

EARTH TO SPACE: EXPLORATIONS
AN EDUCATORS' RESOURCE GUIDE

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South Florida Museum

Introduction

What is Earth most like?... It is most like a single cell.

-Lewis Thomas, biologist

The planets of our solar system can be divided into two major categories: the terrestrial, or rocky, planets and the Jovian, or gaseous, planets. The Earth is one of the four terrestrial planets, the others being Mercury, Venus, and Mars. These small planets have in common dense, solid surfaces and denser cores of iron and nickel. Here, the similarities end. The differences in the composition and amount of gases in the atmosphere, the presence or absence of water and the surface temperatures of these planets is pronounced.

Today, we know a great deal about the processes that formed the earth and brought into one small place the elements and conditions necessary for the beginnings and sustenance of life. It is possible now to view the Earth as a unified system, in which the solid, liquid and gaseous aspects of the planet have conspired to create a global habitat for a variety of life forms. Consider the following sequence of events: Intense heat deep inside the Earth melted rock and metal which had trapped gases for millennia. Volcanoes released these gases, which included water vapor, to create the atmosphere, out of which water condensed to form the oceans. The oceans in turn provided a protective shield from harmful ultraviolet solar radiation, allowing life to begin. The simple plant life that began in the oceans then created oxygen, from which ozone is created, forming an atmospheric shield against ultraviolet radiation, and thus allowing life to leave the safety of the oceans and appear on land. From these beginnings, mankind has developed the technology to leave the safety of the life-giving Earth, to explore the space around our planet, and to learn about our neighboring planets to see why they were not so hospitable as to allow life to flourish.

When contemplating the Earth, then, it may be helpful to think not in terms of the separation of its various parts, but instead to think of the Earth in terms of *interacting* spheres, each with unique properties. Starting from the ground up, we should first consider the solid earth, the densest sphere in terms of its material and the anchor for all of the planet's features. Next, covering most of the surface of the solid earth's outermost layer (and the lower parts of the atmosphere) is the Earth's hydrosphere – water in all three of its states. Blanketing the whole layer of gases called collectively the atmosphere. And finally comes the biosphere (in this case a sphere in a more metaphysical sense than geometrical), a sphere composed of relationships between living things and their habitats.

Formation of Our Solar System

During the 17th century, Archbishop James Ussher declared that the Earth was created at 9 o'clock in the morning on October 23, 4004 B.C., which would make Earth about 6000 years old today. Since then, scientists studying the Earth and space have determined that, far from being created in a single day, our solar system, including the Earth, was created in a process that took millions of years, and continues today. Astronomers peering out into the Universe have spied stars engaged in various stages of planet-making, and indication that planets are a natural by-product of star formation. Geologists here on Earth have identified rocks as old as 3.8 billion years, and meteorite samples almost 4.5 billion years old. The combined efforts of these scientists have led to a coherent theory of solar system formation, which supposes our solar system to be approximately 4.6 billion years old.

The Sun, a typical mainstream star, began forming approximately 4.6 billion years ago from a cloud of gas and dust. As the cloud contracted under its own gravity, a rotating core was formed at its gravitational center, a process that took tens of millions of years. In the core, hydrogen gases reached a density 160 times that of water and a temperature of approximately ten million degrees Kelvin, resulting in a nuclear reaction in which the hydrogen atoms fused to form helium atoms. The onset of this fusion reaction marked the birth of the Sun as a new star.

The new-born Sun was surrounded by a swirling “cocoon” of remnant gas and dust called a solar nebula. The rotation of the Sun and its nebula caused the nebula to flatten out into a protoplanetary disk, similar to the series of rings found around Saturn today. The particles of gas and dust in this disk, called planetesimals, were re-distributed by heat from the Sun. High temperatures close to the Sun prevented more volatile elements from condensing, while farther out colder temperatures meant that gases and ice could form. Thus, the materials available for planet formation differed as distance from the Sun increases, with denser materials (iron and silicates) found closer to the Sun and less dense materials (gases and ices) farther out.

