CHAPTER 1

OUTSIDE AND INSIDE THE EARTH

The picture shows our earth as it looked by 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.

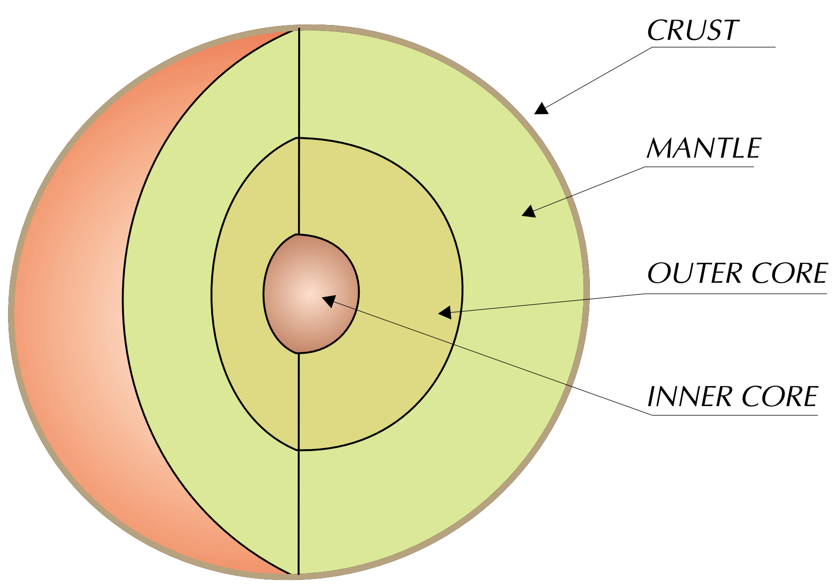
1.1 CHARACTERISTICS OF THE EARTH

• 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?

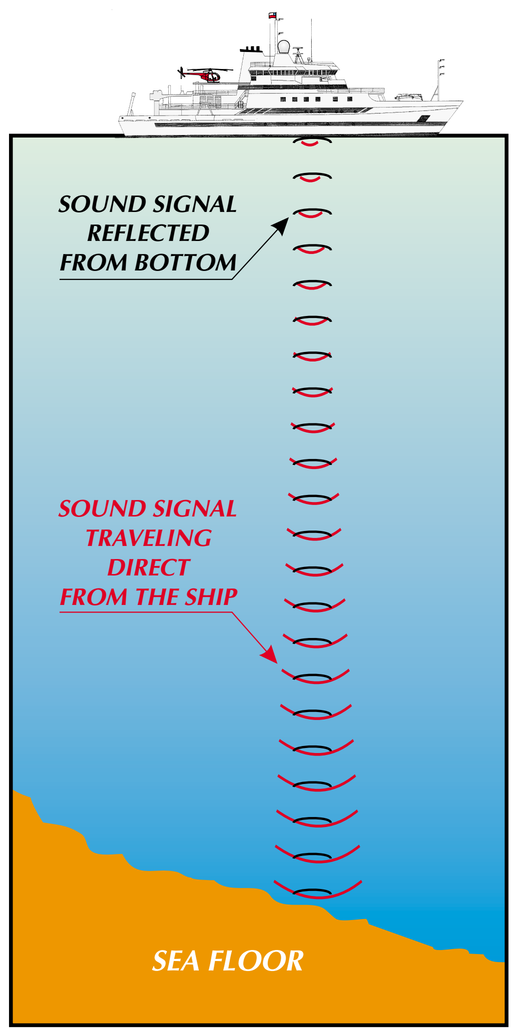
Soundings are measurements of water DEPTH. In the past, sailors took soundings by lowering ropes with weights. When the weight touched the bottom, the length of wet rope showed the depth of the water. In deep water, a sounding was inaccurate because of the water's movement.

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.

DO YOU KNOW?

