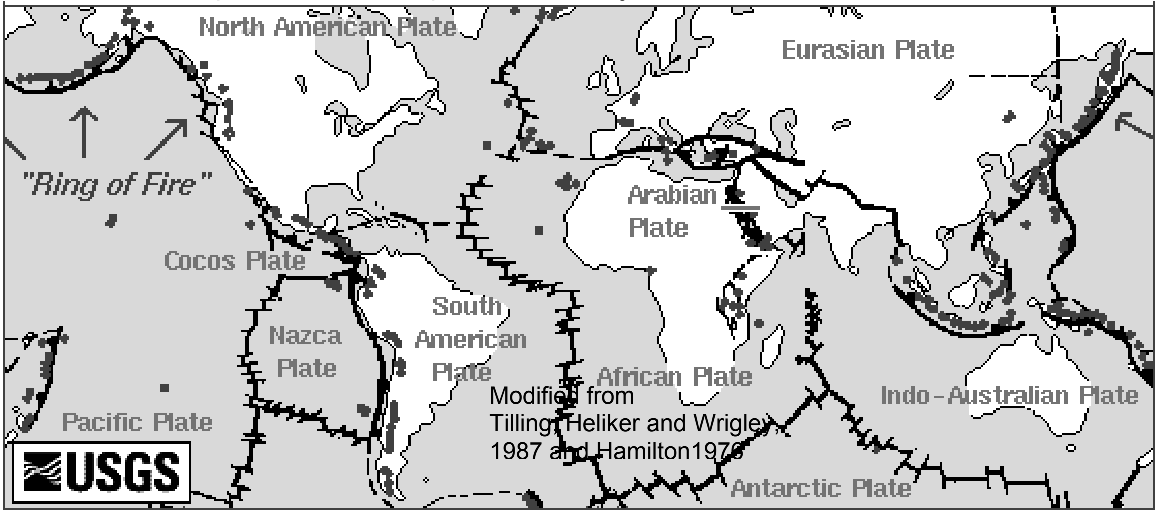
10 The Earth, Our Point of Comparison

As of June 2005, humans have visited only the Earth and our Moon. Unmanned machines from Earth have landed on Mars, Venus, Titan, the asteroid Eros and our Moon. And we a probe has entered Jupiter’s atmosphere. Since our experience with other planets and moons is so limited, we tend to use the Earth as a point of comparison and then compare and contrast the landforms, mountains, rivers, glaciers and oceans floors on the Earth can be compared with the features on other planets and their moons.

On the Earth, we see the effects of wind, water, and the molten interior. Wind and water are felt by each of us and also produce erosion. Effects of the molten interior can be seen in movements of the continents, mountain building, positions of volcanoes, and the presence of the Earth’s magnetic field. The overall theory of how the surface responds to the Earth’s heated interior is called **plate tectonics.**

Plate tectonics can be summarized as follows. The surface of the Earth appears to be divided into major sections, called “plates”. The plates are moved around on a slippery layer, called the aesthenosphere due to convection currents in the next layer down, the mantle. As we go into the interior of the Earth, models, experience, and earthquake evidence lead us to think that the temperature increases with depth. The outer core is interior includes liquid, while the even hotter inner core is solid.

Plates under the oceans can be a couple of kilometers thick. Under land, they can be as thick as 50 kilometers. Plates move away from one another where magma is oozing up from the interior of the Earth. Since there is no extra space on the surface of the Earth, they collide and the thinner oceanic plate slides under the land. This wrinkles the land, causing folded mountains, Earth’s most common kind. The plate boundaries are shown below. Small circles are locations of active volcanoes. Earthquakes occur more often under the boundaries of the plates. Volcanoes occur most often above places where sea plates are sliding under land.



Modified from
Tilling, Heliker and Wrigley,
1987 and Hamilton1976

Sometimes the plates move past one another, rather than colliding head on. This is what is happening with the famous San Andreas Fault and also with the Hayward Fault. The San Andreas Fault runs along the San Francisco peninsula, west of route 280 and under the San Andreas Lake and the two Crystal Springs Reservoirs. It goes out to sea at Daly City and comes back in at Bolinas. In the other direction it extends to near Los Angeles.

Today we can measure the actual change in position from one continent to the next, by direct measurement. The speeds typically average several centimeters per year, but some plates and parts of plates move freely and others are stuck. Typically earthquakes occur near plate boundaries. Earthquakes are especially strong, when the locked parts let loose. During the 1906 San Francisco earthquake, the fault moved about 8 feet on the peninsula. But some of the southern parts of the fault have been locked together, and not moving throughout that time. That is why people are predicting an earthquake near Parkfield, one of the stuck places.

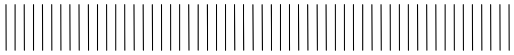
Alfred Wegener (d 1915) suggested that Africa and South America were once joined. The lump of Brazil would have fit into the notch below Equatorial Africa. The land animals and plants are not the same today on these two continents, but there are fossils, from more than 60 million years ago that are the same.

Wegener was not believed during his lifetime. But the evidence accumulated and by the late 1960's scientists became convinced that the continents were, indeed, moving. How did this come to be? It is a long story.

Over the years, people measured the effects of earthquakes. These effects (besides fear, destruction etc.) appear in the form of earth motion. Seismographs at a variety of distant locations record the motion in each direction. As people observe the vibrations from earthquakes, they use mathematical models to see how the vibration has traveled through the earth and where it came from. Whenever we have an earthquake, you will hear the announcement of the "epicenter". This is the location on the Earth's surface directly ABOVE the source of the earthquake waves.