The second stage, **cratering**, took place after the crust had formed. Planetesimals, asteroids, and meteoroids that had not become part of any planet crashed into the newly formed crust of the terrestrial planets as they orbited the Sun. These impacts cratered the Earth just as they did the Moon, Mercury and Mars. Many scientists believe that water-laden comets deposited large amounts of water on Earth during this stage. In time, most of the extra-planetary debris in the Earth's orbit had been “swept up” and

cratering lessened. It is interesting to note, however, that the Earth still has over 1000 tons of cosmic debris fall to its surface every day.

The third stage, **flooding**, occurred as radioactive material decayed in the Earth's interior. Heat released from the radioactive material, in combination with the already great temperatures deep in the Earth, created massive magma deposits beneath the crust. Magma welled up through fissures and volcanoes and flooded the surface with lava. On Earth, a great deal of water vapor and carbon dioxide was released during this period. As the surface cooled, the water vapor in the atmosphere began to condense and fell as rain, which flooded low regions to form the oceans.

The fourth stage, **surface evolution**, began 3.5 billion years ago at the end of the flooding stage, and continues today. Earth's surface changes slowly as the result of plate tectonics and wind and water erosion. These forces have erased most of the evidence of the cratering stage on Earth.

SOLID EARTH

Earth's Internal Structure

The solid Earth can be compared to a spherical hard-boiled egg with its concentric layers of shell, egg white and yolk. The shell corresponds to the Earth's thin **crust** of solid rock, the egg white to the layer below the crust called the **mantle**, and the yolk to the Earth's core.

The crust of the Earth is a thin layer of relatively light, solid rock. There are two types of crust, continental and oceanic. Continental crust is on average 35 km (21 mi.) thick, and may be as thick as 70 km (4 mi.) beneath major mountain ranges. It is composed of felsic (granite) material. Oceanic crust is thinner, only 7 km (4 mi.) deep, and is composed of denser mafic rocks (basalt and gabbro) overlain by sediments. [See Figure 2]

FIGURE 1

As the protoplanetary disk continued to revolve around the Sun, planetismals began to form "clumps" through a process called **accretion**. Accretion is basically a process in which particles collide and stick together to form larger clumps. The larger planetismals, with their greater gravitational pull, swept up the smaller planetesimals in their orbits until they grew large enough to be described as protoplanets and, eventually, planets.

[See Figure 1]

Earth's Four Stage History

The Earth has undergone remarkable changes as it has evolved from a protoplanet into the mature, life supporting planet it is today. As the early stages of the solar system's formation ended, nine major bodies emerged as planets. Earth and the other terrestrial planets then began a series of changes. The first stage was **differentiation**, the separation of materials according to their density. The newly accreted material forming the Earth was being pulled toward the planet's center by gravity. Heat from compression raised temperatures to the point where the Earth actually melted through to its core. In this liquid state, the densest materials, iron and nickel, sank toward the center of the planet forming a solid metallic core, while other materials formed layers around the core according to their density. Eventually, the least dense materials, the silicates that made up the outermost layer, cooled and solidified to form a thin crust.

FIGURE 2

Beneath the crust, and extending to a depth of 2900 km (1800 mi.) lies the mantle, dividing into upper and lower sections. The upper mantle is solid, and combines with the crust to form the lithosphere ("litho" = "rock"), which drifts as a unit over the lower mantle's more fluid material. At its deepest, the lithosphere extends 100 km (60 mi.) below the Earth's surface. Temperature in the lithosphere increases with depth at a rate of about 25° C. per km (77° F. per mi.) Beneath the lithosphere, temperature increases at a slower rate. The lower mantle is divided into two sections, the **asthenosphere** and the **mesosphere**. Like the upper mantle, the lower mantle is composed of rock. The topmost layers of the lower mantle, the asthenosphere, extend to a depth of 350 km (210 mi) beneath the crust. In this layer, high temperature (which tends to melt rock) and high pressure from the overlying layers (which tends to inhibit melting) create a situation where the rock acts more like a liquid than a solid.

