Chapter 7 Earth

Overall Structure of Planet Earth

Using techniques that we talked about in Ch. 6 we have been able to determine many things about our Earth. The average density is around 5500 kg/m^3. The water on Earth has a density of 1000 kg/m^3 and the rock on the continents is between 2000 – 4000 kg/m^3. That means that the interior of the Earth must be made up of much denser material.

The Earth is divided up into 3 basic regions: the *crust*, the *mantle*, and the *core*. The solid part is called the *lithosphere* (the crust and upper lithosphere) and the liquid part of the Earth, which is 70%, is called the *hydrosphere*. We are surrounded by gases that make up our *atmosphere* and we have a band of charged particles around the Earth called the *magnetosphere*.

Earth's Atmosphere

Our atmosphere is made up of several gases. The most prominent gases are nitrogen (78%) and oxygen (21%). The rest is CO_2, water vapor and a few others.

Atmospheric Structure

Our atmosphere is made up of several layers. About 50% of the atmosphere is found within 5 km of the ground and 99% of the atmosphere is within 30 km of the ground. From the ground to about 12 km you have the *troposphere*. Above that up to 40 – 5- km you have the *stratosphere*. Between 50 – 80 km up you have the *mesosphere* and above that you find the *ionosphere*. As most of you know the air pressure decreases steadily as you higher into the atmosphere.

The troposphere is where you find *convection* taking place. This is where air is heated up and it rises. When it rises, colder air takes its place and it warms up and rises. As this is happening, the warm has risen and cooled off and it falls. Thus you have a cycle of moving air or winds. Above 100 km you have the ionosphere. It is here that you have charged particles. It is because of this layer that you can hear AM radio for great distances. The radio bounces off the ionosphere. This doesn't work for FM because the ionosphere is transparent to the shorter wavelengths.

Atmospheric Ozone

In a layer between the stratosphere and the mesosphere at about 50 km up you find the *ozone layer*. Ozone is made up of 3 oxygen atoms (O_3) unlike molecular oxygen which is O_2. The ozone is absorbs ultraviolet that comes in from the Sun. Through our modernization we are making significant changes to our planet. One of these changes is in the ozone. A substance called chlorofluorocarbons (CFC's) has been used in the past to propel hair spray, deodorant, and other things from their cans. It is the chlorine in the CFC's that destroys ozone. A single chlorine can destroy over 100,000 molecules. Every year an ozone hole forms over Antarctica. Since the 1980's it has gotten bigger. That is why in the 1980's many countries banned CFC's. They hope to have the ban total by 2030.

Surface Heating

The sunlight that reaches us takes on the form of light and near infrared (heat). This is the light that is not reflected back into space by clouds, ice, and some by the water. The surface of the Earth will absorb this heat. It won't do this indefinitely or else the Earth would be too hot to live on. The energy is reradiated back following the blackbody curve we discussed in ch. 3. As it gets hotter, the surface radiates more and more until it radiates as much as it receives. This heat is radiated in the form of infrared. Some of this infrared escapes back into space, but due to CO_2 and water vapor some of it is absorbed causing the temperature to go up. This is called the *greenhouse effect*. These gases make the Earth about 40° hotter than it should be (thank goodness). As we mentioned, the gases responsible for this are CO_2, water vapor and several others in lesser amounts. These are called *greenhouse gases*. Since the industrial revolution the amount of CO_2 in the atmosphere has doubled. A runaway greenhouse effect has caused Venus to have a temperature of 700 K.

Origin of the Earth's Atmosphere

Where did we get the atmosphere that we have today? The early atmosphere should have contained the same material as the early solar system such as hydrogen, helium, methane, ammonia and water vapor. Most of this would have escaped into space early in our history. This was called our *primary atmosphere*. After this we formed the *secondary atmosphere*. These were gases that probably outgassed from the Earth due to volcanic action. Water vapor, CO_2, methane, SO_2, and nitrogen containing compounds were released into the atmosphere. The UV split some of the lighter compounds in the atmosphere. Any oxygen that was formed was quickly absorbed by other things at this time, which is why nitrogen took over the atmosphere. The final piece to the atmospheric puzzle would have been the formation of life. The blue-green algae would have been a major oxygen producer which allowed animals to form.