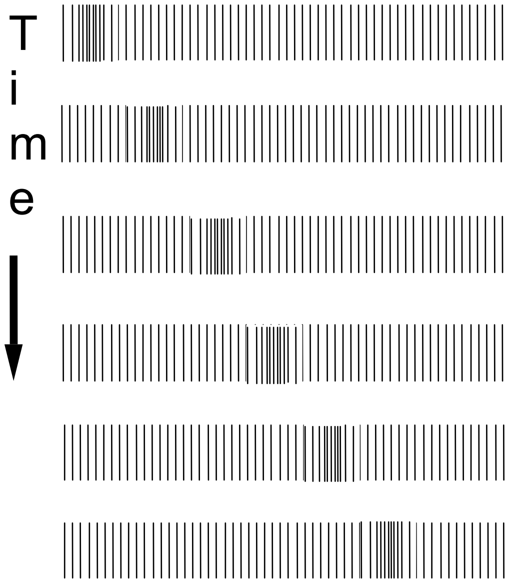
As people traced back earthquake effects, they follow several types of wave. There are surface waves (along the surface only), P waves and S waves. The P waves are also called primary or pressure waves. They are primary because they travel faster through the Earth and arrive first. The second waves to arrive, S waves or secondary or shear waves have a different pattern as shown.

Undisturbed Layers



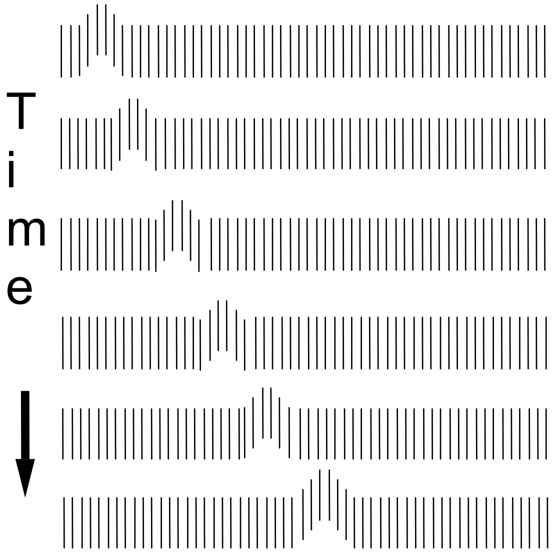
Surprisingly, it was found that P and S waves could not be seen from everywhere on Earth. It was not that the instruments were insensitive. It was found that both P and S waves could be seen near the earthquake epicenter. Then neither could be detected. And then on the side of the Earth opposite the earthquake, the P waves were detected, but not the S waves.

P wave, material is compressed along the direction of wave motion



Because of the way that the S wave moves material side-to-side, S waves will not travel through a fluid (liquid or gas). The P wave, however, will go through solid, liquid or gas. (Sound is a P wave and you can easily hear speech as it carries through gaseous air, or though solid walls. Sound travels through water as well, but it is pretty hard to talk under water.)

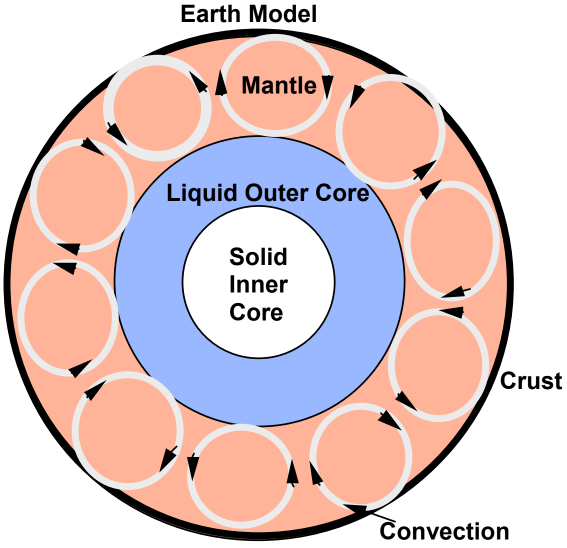
S wave, material moves perpendicular to direction of wave motion



As people modeled the interior of the Earth and tried to match the way that earthquake waves travel, it was found that S waves cannot complete paths that go within about the inner 2/3 of the Earth's radius. This is consistent with the presence of a fluid layer starting about 1/3 of the way in.

As scientists modeled the overall structure of the Earth, using the equations in described in chapter 9, they found that radioactive elements decaying and pressure from Earth's gravity do make it hotter inside than outside. The interior temperature is easily hot enough to melt rocks. As time goes by, the amount of the radioactive elements decreases and so does the head they provide. If we wait long enough (and the Sun does not vaporize the Earth first), the interior of the Earth would cool off to the point where it would all be solid. That is probably the situation today with small bodies like our Moon, Mars and various asteroids.

Our models of the Earth, supported by earthquake wave transmission data, lead us to an Earth of the Earth pictured below. The Earth includes a **solid inner core, a liquid outer core, a fairly rigid mantle, and a thin solid crust**. The slippery aesthenosphere is between the Mantle and the crust. The inner core is thought to be solid based partly on the high pressure and partly on the observation that waves travel faster going north-south, than going at different speeds depending on what direction they go. This is consistent with a partly crystal inner core, possible with a solid, but not with a liquid.



The overall idea of a molten interior, at least starting at the bottom of the mantle, dates from the 1930's. Evidence for the inner core with crystalline structure has been solidified in the 1990's.

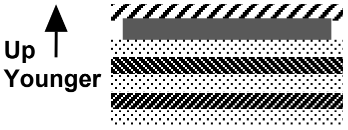
By the early 1960's special submarines were able to observe the ocean bottoms. They found that lava oozes up near the Mid-Atlantic Ridge and the East Pacific Rise. The lava heats the seawater above the normal boiling temperature. The water cannot become steam because it is under too much pressure. Specially-adapted forms of life found near these hot spots survive from the energy of chemical reactions in the material coming from the interior. Finding these life forms has substantially expanded our concept of where and how life can exist. Actually observing places where magma is coming up was a powerful demonstration that the plates might have a reason to move. So scientists looked at points at varying distances from the mid-oceanic ridges, they were able to observe

a) The seafloor got older and older going away from the ridge
b) The seafloor is magnetized in changing directions.