In the asthenosphere, high temperature (which tends to melt rock) and pressure from the overlying layers (which tends to inhibit melting) create a situation where the rock acts more like a liquid than a solid. Rock in the lower mantle has been compared to Silly Putty. If pulled apart quickly, Silly Putty will snap, as the rock in the mantle would if subjected to sudden severe stress. But pulled slowly, Silly Putty will stretch almost indefinitely. Rock in the lower mantle moves like Silly Putty pulled slowly: it will

“flow” over time, but it is not truly “liquid”. Farther down in the mesosphere, increased pressure prevents rock from melting despite higher temperatures.

FIGURE 3

The Earth’s core consists of two sections, the outer and inner core. Both are made of dense metallic elements, mainly iron and nickel. In the outer core, extremely high temperatures cause the metals to occur in liquid form. Convection of this metallic liquid is thought to create the Earth’s magnetic field. Despite high temperatures, however, the pressure near the center of the Earth – about 4 million times atmospheric pressure at the surface – forces the material of the inner core to become solid. The center of the Earth is some 6370 km (3958 mi.) from the surface. [See figure 3]

Plate Tectonics

Since they began exploring the Earth, mapmakers and geographers were intrigued by the shape of the Earth’s continents, especially the coast lines of western Africa and eastern Southern America, which appear to fit together like pieces of a jigsaw puzzle. In the 19th century, more interest was generated when geologists discovered that the two continents had similar coastal rock formations and fossils. In 1912, German meteorologist Alfred Wegener proposed that the Earth’s continents were once joined together as one giant continent, which he called Pangea (Greek for “all Earth”), and that over the millennia the pieces have drifted apart. Wegener’s theory, though recognized by some scientists, was generally dismissed. It wasn’t until the 1960’s that studies of the ocean floors revealed sufficient evidence for sea floor spreading, which could explain the puzzling observations of the past. Wegener’s theory of “**continental drift**” has since been refined and continues to develop as the theory now known as “**plate tectonics**”.

Plate tectonics theory states that the Earth’s lithosphere is broken onto seven large and several small sections called plates, which float like rafts over the asthenosphere. Like the Earth’s crust, plates may be described as continental or oceanic. Continental plates are generally thicker, but less dense than oceanic plates. These plates travel in different directions and can diverge, converge, or slide past one another. It is at plate boundaries that most major tectonic activity, such as earthquakes and volcanism, occurs.

There are four principal boundary types between plates. A boundary where one oceanic plate collides with another, or with a continental plate, is called a **subduction zone**. In such collisions, the denser of the two plates will slide under the lighter plate into the mantle below. The second type of

boundary is called a **transform boundary**. Transform boundaries occur where two continental plates slide past one another, creating friction, which may eventually result in an earthquake or volcanic activity. An example of this type of boundary is the San Andreas Fault near the California coast. The third type of boundary is the **collision zone**. When two continental plates collide, subduction does not occur, because continental plates are too light to sink into the mantle. Instead, the two plates crumple against each other, forming huge mountain ranges, such as the Himalayas. The fourth type of boundary, a spreading zone, occurs when two plates diverge, or move away from one another. As two continental plates move apart, a rift or valley may form, such as the Rift Valley in eastern Africa. Under oceans, gaps created by diverging plates are filled by magma that rises from the atmosphere. As the magma cools, it becomes part of the lithosphere, in the form of a long, narrow range of hills or mountains, such as the Mid-Atlantic Ridge. [See Figure 4]

FIGURE 4

Types of Rocks

Rocks can be divided into three main groups based on the way they are formed. **Igneous** rocks formed from solidified molten material called magma while still inside the Earth's crust or lava when it reaches the surface. There are two basic types of igneous rocks: **intrusive** and **extrusive**. Intrusive, or plutonic, rocks such as granite and gabbro are formed from magma that cools and solidifies deep beneath the surface of the earth. Because they cool slowly, large mineral crystals grow. Extrusive or volcanic rocks, such as obsidian and basalt, form from the solidification of lava on the surface of the earth. Because they solidify more quickly than intrusive rocks, mineral crystals in volcanic rocks are very small to non-existent.

