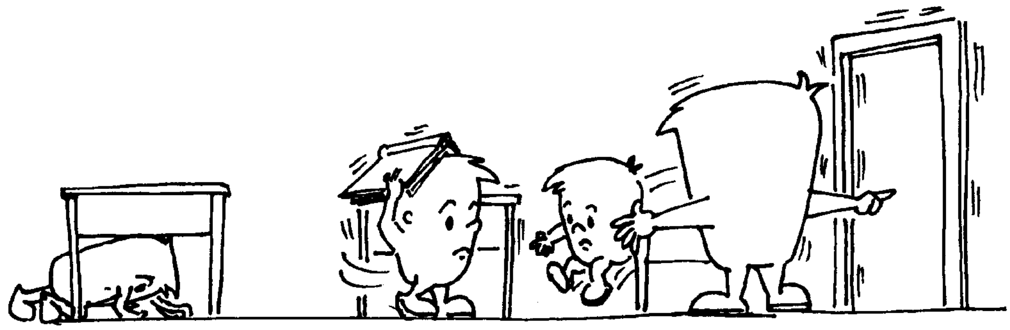
g) Finally, during the actual earthquake keep calm, react properly and DO NOT PANIC.





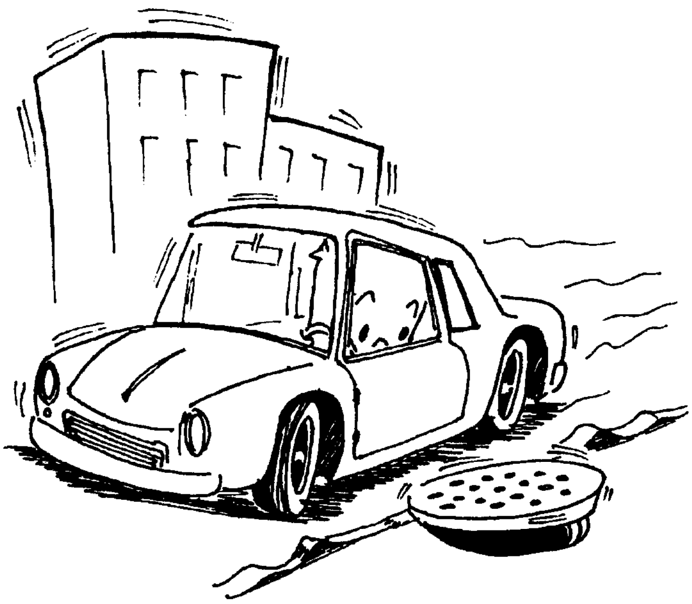
6.2.3 Actions to take if you are at the school.

If an earthquake should strike while you are in the classroom, get under the desk. Listen carefully to the teacher's directions. Put something over your head and without pushing file quietly out into the playground. When you have reached the evacuation area, line up and wait for further instructions.



6.2.4 If you are driving.

In a violent earthquake it is very difficult to control a moving car. The driver should slow down, pull over to the side of the road or street and stop the car. Avoid overpasses or power lines. Remain inside until the shaking is over, it will provide you with some cover.



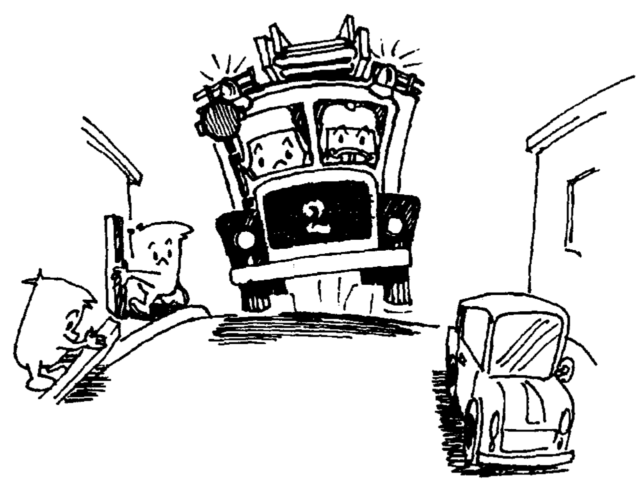
6.3 WHAT TO DO AFTER THE SHAKING STOPS

STAY CALM!