How could anyone decide on the age of a rock?

Finding the ages

As geologists (and you) look at layers in rock or dirt or dirty laundry, there is an initial presumption of age. Where would you say is the oldest part of the heap in the figure?

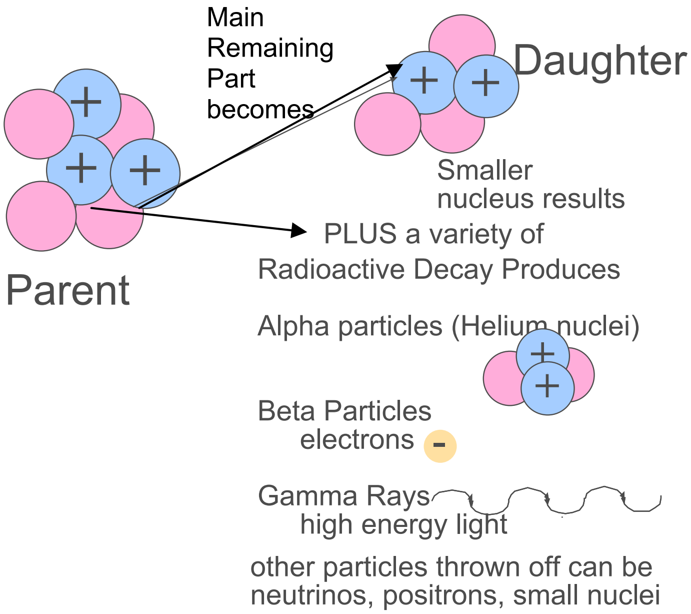


Given that the layers of stuff appear horizontal, we would expect that the lowest level is the oldest. We don't know for sure HOW old unless there is something with a definite date, like a newspaper buried or unless we have an accurate idea of how fast material is accumulating. Early geologists estimated the rate that rocks and earth would accumulate and estimated the age of the Earth to be at least a Billion (10^9) years. They did not have any way to get an age in years until well into the 20th century.

What would happen if there were several sets of layers, like in this figure? You could reasonably expect that the top layers are the youngest, but there is no way to tell whether the layers in the right hand pile are older or younger than the others, because there is no overlapping relationship. As here, the layers are not generally identical at widely distant points.

To get a relationship between these distant layers, we might use fossils found in each area. When a fossil is found in a layer, at least we can be sure that the layer was formed during the time that the particular type of creature was alive. This pins down the age of the layer somewhat. Typical species are around for ~ 5-10 Million years (not the individual plants or animals, the species), but some species change little over much longer times. And some fossils are not readily identified with fossils in other locations.

To get an actual age for a rock layer, the best way is to use radioactive dating. This is how we can find absolute ages for the seafloor. To use radioactive dating, it is important to understand how it works.



We often think of atoms and their nuclei as permanent, going on forever. But many nuclei are unstable. They fall apart spontaneously, without our doing anything. The falling apart process is called “**radioactive decay**” even though it has nothing to do with rot or fungus.

When a nucleus falls apart, it doesn’t just disappear. Usually it becomes one comparatively large nucleus, called the daughter, and a variety of smaller pieces (It’s like when you pick off a piece of a muffin. Most is left, and then there are crumbs). Some of the pieces are shown in the figure. Often when people talk of “radiation” they mean the results of a radioactive decay. In general it is not beneficial to get hit by these smaller pieces.

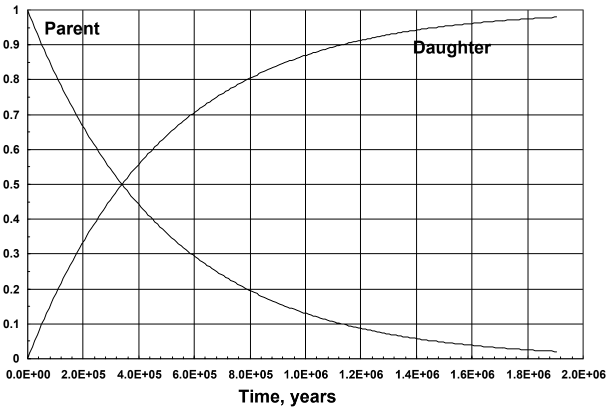
The timing of radioactive decay is what makes it useful for measuring dates. Each nucleus generally falls apart in the same way. They don’t get old, wear out, and fall apart (like us). They have a fixed probability of falling apart every second. The probability depends on the type of nucleus, but nothing else. People measure the probability of decay in the laboratory and then apply the knowledge to samples of rocks, bodies etc.

A plot of the decay of a hypothetical nucleus is shown below. The plot has two curves. One is the amount of parent, the original nucleus. The other is the amount of daughter, the nucleus that results from decay. The vertical axis shows the amount of each type of nucleus. It is given in relative terms. That is 1, or 100%, is the starting position for the parent. It doesn’t mean that something needs to be made of 100% parent, rather that whatever amount of parent you started with is all there.

Often people characterize the way a nucleus decays by its **half-life**. The half-life is the time for half of the existing parent to decay into daughter. After waiting one half-life, there is 50% as much parent as we started with. After two half lives, there is 25%. After 3 half lives, there is 12.5%. Theoretically, the amount of parent is halved each time one half life goes by.

As can be seen, the amount of daughter increases as the amount of parent decreases. This is because every time a parent nucleus decays, a nucleus of daughter is created. At every time, there is a unique combination of amount of parent and amount of daughter. So if we have a body and can measure the amounts of parent and daughter.