Sedimentary rocks such as sandstone and shale are formed from other rocks that are broken down into small pieces, transported by wind, waves, and running water, and deposited in layers on land or at the bottom of lakes and oceans, where they are squeezed and cemented together. Evaporites such as salt and gypsum are sedimentary rocks that form by precipitation of minerals from a saturated solution. Sedimentary rocks are also generated by or composed of formerly living organisms: limestone is made of calcareous shells of marine organisms; coal is composed of ancient plants.

Both igneous and sedimentary rocks can be changed or recrystallized into metamorphic rocks by additional heat and pressure. For example, granite (an igneous rock) can become gneiss, and sandstone (sedimentary) can be metamorphosed to quartzite. [See Figure 5]

FIGURE 5

Explorations

While it is impossible to travel deep into the interior of the Earth, it is possible to learn about its structure indirectly by studying seismic waves as they pass through the various layers that make up our planet. Geologists and seismologists study the energy released by earthquakes. Earthquakes release their energy in four different types of waves, primary waves (P-Waves), secondary waves (S-Waves), Love waves and Rayleigh waves. P-waves and S-waves travel through the Earth, Love waves and Rayleigh waves are surface waves. Only P-waves are compression waves, they move by compressing and stretching the material, much like waves on the ocean. S-waves cannot travel through liquids. [See Figure 6]

By studying the paths of P- and S-waves as they travel through the interior of the earth, scientists have been able to locate many boundaries, areas where density and composition change, deep within the Earth. Most importantly, it was discovered that S-waves did not travel through the outer core, an observation which suggests that the outer core is molten.

LIQUID EARTH

A visiting extraterrestrial might be amused at our chosen name for our planet. Earth, if taken to mean a solid dense substance derived from rock and minerals, covers only about 24% of the surface of the planet; water accounts for about 76%. In all fairness, the planet should be called "Water".

Liquid water is perhaps the most important feature of the planet Earth. Water is fairly common in our solar system, but it appears that only on Earth does liquid water occur in an appreciable quantity (Jupiter's moon Europa may be an exception). The presence of liquid water has altered the atmosphere, moderated Earth's temperature and allowed for the formation and sustenance of life.

Formation of the Earth's Oceans

The first question that must be addressed when discussing the formation of the Earth's ocean is, "Where did the water come from?" We have already seen that during the early stages of our solar system's formation volatile substances, such as water, could not exist in the hot inner realms of the protoplanetary disk where the Earth formed. The answer seems to be that water was added to the Earth system late in its development, carried by ice-laden planetesimals and comets from the outer solar system.

During the cratering stage in its development, the Earth experienced an intense bombardment of cosmic debris. Many of the bodies that crashed into Earth were thrown into the inner solar system by the gravity of the giant outer planets. Planetesimals that formed in the neighborhood of Jupiter, and beyond, were rich in water ice. Comets, often described as "dirty snowballs" because of their icy composition, were formed at the cold outer edge of the solar system and had irregular orbits which brought many of them into the inner solar system. Upon impact, materials from these comets and planetesimals were incorporated into the Earth's crust, including much of the water they carried.

During the next stage of the Earth's development, the **flooding stage**, water that had been trapped in the rock beneath the Earth's surface was released into the atmosphere as magma deposits rose through volcanoes and fissures on the surface. [See Figure 7] The water vapor remained in the atmosphere until the temperature dropped sufficiently for condensation to occur, beginning a steady rain that eventually formed the oceans.

Earth's Water

There is such a tremendous amount of water on Earth that the figures quickly become inconceivable. Imagine collecting all the Earth's water and putting it into bathtubs. Assume that a full bathtub holds 35 gallons of water. Once you begin filling bathtubs, the job would be finished only after you had filled 10 quintillion, 566 quadrillion, 293 trillion (10,566,293,000,000,000) bathtubs. That's 369 quintillion, 820 quadrillion, 255 trillion gallons of water.