Earth's Interior

Even though we live on the Earth, learning about its interior is not an easy thing to do. We just don't have the capability to drill deep and see just what things are like in the interior.

Seismic Waves

When we have an earthquake systematic waves are produced. These waves are called *seismic waves*. Like all waves, they carry information and it is picked up and recorded by a *seismograph*. There are several types of waves. The first to arrive are called the primary waves or *P-waves*. These are pressure waves. These waves will contract and expand alternately as they travel. The next waves to reach you are called the secondary waves or the S-*waves*. These are called *shear waves*. This motion is more sideways like a guitar string. The P-waves can travel through anything while the S-waves can't travel through liquid.

The speed at which these waves travel is dependent on the density of the material they are going through. By measuring the time it takes for these waves to get from the site of the earthquake to our detector, we can determine the density of the material that it traveled through. It was seen that seismographs on the opposite side of the Earth never get S-waves. Thus the core must be liquid. The P-waves appear to be refracted or bent as it passes through the Earth. From all of this work, we have determined that the Earth's core is about 3500 km in radius. More careful observations of the P-waves reveal that there appears to be a solid inner core that is 1300 km in radius and the liquid outer core.

Modeling the Earth's Interior

From all the data that has been gathered from earthquakes and our knowledge of the rocks on the surface we have developed mathematical models for the interior of the Earth. Our knowledge of the deepest reaches of the Earth are all done on our modeling. According to the model, the core is surrounded by the mantle which is 3000 km thick. It makes up about 80% of the bulk of the Earth. The crust has an average thickness of about 15 km (8km under the oceans and 20-50 km under the continents). The density goes from 3000 kg/m^3 at the crust to over 12,000 kg/m^3 in the core. The temperature goes from 300 K to over 5,000 K. The high density in the core tells geologists that the core must be mainly iron and nickel. The increase in density at the mantle-core boundary is simply due to the type of material in the layer. The mantle is mainly rocky material and the core is metal. It is thought that the core contains some light material, but what it is is not certain. All of the geologists agree that a major part of the core is liquid (from the seismic data) Due to extreme pressure at the very center, 4 million times the atmospheric pressure; the central core has been compressed into a solid.

We have never been able to drill into the mantle, but we do have material from there. It comes from volcanoes. This material is from the mantle which is a semi-liquid. By studying this we know what the make-up of the mantle is. The mantle material can be found in the form of basalts and granites. The difference is due to chemical composition of each.

Differentiation

The entire Earth has been molten several times in its history. When it was molten, the heaviest material settled to the inside, then the next heaviest and so on. This separation out due to density is called *differentiation*. As the small body that is the Earth started to get bigger, its gravity increased and it pulled in more material. These impacts would have heated up the body. More mass means more gravity which means more material hitting the Earth. Now you have this molten world separating out into layers and more and more material struck it. Another reason that we are hot in our interior is due to *radioactivity*. As the material decays inside the Earth it releases energy, keeping the interior hot. Measurement of the surface rocks shows that it started to solidify about 700 million years ago.

Surface Activity

Our Earth is geologically alive today. We see volcanoes and we experience earthquakes. It isn't so bad today, but looking at the rock record shows it must have been very violent in the past.

Continental Drift

Erosion and wind has wiped out much of the evidence for what has occurred in the past on the surface. We are able to monitor and study the changes going on today. We can see that there are all kinds of active sites around the world, but they are not evenly spaced out. They seem to lie along certain lines on the Earth. In the 1960's it was determined that the se lines were actually the boundaries of giant "plates" on the Earth. These plates are slowly moving apart due to convection currents in the mantle. It was called *continental drift*. The study of the movement and its causes is called *plate tectonics*. The original idea was proposed in 1912, but it was laughed at and not very widely accepted. It was pointed out that South America and Africa seem to fit together so well. People wouldn't listen. We now realize that the idea was right. From looking at what is still going on, it has been estimated that the split originally occurred about 200 million years ago. If you look at the plates which is the crust and the solid part of the mantle you have the lithosphere. The semi-liquid part of the mantle that the lithosphere rides on is called the asthenosphere.

Effects of Plate Motion

A number of different things occur along the plate boundaries depending on what is happening at that plate.