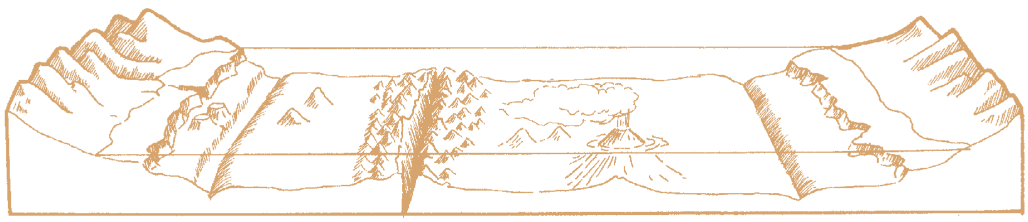
The Pacific Ocean is so large that all the continents put together could fit into it. It covers 165,200,000 square kilometers.

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.



Echo sounder operation.

If all the water were 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 how does the interior of the earth look like?

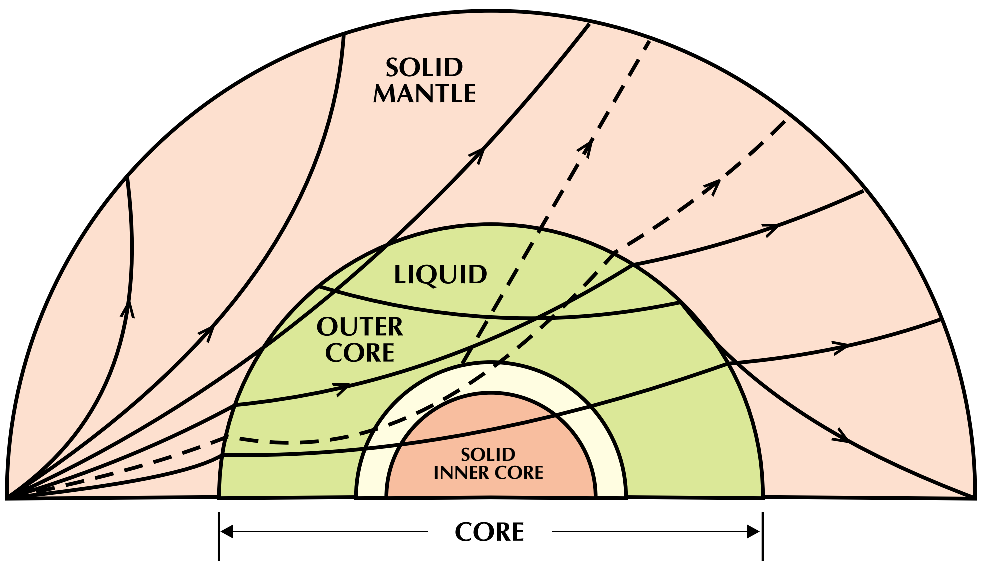
Nobody can make a trip to the center of our planet to discover its internal structure, however, today we know the internal structure thanks to instruments that record the waves produced by earthquakes.

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 seismologists 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?

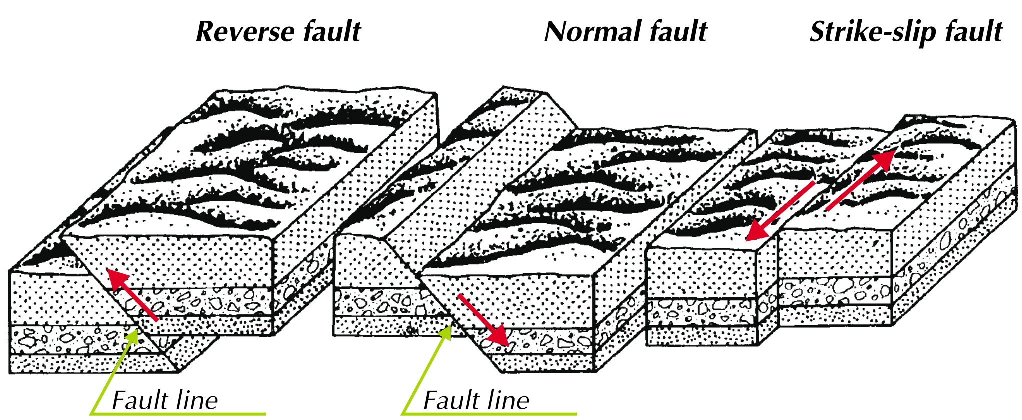
The record of drilling in the exploration of the earth's crust is held by the former Soviet Union with a well 12 kilometers deep drilled in MURSMANK.