The horizontal scale is the age of the sample, since the time that there was all parent and no daughter. It is written in scientific notation by a computer. The value 8.0E+05 means 8.0 times x10^{+5}. The computer uses “E+05” to say, “The exponent of the power of 10 is positive 5.” It cannot write superscripts, so it uses the “E”. People normally write 10 and an exponent, NOT **E**.



Considering this particular plot, each large division on the horizontal scale is 2.0E+05 or 0.2×10^6. The next number after 8.0E+05 is not 10.0E+05 because it must be in scientific notation (only one digit before the decimal). So instead, it must be 1.0E+06 .

The small divisions are 1/5 as large as 2.0×10^5 or 4.0×10^4 years, just the result of dividing the number 2×10^5 (=200,000) by 5. Other types of nucleus will have different decay rates and different horizontal scales, but the principle will be the same.

How old is the material above when there is 70% daughter and 30% parent? 6.0×10^5 years
When there is 30% daughter and 70% parent?

It may seem odd to bother with the daughter. If we were running a simple experiment, we would know the amount of parent we started with and it would be unnecessary to assess the amount of daughter. In the real world, especially with rocks, we rarely know how much parent was present to start. This is because the minerals in rocks don't usually have fixed amounts of each element. Since you don't know how much of each element the rock started with, there is no way to tell how much of one element has decayed into another. IF both the remaining parent and daughter are still in the rock, one can add up the amounts and find the original amount of parent. THEN it is possible to find the age. If the daughter has been washed away or if it is a gas that has escaped, then the original total amount is not known, and there is no accurate way to find the age.
(Minerals are rather like lemonade. You make lemonade with water, sugar and lemon juice. There is no exact fixed amount of these different components, although there are limits to how much sugar you can get to dissolve. Because you wouldn't know the amount of lemon juice that you started with, it wouldn't be possible to know what fraction of it was left at some later time.)

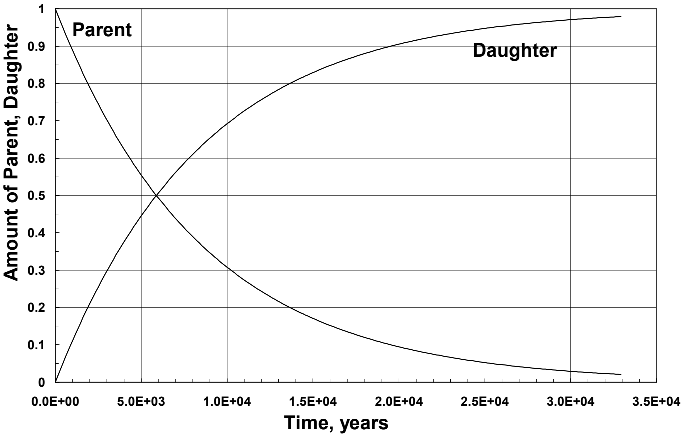
Not every rock has any radioactive elements in it, and not every radioactive element allows us to find the age of a rock. The amounts of parent and daughter give a good age determination when there are substantial amounts of both present. When a sample has 99.99% daughter, for example, it is hard to tell the age accurately. The amount of parent is so tiny it is hard to measure and the amount of daughter is not sensitive to the age.

The properties of some radioactive elements are shown in the table. The number before the element name tells the atomic weight, the number of protons plus the number of neutrons in the nucleus. As you can see, in some cases the decay causes a substantial change in the atomic number. In others, one neutron changes to a proton and the atomic number stays the same.

Parent	Daughter	Half-Life (years)
^{238} Uranium	^{206}Lead	4.508×10^9
^{235} Uranium	^{207}Lead	0.713×10^9
^{129} Iodine	^{129}Xenon	1.7×10^7
^{40} Potassium	^{40} Argon	1.3×10^9
^{14}Carbon	^{14}Nitrogen	5870

For rocks, elements like Uranium and Potassium are useful. The half-lives for these elements are so long that there will surely be some of the parent left in a rock. The Argon produced when Potassium decays is a noble gas. It does not form compounds. So argon will be bubble out of a rock if it melts after the argon is formed. The age from potassium-argon dating tells the time since the rock solidified.

You may have heard about Carbon 14 (^{14}C) dating. It is important, but never used for rocks. It is only useful for things that were once alive and that have died within the last 30,000 years or so. This is because the short half-life of ^{14}C means that it will be all decayed by the time a rock has formed.



Carbon 14 is continuously created in our atmosphere by the effect of cosmic rays on the nitrogen. As we all eat and breath, some of the ^{14}C is incorporated in our bodies. It is always decaying, but we renew the ^{14}C by eating and breathing more.

When we die, the carbon changes to nitrogen. Anthropologists often dig up sites where people used to live. They find bones and baskets (made of reeds) and are able to find the time since these things were alive from the ^{14}C dating. Carbon 14 dating has been compared with tree ring ages for the last several thousand years, thus verifying its time scale. Trees form rings every year and the size of the ring depends on growing conditions. So the rings and ^{14}C both tell an age, and the ages can be corrected to be the same.

How old is a sample with 90% ^{14}C and 10% ^{14}N ? (as shown in the plot)

So to **summarize**, we find ages by

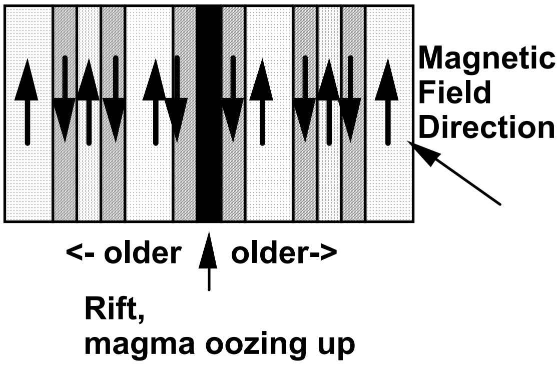
a) Stratigraphic Dating , the younger thing is on top, if the layers are horizontal
b) Fossils tell that a layer was first formed when the species was living
c) Radioactive dating tells the actual age since the rock was formed

Back to Plate Tectonics

So as scientists looked at the rocks in the sea floor on either side of the mid –oceanic ridge, they found that the further away from the ridge, the older the rocks.