1) When 2 plates collide, you can form mountain ranges. This happened when the Indian plate slammed into Asia forming the Himalayas.

2) Not all colliding plates form mountains. Sometimes one of the plates is pushed under the other one. Here you form subduction zones. Here you form trenches which are some of the deepest parts of the ocean. Here you also have material being pushed under and melted to become part of the mantle again.

3) Some plates slide along each other just like the San Andreas fault in California. As the plates slide by each other you have earthquakes.

4) One other thing that can happen is that you have 2 plates moving away from each other. The mid Atlantic ridge is an example of this. Here a separation is occurring ar a rate of about the speed that you fingernails grow. This has hel[ped us determine what has been going on with the Earth's magnetic field. As it wells up from the mantle and solidifies it becomes magnetized, taking on the characteristic properties of the magnetic field at that time. By looking at the ocean floor, we have an idea bout our atmosphere.

What Drives the Plates?

As we mentioned before, convection currents drive continental drift. As the molten material is being driven upwards it sometimes finds a crack to push through and you now have a volcano. So as you can see the rock is pushed to the surface and some of it is pushed under the plates. This is the *rock cycle*. The molten rock under ground is called *magma* and when it reaches the surface you have *lava*. When it reaches the surface and cools you get basalts and granites which are forms of *igneous rocks*. As these rocks weather, they break into small pieces which may at a later date form *sedimentary rocks*. If the igneous or sedimentary rocks are put under high heat and stresses, you will form *metamorphic rock*.

Past Continental Drift

Scientists now believe that the Earths plates were all connected at one time. This one supercontinent was called *Pangea*. At a time of about 200 million years ago these plates started to split apart. There is nothing special about that time, it just happened.

Earth's Magnetosphere

After our entry into the space race in the late 1950's, it was discovered that the Earth had a series of *magnetic field lines* surrounding us. This became know as our *magnetosphere*. At the north and south poles the magnetic field lines are almost perpendicular to the Earth. They align pretty well with the spin axis of the Earth. It is very much like a bar magnet. The magnetic poles drift about 10 km per year and they don't have positions opposite each other. Currently the north magnetic pole is in northern Canada at a bout 80° north and about mid North America. The south magnetic pole is at about 60° just south of Adelaide, Australia.

There are 2 zones of charged particles, one 3000 km out and the other 20,000 km out. These are where the magnetic field has trapped high energy particles. They are called *van Allen radiation belts*. The outer belt has mainly electrons while the inner belt has mainly protons. Sometimes particles escape from the van Allen belts and cause the *aurora* to form. Often after a major solar storm the van Allen belts become overloaded with particles and they bombard our atmosphere. Why do we have it? It is thought that the magnetic field comes from the planet's liquid core rotating causing what they call the *dynamo effect*. You need both rapid rotation and a liquid core to produce an electric field which produces a magnetic field.

The Tides

We are quite unique because so much of our surface is covered with water. Most people have some understanding of what the *tides* are. At most coastal locations there are 2 low and 2 high tides per day. Lets look at what causes them.

Gravitational Deformation

Tides are due to the gravitational tug of the Sun and Moon on the Earth. The Moon plays a bigger part in the tides than the Sun. On the side of the Earth where the Moon is you have a slight pull on the water and it bulges slightly. This is called a *tidal bulge*. We get high and low tides because the Earth rotates on its axis. The Moon's gravity varies over the Earth and results in a *tidal force*. When the Sun, Moon and Earth line up in a straight line, the gravitational effects will be the greatest. You will have the greatest tides here. This is called the *spring tide*. It occurs during full and new moon. When the Sun, Moon, and Earth are right angles the tides are less pronounced. These are the *neap tides*. They occur during the first and third quarters.

Effects of Tides on Earth's Rotation

According to our measurements, the Earth is slowing down by about 1.5milliseeconds per year. That means that 500 million years ago the day was 22 hours and 397 days per year. The Moon is slightly behind the bulge of water that is the tide simply because the Earth is rotating faster than the Moon is going around it. So the Moon is always pulling on the bulge of water and the water is dragging across the ocean floor. This causes friction and causes the Earth to slow down slightly. In several billion years the Earth will have slowed down enough so that the Moon will remain over the same place on the Earth.