HAVE YOU ALSO HEARD?

At a depth of forty 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.

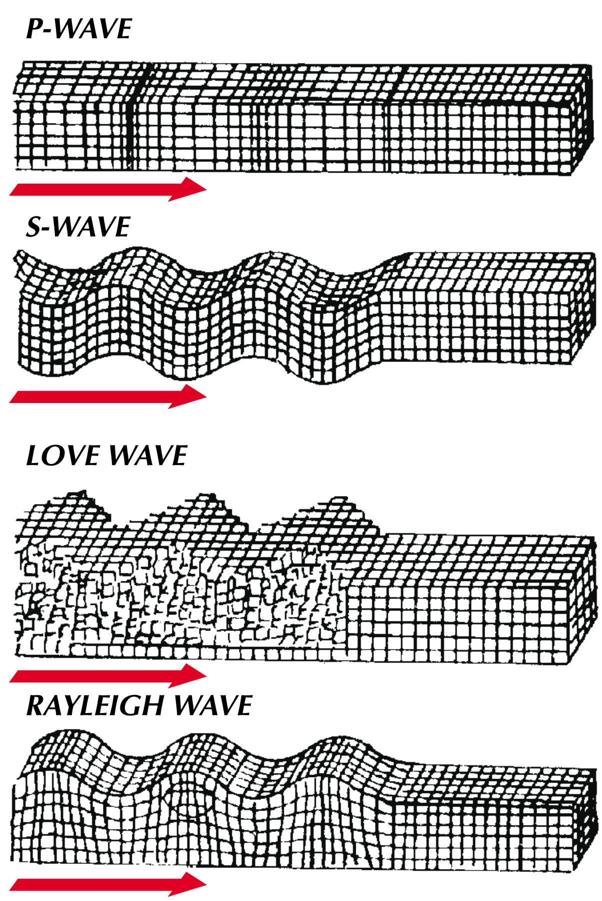
2) ***The transverse, distortional, or shear wave, S***. This is analogous to a light wave or the transverse vibration of a string. A particle is always displaced in a direction normal or transverse to the direction in which the wave is traveling. Interior transverse waves travel at about 0.6 the speed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



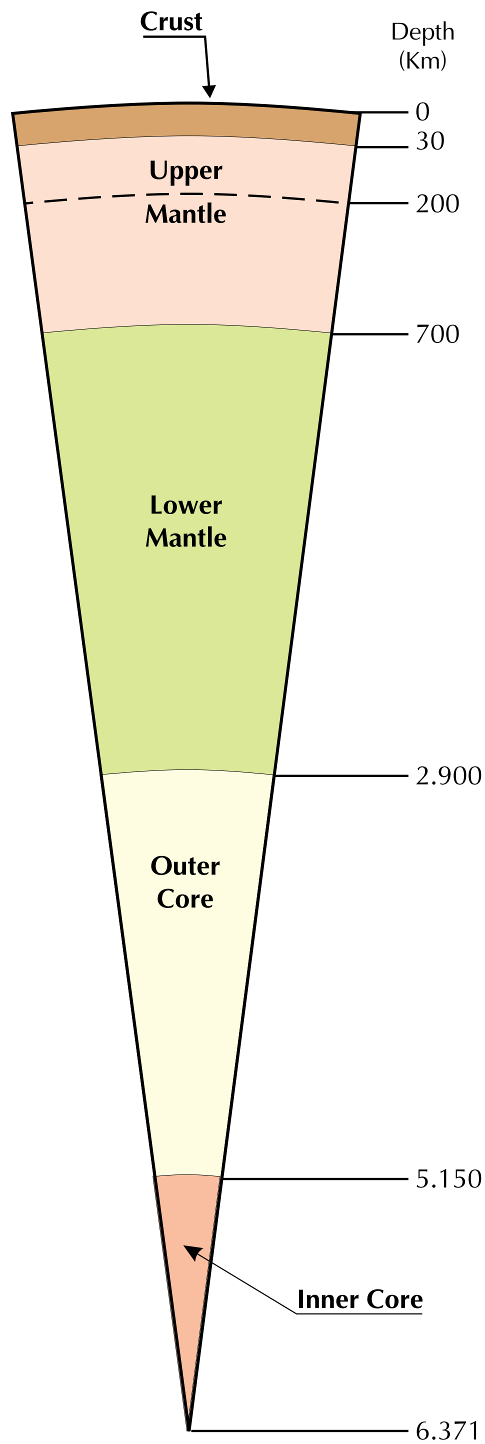
Seismic wave propagation.