They also found that the rocks at the bottom of the ocean are igneous rocks, that is rocks that are formed from solidification of lava or magma.

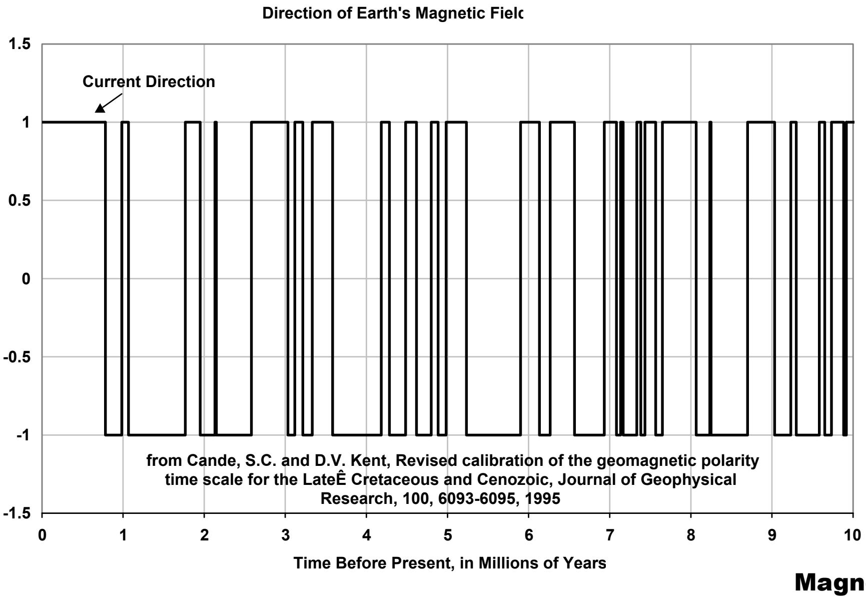
When these rocks solidified, they were magnetized by the Earth's magnetic field. A magnetic field is due to the orbits of the electrons in the atoms aligning to one another, so that the electrons have a predominant direction of motion. The electrons can align when the atoms move around as a melted material cools and solidifies. Once it is solid, the atoms do not move around very much and the magnetic field remains fixed. If the material is heated too much, even if it is not melted again, the electron orbits realign. The magnetic field can be lost.



When scientists examined the material in the seafloor, they found that there were regions of reversing magnetic field, symmetrically placed on the sides of the mid oceanic ridge. This is just what we expect for a seafloor formed in the presence of the Earth's magnetic field. For many years, geologists have noticed that as they dig down into rock layers, the rocks have reversing magnetic fields. At least 92 magnetic field reversals have been detected in just the last 118 million years. But there may have been more. If the magnetic field reversed for just a short time, there would be few rocks magnetized by the reversed field and it would be hard to detect.

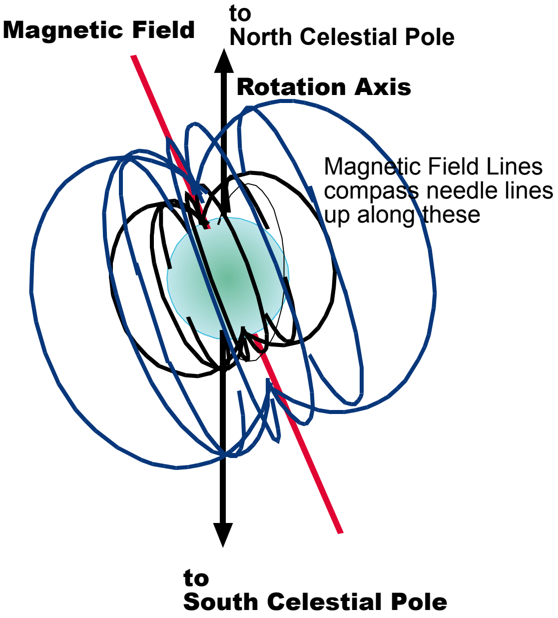
The plot shows the history of the direction o f Earth's magnetic field over the last 10 million years. The magnetic field has been in the same direction for about 780, 000 years, an unusually long time.

The Earth's magnetic field has a consistent shape over the entire surface of the Earth, called a dipole, as shown in the diagram. It is a little like the surface of an apple, with the North and South magnetic poles at the stem and flower ends of the apple. Magnets, like the magnet in a compass or like the magnetic field of a rock, line up just opposite the magnetic field lines. Because of this consistent shape, we can relate the direction of the field at any two positions near the Earth.



from Cande, S.C. and D.V. Kent, Revised calibration of the geomagnetic polarity time scale for the LateÊ Cretaceous and Cenozoic, Journal of Geophysical Research, 100, 6093-6095, 1995