- It is possible that the shaking was just part of the process and that more aftershocks or an earthquake of even greater intensity could follow.
- Check for injuries. Give first aid to those who need it. Do not move seriously injured individuals unless they are in immediate danger.
- Douse all fires and do not use matches, candles, etc., because of possible gas leaks.
- If you smell gas, open windows and shut off the main valve, then leave the building.

Hunt for hazards:

- Check for gas and water leaks, broken electrical wiring or sewage lines. If there is damage, turn the utility off at the source.
- Check the building (including roof, chimneys and foundation) for cracks and damage.
- Check food and water supplies. Emergency water may be obtained from water heaters, melted ice cubes, toilet tanks and canned vegetables.
- Purify water by straining through a paper towel or several layers of clean cloth and then boiling it vigorously for six minutes.
- Do not eat nor drink from open receptacles located near broken glass.
- Do not use the telephone unless there is a severe injury or fire.
- Turn on your portable radio for instructions and news reports.
- Do not use your vehicle unless there is an emergency. Keep the street clear for emergency vehicles.

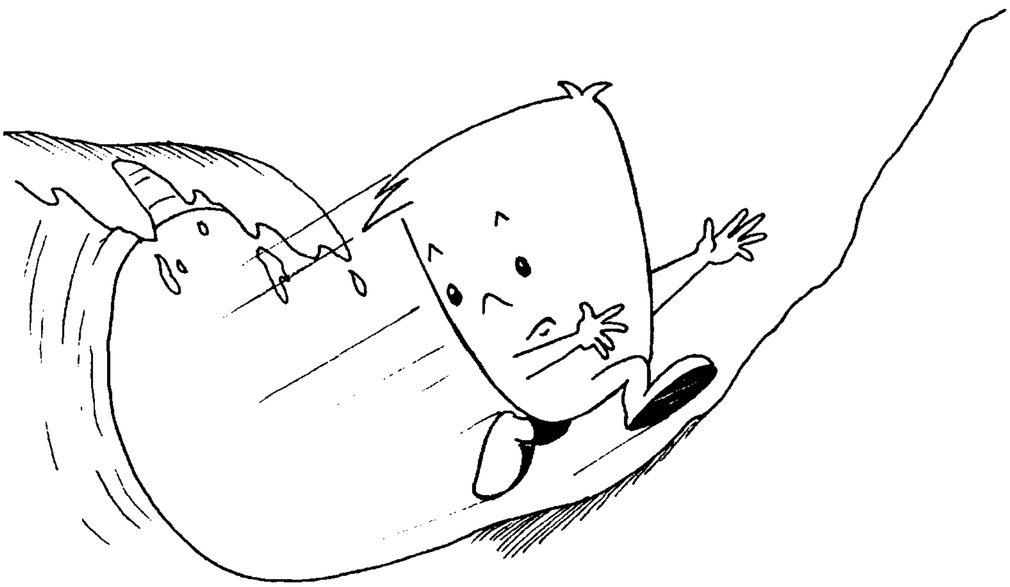


Be prepared for aftershocks. Although they are commonly smaller than the main shock, some of them could be large enough to produce aditional damage.

If you are not directly affected by the earthquake, do not try to get into the affected area. You will not be welcomed by people in the area.

6.4 WHAT TO DO IN CASE OF A TSUNAMI

A major earthquake whose epicenter is under the ocean may produce vertical displacements of the ocean floor that generate tsunami waves. The height of a tsunami at the coastline depends on the following factors: magnitude of vertical displacements, distance from the epicenter and shape of the shoreline.