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 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

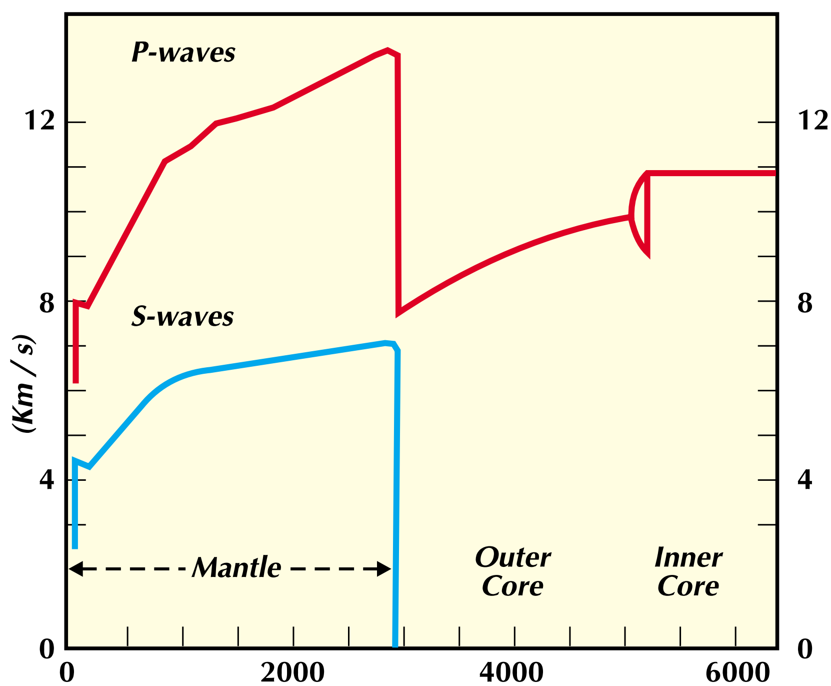


Internal structure of the earth.

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.



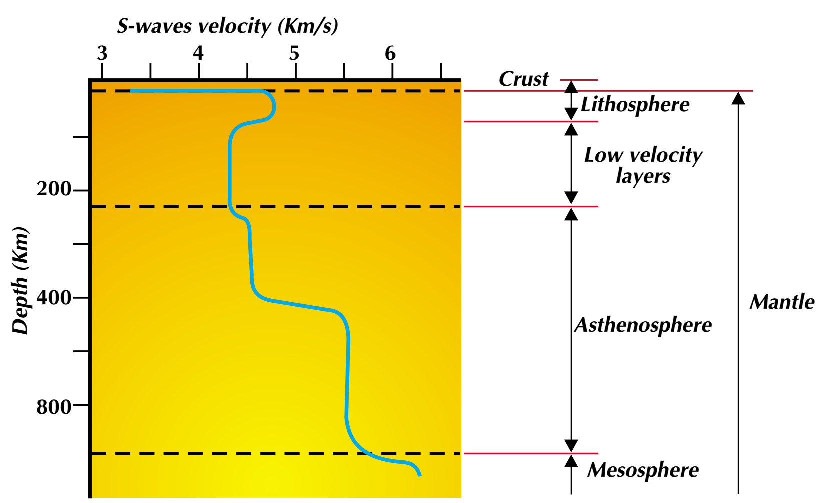
Velocity of seismic waves at different depths.

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 350ºC. 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 t " he 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 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 2º 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 15º C be the starting temperature of the crust. Compare your result with the suggested temperature of the earth's core, which is 5,500º 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 1 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	i. lithosphere
( )	10. Relative movements between blocks of the crust	j. mesosphere
		k. 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