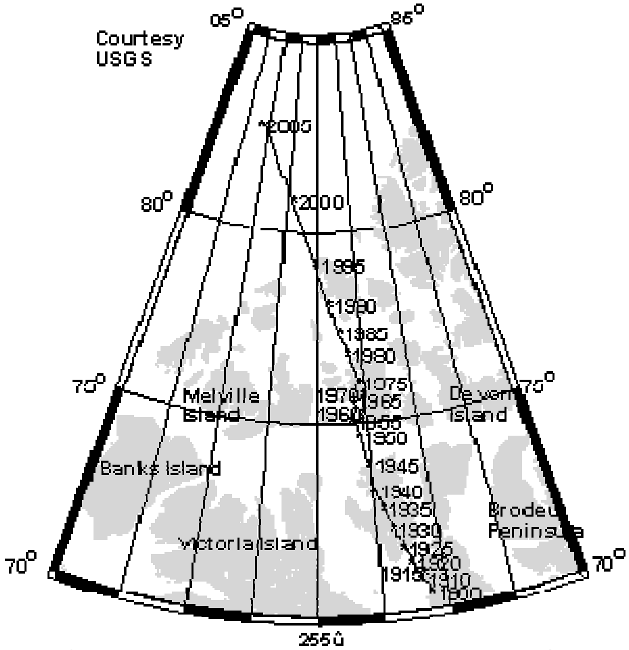
You may notice, that the directions of the North and South MAGNETIC Poles are not the same as the North and South GEOGRAPHIC poles. Maps, latitude and longitude are all referred to the geographic poles. Many maps show the correction to apply to the magnetic north direction (what a compass shows). The magnetic poles wander around on a scale of years, as can be seen in the figure.



But why a magnetic field? And why does it change? We think that the rotation of the liquid outer core, an electrically conducting material, will generate electric currents. These currents, in turn, result in magnetic fields. As time goes by, the direction of the flow changes. Since approximately 1995, computer simulations that model the motion of the interior of the Earth have resulted in magnetic field reversals.

Regardless of exactly how the magnetic field reversal occurs, the combination of the overall dipole shape and the worldwide reversals gave scientists the clue they needed to map positions of the continents well into the past.

NORTH MAGNETIC POLE MOVEMENT



Courtesy USGS

Remember, near the mid oceanic ridge the seafloor is magnetized in stripes. If we go back in time, to times BEFORE these stripes of seafloor were present, the Atlantic Ocean was smaller. Wegener was right, North America and Europe used to be connected, as did South America and Africa. The compression of North America into Europe caused the wrinkles that are now the Appalachian Mountains in the United States.

As we go further back in time, the stripes are not strictly parallel. Using the radioactive dates for these stripes and forcing the magnetic field to a dipole shape, it becomes clear that the continents were not all aligned as they are now, and their locations were very different. Current models go back to about 650 Million years ago. At that time, the placement and size of the continents was entirely different from today. Past positions of the continents will be discussed in class and can be found from the Internet.

Is 650 Million years the entire age of the Earth, or of the rocks? Hardly. Based on models of the Sun and on the oldest rocks from Earth and Moon, we think that the entire Solar System is about 4.56 Billion years old. So why don't the models go all the way back?

For one thing, the seafloors are formed, then thrust under the continents and melted. Once the crust has been melted again, there are no magnetic stripes and no radioactive dates. So it is hard to establish just where the land and the ocean were. Also there are few fossils before about 550 Million years ago. There was plenty of life before that, but it had no hard body parts (skeletons, shells etc). So again it is hard to trace.

What was the very Early Earth like then?

The very earliest Earth would have been melted due to heat from collisions of dust and later planetisimals. The melted material would allow the denser materials, like Iron, to fall to the center. This is consistent with both our models of the Earth and with the effect of its gravity on satellites and the Moon.

The earliest atmosphere was hydrogen and helium gas from the solar nebula.

For the first 1 Billion years or so, there were many planetisimals left in the solar nebula. Many of them collided with the planets (including the Earth), helping to keep them hot. A crust did form over the molten interior, and the composition of the atmosphere began to change. Hot lava oozed up from volcanoes. But as this happened, the atmosphere began to change.

When lava comes up from below the Earth's surface, water (H_2O) and carbon dioxide (CO_2) are released. Typically these molecules are dissolved in the lava when it is under pressure inside the earth. As the lava reaches the surface, water and carbon dioxide come out of solution. They form bubbles in the lava, and are released into the atmosphere. They formed a second atmosphere for the Earth. The water, of course, was not only present as a gas. It formed oceans, lakes, and rivers as well. The carbon dioxide formed the bulk of Earth's atmosphere.

We can tell that the atmosphere was largely carbon dioxide from our observations

a) Anaerobic bacteria and other life forms are found now and in the fossil record. Anaerobic means without air, in the sense of without oxygen. Some anaerobic life forms cannot live in the presence of oxygen, others just do not use oxygen. These were the dominant form of life before Oxygen became abundant in our atmosphere.
b) Minerals, like the Banded Iron Formation, that were formed in the presence of a very low level of oxygen. Banded Iron Formation deposits with ages from 1.8 to 3.2 Billion years demonstrate that there was less than 1% as much free oxygen when they formed as is available today.
c) Molecules of Oxygen gas (O_2 or O_3).are not stable. They react readily with many materials. To maintain oxygen in the atmosphere, it must be renewed constantly. Today, and in the past, life forms release free oxygen. One easy indication that a planet has life is oxygen in its atmosphere.

Even though there are few fossils before about 550 Million years ago, there are evidences of life. One of the most striking is **stromatolites**. These are mineralized remains of colonies of single-celled lifeforms. For a long time, stromatolites were not clearly identified as fossils. They were thought to be just rocks. Then living stromatolite communities were discovered in some low oxygen water off of western Australia. The community includes bacteria that produce oxygen on the outside in contact with the water, bacteria that cannot tolerate oxygen further in. As time goes on, the outside layers die and their remains become mineralized. New layers of bacteria grow on top, until the entire colony gets quite large. Entire decorative columns in China are built of the mineral remains. The earliest known stromatolite colonies are dated to about 3.85 Billion years before the present.

So how did there come to be free oxygen in our atmosphere? Green plants do, today, free oxygen. But green plants and land-based life (as opposed to life in the oceans) developed when oxygen levels were nearly as high as today. Oxygen levels rose from negligible levels to current levels between abut 1.9 Billion years ago and 400 Million years ago.