6.4.1 Tsunami safety rules.

a) All earthquakes do not cause tsunamis, but many do. When you hear that an earthquake has occurrred, stand by for a tsunami emergency.

b) An earthquake in your area is a natural tsunami warning. Do not stay in low-lying coastal areas after a strong earthquake has been felt.

c) A tsunami is not a single wave, but a series of waves. Stay out of danger areas until an "all clear" is issued by competent authority.

d) Approaching tsunamis are sometimes preceeded by a noticeable rise or fall of sea level. This is nature's tsunami warning and should be heeded.

e) A small tsunami at one point on the shore can be extremely large a few kilometers away. Don't let the modest size of one make you lose respect for all.

f) The Pacific Tsunami Warning Center does not issue false alarms. When a warning is issued, a tsunami exists. The tsunami of May 1960 killed 61 people in Hilo, Hawaii, and they thought it was "just another false alarm."

g) All tsunamis - like hurricanes - are potentially dangerous, even though they may not damage every coastline they strike.

h) Never go down to the shore to watch for a tsunami. When you can see the wave you are too close to escape it.

i) Sooner or later, tsunamis visit every coastline in the Pacific. Warnings apply to you if you live in any Pacific coastal area.

j) During a tsunami emergency, your local civil defense, police, and other emergency organizations will try to save your life. Give them your fullest co-operation.

A) REPORT

EARTHQUAKE
Prelude to The Big One?

by THOMAS Y. CANBY (Extracted from "NATIONAL GEOGRAPHIC, VOL.117, NO.5, MAY 1990")

Like thousands of other good Californians, Lee and Terry Peterson had gone to the third game of the World Series that evening, to see the Giants try to bounce back against Oakland at Candlestick Park. Far south of the park the Petersons' new frame home, their pride and joy, clung to a shoulder of the Santa Cruz Mountains, near a dark peak named Loma Prieta.

Eighteen kilometers beneath that home and peak another contest was playing, in an arena known as the San Andreas Fault. Here two enormous plates of earth's crust had been locked in a planetary pushing match since the great San Francisco earthquake of 1906. These players were tiring, reaching the breaking point. Their game was in the last inning.

The Petersons found their seats at Candlestick Park. Expectantly they watched the teams warm up. The clock hans reached 5:04.

Deep beneath the Petersons' mountain home a section of weak rocks snapped. The two sides of the San Andreas shot past each other. Simultaneously the west side of the fault rose, lifting the mountains themselves.

The ripping was unstoppable. For about eight seconds earth's crust unzipped at more than two kilometers a second, 20 kilometers to the north and south. The bucking Santa Cruz Mountains flicked the Peterson house off its foundation, cracking it like an eggshell.

The faulting released a frenzy of seismic waves. They set seismometer needles scribbling around the world and carried a lethal message to Californians.

Waves rolling to the south bludgeoned the city of Santa Cruz, only 16 kilometers from the epicenter. They took out its commercial heart and snuffed four lives.

The waves smashed into Watsonville, damaging or destroying most homes and turning Main Street into a ghost town. They mutilated Hollister and churned the rich sediments of the Salinas Valley.

Waves rolling north roiled the ground beneath picturesque Los Gatos, shattering Victorian houses and half the business district. They shook San Jose, but most buildings held. The waves swept up the peninsula, rattling securely planted cities such as Palo Alto and Menlo Park. At Stanford University they found old, brittle structures and tewisted and cracked them.

Ahead lay Candlestick Park, packed with 62,000 fans and ripe for disaster. The waves shook the Petersons and other bewildered spectators. But Candlestick sits on bedrock, and it defeated the waves.

Now the waves were weakining. With little effect they jiggled southern San Francisco and towns across the bay.

A tiring vanguard of waves reached San Francisco's old Market Street area and Marina district and Oackland's busy waterfront. These areas sit on man-made fill. Here the waves found soil in tune with their own vibrations and strummed it like a guitar string.

More waves arrived and pumped in more energy. The earth grew alive and danced.

The vibrations flowed upward into buildings and highway structures. Picking up the rhythm, soil and structures swayed to the strengthening beat like partners in a dance.

Marina buildings buckled; many fell. Column joints supporting Oakland's Interstate 880 failed, and 44 slabs of concrete deck, each weighing 600 tons, collapsed on cars below. The waves pushed the Oakland end of the Bay Bridge 18 centimeters to the east, and a 15-meter section crashed onto the level beneath.

Within 15 seconds the vibrations faded. But 63 persons lay dead or dying. Some 3,800 others suffered injuries requiring medical attention. The waves damaged more than 24,000 houses and apartment buildings as well as nearly 4,000 businesses. At least a thousand structures faced demolition.