Earth's water exists in all three of its states: solid, liquid, and gaseous. But by no means is the water distributed equally between these states. By far, the greatest amount of water is found in the oceans and seas. These vast bodies account for 97.5% of the total water supply on Earth. Seawater is, on average, 96% fresh water, 4% sodium, chlorine, and other minerals. Sodium, which makes "salt water" salty, makes up only 1% of seawater (the equivalent of 105,662,930,000,000 bathtubs full of salt.) [See Figure 8].

FIGURE 8

The remaining 2.5% is fresh water, but most of this water is in its solid form, and therefore not available for use. Glaciers and ice sheets in mountainous regions and at the Earth's poles account for 1.8% of the Earth's fresh water. This percentage fluctuates over time, as periodic Ice Ages allow for the spread of ice into areas which are usually temperate.

Taken together, seawater and frozen water account for 99.3% of the water on Earth. Of the remaining .7% fresh water found in lakes, streams, and groundwater make up .699% of the balance. This is the water available for consumption by humans and other land organisms, and for use in the irrigation of crops. The remaining .001% is found in atmospheric water vapor and clouds. [See Figure 9]

FIGURE 9

The Water Cycle

Liquid water is essential to life on Earth; no plant or animal can live without it. And while the Earth is a watery place, not all of the water is suitable for all types of life. The small percentage of sodium in seawater makes it unsuitable for land organisms, which require fresh water for survival. But because of the water cycle, a continual process of evaporation, condensation and precipitation, seawater is cleansed of its impurities and fresh water is transported from the oceans onto land. If not for the water cycle, life would not have been able to occur more than a few feet from the ocean's shore.

Under the Sun's heat, water can change from a liquid to a gas or vapor, a process called **evaporation**. This is the process that seems to make puddles "disappear" on hot days, but it is also responsible for the fresh water needed by land creatures for survival. When sea water evaporates, the salts and minerals are left in the oceans; the water vapor that rises up into the atmosphere is fresh.

When it cools, water vapor once again becomes a liquid, a process called **condensation**. In the **troposphere**, the lowest level of the atmosphere where the Earth's weather occurs, temperature drops by approximately 4 F for every 1000 feet of altitude. Eventually, the water vapor will reach an altitude at which the temperature is cool enough for condensation to occur. This is the mechanism by which clouds form. When enough liquid water collects in clouds, it falls to the ground by the force of gravity in the form of precipitation. [See Figure 10]

FIGURE 10

The Impact of Oceans on Planet Earth

The importance of liquid water to the evolution of the planet, and life, cannot be overestimated. In a remarkable series of events, the oceans altered the Earth's atmosphere and provided a medium for the formation of life, which then further changed the atmosphere to allow life to flourish on land.

As a result of outgassing during the **flooding stage** of Earth's development, the atmosphere contained a high percentage of carbon dioxide. Carbon dioxide is a "greenhouse" gas, a gas that traps heat. If these early levels of carbon dioxide existed today, the Earth would be subjected to a greenhouse effect similar to that of Venus, with its surface temperature of 869° F. However, Earth's oceans provided a means of removing carbon dioxide from the atmosphere. Carbon dioxide dissolves readily in water, as evidenced by the profusion of carbonated beverages available today. Much of the carbon dioxide in the atmosphere dissolved into the oceans, where most of it was "trapped" in the form of **carbonate rocks**, lessening the amount of this greenhouse gas in the atmosphere.

Carbon that was not incorporated into carbonate rocks became part of a mixture of elements in the primordial seas. This concentration of carbon in the oceans proved important for two reasons. First, carbon readily forms chemical bonds with hydrogen, oxygen, nitrogen, and other elements, making complex chains of elements known as **organic molecules** and **amino acids**. Second, organic molecules have the ability to split themselves down the middle, creating "carbon copies" of the original molecule. This ability of carbon to create self-replicating molecules is the chemical basis for reproduction, and the first step toward life.