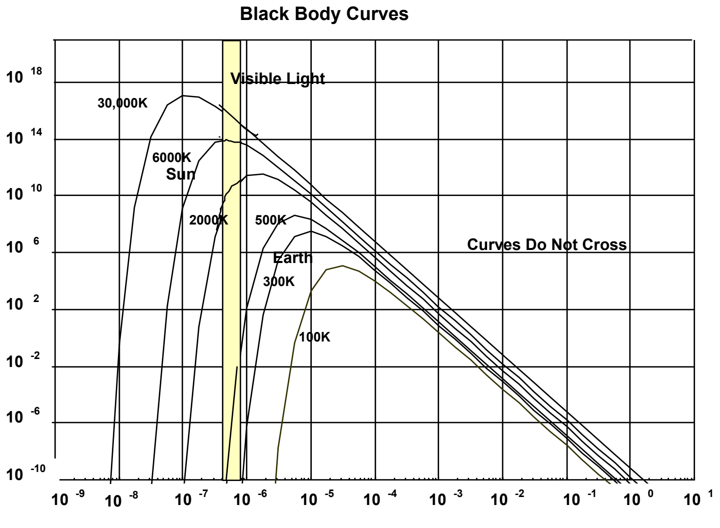
We think that this was due to a combination of Carbon Dioxide dissolving in the oceans and some of the carbon precipitating to the bottom and to the development of skeletons. Skeletons, in the form of sea shells, use carbon. When the animals die, the shells are not all immediately recycled. Many of them fall to the bottom of the sea. Some are compressed into the limestone we see today, some of the seafloor is dragged back under the continents as a result of plate tectonic motions. These processes reduce the amount of carbon dioxide in the atmosphere implying that our atmosphere was once much denser. This is consistent with what we see on Venus. Venus' atmosphere is mainly carbon dioxide and it is some 90 times as dense as is Earth's. We think that Venus has never had life or water to remove the carbon dioxide.

What is a better atmosphere? Oxygen or carbon dioxide? We humans cannot breath carbon dioxide. But plants do use it and it may be possible to breed plants to live in an all carbon dioxide atmosphere. Many anaerobic bacteria cannot live in the presence of an oxygen atmosphere. So for them, carbon dioxide is MUCH better.

Oxygen benefits life on land because it forms the molecule ozone (O_3) as well as O_2. Ozone is toxic to us and is considered air pollution when it is at ground level. (You many have smelled it when there is an electrical fire or lightning.) But ozone high in the stratosphere protects us from some of the Sun's ultraviolet light. Ultraviolet photons carry a lot of energy and can break up molecules. When they hit our body, they can cause tanning, cataracts, and sometimes skin cancer. When an ultraviolet photon hits an ozone molecule, the molecule can be broken up. The energy of the photon goes into breaking up the ozone and into giving kinetic energy to the resulting O and O_2. This protects us in the same way that a bulletproof vest protects a person. If a bullet hits a person in a bulletproof vest, the energy of the impact is spread out and the bullet doesn't go straight into the person's flesh. When an ultraviolet photon is absorbed by the ozone, the energy is spread out. It heats the atmosphere, but doesn't get to break up our molecules.

Ozone in the stratosphere is not constant. During the winter, the ozone near each pole decreases. Weather patterns isolate the air near each pole from the rest of the atmosphere during the winter. In the spring, ozone-rich atmosphere from nearer the equator mixes with the polar air and enriches the ozone. We have been monitoring the amount of ozone and finding that the area with low ozone has been increasing and the amount of ozone in a column of air above the polar region has been decreasing (at least up to about 2000). In the last few years the amount of ozone has varied, but the hole has not really gotten larger.

This change may be part of some long-term cycle, but we think it is also part of a reaction to man-made pollution. In the 1960's and early 1970's chlorofluorocarbons (CFC's) were used as propellant in spray cans and as refrigerant (the working fluid to make air conditioners and refrigerators work). The CFC's were released into the atmosphere when the cans were sprayed or when air conditioners leaked. The molecules slowly rose to the stratosphere where we think that the chlorine atoms become detached from the rest. Chlorine is very reactive. It is able to break up an ozone molecule, rather than allowing the ultraviolet light to do it. One chlorine atom doesn't just break up one ozone molecule. The chlorine atoms interact with the atmosphere, are freed up, and



can break ozone after ozone so long as the chlorine remains in the stratosphere, expected to be around 50 years.

When it was realized that the CFC's would affect the ozone, a series of international treaties were implemented. The goal was to limit the CFC release. At the time, there was no known substitute for freon, a refrigerant. In the last 30 years, substitutes have been found and refrigerators have been redesigned. Based on these treaties and the smaller amounts of CFC's released, we still think it will take until about 2100 for the ozone level to come back to the level before CFC's. The worst time for the ozone is predicted to be around 2000-2001.

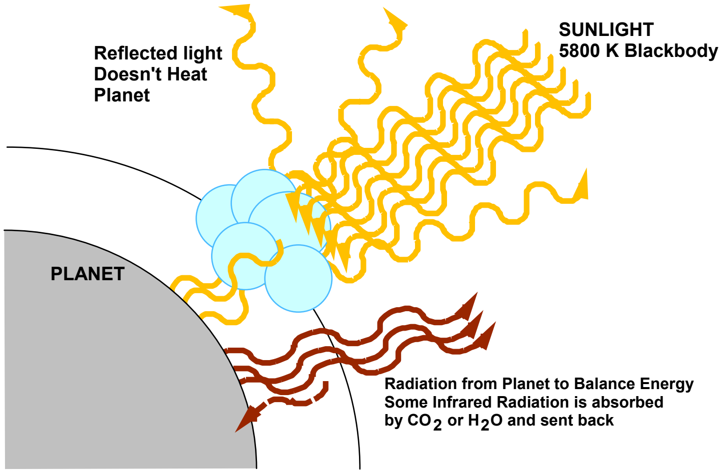
So ozone protects life on land from ultraviolet light. Life in the ocean is protected by the overlying water. Oxygen dissolved in the upper levels of the oceans are what fish use for their respiration. The deeper levels of the ocean have little oxygen, and (we think) much lower prevalence of life.