Measured in adjusted dollars, property damage approached that of the dreadful temblor of 1906, which unleashed 60 times as much energy. The Loma Prieta damage exceeded that inflicted by Hurricane Hugo during the hours it lashed the Southeast.

Still, California had been lucky. A few more seconds of shaking could have severed a crucial joint of San Francisco's battered Embarcadero Freeway, bringing it crashing down like I-880, and thousands more homes would have been damaged or destroyed. If bolts hadnot failed on the Bay Bridge, swaying trusses could have pulled down more of the vital span. If the World Series had not riveted Californians in their safe homes to watch TV or clustered them in the protective nest of Candlestick Park, who knows the tally of highway victims?

With the many wounds, moreover, came a new sense of confidence among Californians, a belief that they are doing many things right about quakes. A few of the pluses:

> ***The relatively low level of damage.*** *"Keep in mind that the vast majority of bay area buildings suffered no damage," emphasized John Osteraas of Failure Analysis Associates, Inc., a Menlo Park engineering firm.*
>
> ***The value of preparedness.*** *Within hours of the earthquake, shelters opened from the Marina district to Hollister. Though staffed partly by legions of spontaneous volunteers, these nerve centers had been carefully planned. Throughout the year the Red Cross, the state Office of Emergency Services, and other agencies conduct rehearsals that bore fruit in the October 17 response.*
>
> ***The growing reliability of quake forecasts.*** *A 1988 assessment of earthquake probabilities along the San Andreas Fault, published by the U.S. Gelogical Survey, had assigned the southern Santa Cruz segment the highest likelihood of slipping for northern California.*
>
> ***The human response.*** *Like an opened spigot, the quake released an untapped flood of caring and kindness. Volunteers materialized as if from the shaking earth, directing traffic on darkened streets, comforting the terrified with a word and a hug, extricating the injured and the dead.*

B) CHAPTER SUMMARY

- Earthquakes cannot be predicted. We must prepared ourselves by knowing what is expected to happen and by knowing what to do before the earthquake in order to minimize lose of life and damage to property.
- Hazards most likely to occur are: collapse of buildings, injures due to falling objects, fires, electrocution, and gas explosions.
- Actions to take to minimize risk are: know the safe spots, know the danger spots, practice drills, learn first aid and cardiopulmonary resuscitation, keep a list of emergency numbers, learn how to shut off gas, water and electricity.
- Do not panic during the shaking of the earthquake.
- Open space is the safest location during a strong earthquake.
- If access to the open is not immediately available, seek shelter under strong objects.
- Do not use elevators during the earthquake.
- If driving a car, slow down and pull over to the side of the road or street and stop the car.
- Beware of the aftershocks.
- After the earthquake hunt for hazards like gas or water leaks, fires, cracks and building damage.
- Turn on your portable radio for news reports and instructions.
- If you live near the coastline be prepared to follow the tsunami safety rules.

C) QUESTIONS/PROBLEMS

1. Describe the hazards most likely to occur during an earthquake.
2. Name five actions to take before an earthquake occurs to minimize risk.
3. Describe the main actions to take during a strong earthquake.
4. List the DON'Ts to consider during an earthquake.
5. Describe actions to take after the earthquake stops shaking.
6. List the DON'Ts to consider after the earthquake.
7. Describe the main tsunami safety rules.

D) CHAPTER TEST

Multiple Choice. Choose and mark the letter that best completes the statement or answer the question.

1. To be safe from an earthquake one should:

   a) stay close to a window
   b) stay close to a fireplace
   c) go to open space
   d) none of the above

2. If you are at school and an earthquake occurs you should:
   a) run away
   b) get under the desk
   c) turn off electric power
   d) go to the window

3. If you are driving a car when an earthquake starts you should:
   a) blow your horn
   b) drive slowly
   c) stop the car
   d) none of the above

4. After the earthquake stops you should:
   a) go to the affected area
   b) drive quickly home
   c) turn your radio off
   d) hunt for hazards

5. If you live on the coastline and a big earthquake occurs you should:
   a) stay close to the coastline
   b) go to higher ground as soon as possible
   c) watch for aftershocks
   d) none of the above