Once the fragile chemical foundations of life had been established, the oceans provided protection which enabled the progression toward life to continue. Ultraviolet radiation from the Sun attacks organic molecules, corrupting the self-replicating process. The oceans provided a shield against ultraviolet radiation, which can only travel through water to a depth of 33 feet. Shielded by the oceans, organic molecules eventually allowed for the formation of simple life, in the form of algae, which began producing oxygen as a waste product of photosynthesis. The build-up of oxygen led to the formation of ozone, a form of oxygen which absorbs ultraviolet radiation. Thus, with an atmospheric shield against harmful radiation, life was able to emerge from the oceans and onto land.

THE GASEOUS EARTH

“Wear sunscreen.” –Kurt Vonnegut

The **atmosphere** is a mixture of gases extending approximately 500 miles from the surface of the Earth into space. This is actually quite a thin layer separating us from the cold of space; If the Earth were the size of an orange the atmosphere would be as thick as its peel. This thin layer of invisible gases is essential to life on Earth.

Not only does the atmosphere provide plants with the carbon dioxide, they need for **photosynthesis** and animals the oxygen they need for respiration, it also regulates the Earth’s surface temperature, provides a medium through which water can travel in it’s gaseous form, and acts as a shield against harmful solar radiation and meteoroid impacts.

The Formation and Evolution of the Atmosphere

The atmosphere surrounding the Earth today is not the planet’s original atmosphere. The original atmosphere was rich in hydrogen and helium, which was pulled to the proto-Earth by gravity from the protoplanetary disk. The original atmosphere was short-lived, as light, fast-moving hydrogen and helium broke free from gravity’s pull and drifted off into space.

The gases that would produce the present, “secondary” atmosphere remained trapped in the planet’s interior until the flooding stage of the Earth’s development. In this stage, great quantities of water vapor, carbon dioxide, and nitrogen were released into the atmosphere through volcanic activity, a process known as “outgassing”. [See figure 7]

As the Earth cooled, water vapor condensed out of the atmosphere to form the oceans, creating an atmosphere composed primarily of carbon dioxide and nitrogen, much like the present atmospheres of Venus and Mars. Earth’s oceans removed most of the carbon dioxide from the atmosphere, initiating a chain of events which eventually led to plant life, which, through photosynthesis, removed further carbon dioxide from the atmosphere and began the production of oxygen. Unlike carbon dioxide, which reacted with water in the oceans, nitrogen is an inert gas, which does not readily combine with other elements. The small amounts of nitrogen released through outgassing steadily accumulated in the atmosphere until nitrogen was the primary component of the Earth’s atmosphere.

The result of these processes is the present atmosphere, which is composed primarily of nitrogen (78%) and oxygen (21), which account for 99% of the Earth's atmosphere. The remaining 1% of the atmosphere is a mixture of gases including argon, methane, carbon dioxide, hydrogen, and water vapor. [See Figure 11]

FIGURE 11

The Structure of Earth's Atmosphere

The atmosphere, while it may appear uniform, is actually a series of distinct layers, which are characterized by differences in composition and temperature.

Closest to the surface of the Earth, is the **troposphere**, the layer of the atmosphere in which most of Earth's weather takes place. The densest part of the atmosphere, the troposphere contains 90% of the atmosphere, and over 99% of the atmospheric water vapor. Gases in the troposphere are in continual motion (tropos = to turn or to change), driven by energy from the Sun. Heat radiated from the surface of the Earth warms the lower regions of the troposphere, creating rising columns of air that are responsible for global weather and wind patterns. As altitude increases, temperature decreases at a rate of 4F per 1000 ft. As water vapor rises, it eventually reaches an altitude where temperature is cold enough for condensation to occur, resulting in the precipitation of water back to the surface.

Above the troposphere is the **stratosphere**, a stable region of layered gases (strato = layered), including most of the atmosphere's ozone. This ozone makes up the now infamous "ozone layer" which absorbs ultraviolet radiation from the Sun, warming the upper region of the stratosphere.