Carbon dioxide and water vapor have their own effects as an atmosphere. They are "**greenhouse gases**". They act to keep a planet warm.

To understand how the greenhouse effect works on a planet, go back to the idea of black body curves. Dense bodies, like the Earth, give off energy like a black body. Depending on the temperature, a black body gives off a specific amount of energy with a specific distribution of wavelengths, as shown. The hotter the body, the more energy given off.

Most of Earth's energy is from the Sun, which also gives off a black body spectrum (with overlying absorption lines) consistent with its surface temperature, about 5800K. Some of this energy is absorbed, some reflected. As the Earth absorbs energy, it heats up. It gives off energy according to its temperature. Earth either heats or cools until the amount of energy it gives off just equals the amount it absorbs. So?

The Sun produces a black body curve with a maximum near 5000 Å, visible light. On the other hand, the Earth produces a black body curve with a maximum near 96,600 Å infrared light. Carbon dioxide and water vapor both absorb light strongly in the infrared. These molecules reemit the energy from the absorbed photons, but not necessarily in the same direction. So the infrared radiation is prevented from leaving the planet. What happens? The planet has not given off the exact same amount of energy that it absorbed. So it must heat up. As it heats up, the black body curve changes to one that gives off more total energy. The planet heats up until the net energy lost, even in the presence of the greenhouse gasses, equals the energy gained. This changing temperature may change the cloud cover and/or the amount of snow. So the energy gained might change too.



(Practical Note: The goal of glass greenhouses for plants, is to keep the plants warm. The glass keeps infrared radiation in, and **also** keeps cold breezes from chilling the plants. Breezes matter a lot for plants, but not for planets. Motion of atmosphere of a planet just evens out the temperature between the day and night. It cannot change the average temperature.)

As you may imagine, it is not easy to figure out how much difference the greenhouse effect makes. Estimates for the Earth are that it is 35K (x 9/5 ^{o}F/K =63^{o}F) warmer today with the current amount of carbon dioxide than it would have been without. Today only 0.03% of the atmosphere is CO_2. In the distant past, when there was a larger amount of carbon dioxide, the greenhouse effect would have been larger. But also the Sun used to give less light.

Is the greenhouse effect a good thing? What would happen if the Earth were 63^{o}F colder?
What would happen if the Earth were warmer? Has the climate really changed?

Over the years, the climate certainly has changed. At one level, we are coming out of an ice age. The northern US (as far south as Indiana and Sacramento) had glaciers on it. On a shorter time scale, we know that Greenland had agriculture when the Vikings moved there in perhaps 800CE. By 1000CE, the climate had changed enough that they were looking for somewhere else to go (like Vinland in Canada). It had become (and remains) too cold on southern Greenland. Some scientists think that the Earth has had periods when ice covered the ocean surface entirely. Based on estimates covering the last 550 million years or so, the current epoch is on the cool side of a variation that covers about ± 10 degrees Fahrenheit.

On the other hand, can people cause climate change? Most scientists are in agreement that the weather has been getting hotter since about 1850. Glaciers are melting and the Arctic (northern) ice pack is getting smaller. Some estimates predict no Arctic ice by about 2020.

This global warming may be due to increasing levels of carbon dioxide in the atmosphere. Most industrial processes burn fossil fuel and release carbon dioxide. Over the past 150 years or so, since the industrial revolution, the carbon dioxide level in the atmosphere has increased by about 17%.There is great concern that if the ice caps melt and the oceans warm up, sea level will rise. Florida would be largely under water. If the greenhouse effect increased enough, all the water might vaporize. Without liquid water, the climate on earth would become very extreme, hotter in summer and colder in winter. This sounds far fetched, but our twin planet Venus, is estimated to be 400K hotter because of its extreme greenhouse effect.

Can we do anything to limit the greenhouse effect? There are international treaties limiting the amount of carbon to be released into the atmosphere in the future. The United States has chosen not to participate in these treaties.

Earth History

TIME (yr ago)	Event	Evidence
~14 Billion	Big Bang	Expansion of Universe as seen in redshift of galaxies and quasars
Before the solar system	Stars create atoms heavier than Hydrogen and Helium, Gas cloud which becomes Sun and Planets exists, Supernova explodes making Aluminum 26	Magnesium 26 (the decay product of Aluminum 26) is found in grains in meteorites, Other stars are seen forming in gas clouds
4.5-4.6 Billion	Formation of solar system from gas cloud	Radioactive dating of Rocks, Computations of Solar Evolution
3.8 Billion	Early Life (really firm evidence 3.5 BY)	Stromatolites and blue green algae fossils found
2.5 Billion	Earliest Known Glaciers	Scratches on Rock Faces, Radioactive Dating, and Strata of remaining rocks
3.2- 1.9 Billion	Oscillations in atmospheric Oxygen	Banded Iron found, Radioactive Dating, and Strata
650 Million	Fossils of soft bodied, complex animals	Burgess Shales
550 Millions	Animals with exoskeletons	Fossils found
400 Million	Oxygen reaches values near modern levels	Oxidation levels in rocks, radioactive dating of embedded fossils
240 Million	Dinosaurs begin development	Fossils and radioactive dating
225 Million	Pangeia all together	Fossils indicate shorelines, radioactive dating, magnetic fields in rocks show alignment of continents
65 Million	Dinosaur extinction, mammals begin rise	Iridium in dark rock layer. Above layer many species become extinct. Ages from radioactive dating.
~5 Million	Earliest known fossils of Human branch	
10,000	Last major glaciation	