The middle layer of the atmosphere is the **mesosphere** (meso = middle). The mesosphere is composed of nitrogen and oxygen in proportions similar to those found in the troposphere. However, the air is very thin: over 99.9% of the Earth's atmosphere lies below the mesosphere. Temperature in the mesosphere decreases with altitude. The lower regions are warmed by the stratosphere below, while temperatures at the top of the mesosphere are the coldest in the atmosphere, reaching -130° F.

The **thermosphere** is the "warm" layer above the mesosphere. The air in the thermosphere is one ten-millionth (.0000001) as dense as that in the troposphere. The molecules of gas found in the thermosphere receive intense radiation from the Sun, resulting in a temperature that is measured at 330° F. However, a person would perceive the temperature to be very cold, because there are so few "warm" molecules available to transfer heat.

The **exosphere** is the layer where the atmosphere blends into space. It has no definite boundaries, but is measurable to an altitude of 500 miles. [See Figure 12]

The Greenhouse Effect

Six gases, which together make up just more than 0.07% of the Earth's atmosphere, play an essential role in keeping the planet's surface at a temperature suitable for life to exist. Water vapor (0-.04%), carbon monoxide (.03%), methane (.00001%), nitrous oxide (.00003%), chloroflorocarbons (CFCs) (.00000001%), and ozone (.000004%) are **greenhouse gases**. These gases trap heat in the atmosphere. These gases are responsible for the moderate 59°F average temperature at the Earth's surface. It is estimated that without the greenhouse effect, the Earth's average temperature would be 0°F.

Most of the Sun's energy that reaches Earth's surface is in the form of **visible light** energy. The surface absorbs this energy, and radiates infrared energy back into the atmosphere. Greenhouse gases absorb infrared energy and reradiate it, thus warming the atmosphere. In this way the atmosphere is similar to a greenhouse, where visible light passes through the glass of the greenhouse, but infrared energy, with its smaller wavelength, is unable to escape through the glass. [See Figure 13]

FIGURE 13

Without this natural greenhouse effect, Earth would not be able to sustain life. Concerns about the greenhouse effect and global warming stem from the addition of carbon dioxide and CFCs to the atmosphere as the result of human activity. The burning of fossil fuels since the 1800s has increased the amount of carbon dioxide in the atmosphere by 25%. **Chloroflorocarbons**, synthetic gases used in refrigerators and air conditioners are less prevalent in the atmosphere, but individual CFC molecules trap 12,000 more times heat energy than individual carbon dioxide molecules.

The Ozone Layer

Ozone (O₃) is an important component of the atmosphere as it is responsible for absorbing most of the ultraviolet energy found in sunlight before it reaches the surface of the Earth. Ultraviolet energy is potentially fatal, as it is able to penetrate living cells and damage nucleic acids. As the atmosphere evolved and formed the **ozone layer**, life forms that could previously survive only beneath the protective shield of the oceans were free to expand to land.

Damage to the ozone layer is due primarily to CFCs, man-made gases used for refrigeration and aerosol applications. The Freon in your air-conditioning is a CFC. CFCs deplete the ozone in the stratosphere through a chemical reaction with ultraviolet light, in which ultraviolet energy releases a chlorine atom from the CFC, which then goes on to steal an oxygen atom from ozone.

THE BIOSPHERE

...imagine yourself on a journey upward from the center of the Earth, taken at the leisurely pace of a walk. For the first twelve weeks you travel through furnace-hot rock and magma devoid of life. Three minutes to the surface –five hundred meters to go- you encounter the first organisms; bacteria feeding on nutrients that have filtered into the deep water-bearing strata. You breach the surface and for ten seconds glimpse a dazzling burst of life –tens of thousands of species of microorganisms, plants and animals within horizontal line of sight. Half a minute later almost all are gone... -Edward O. Wilson

The biosphere is the living portion of the Earth, encompassing all organisms and the environments they inhabit. A minute fraction of the Earth, from just below to just above the crust, supports the remarkable diversity of life. The basis for (almost) all life on Earth is the Sun, which ultimately provides the energy that all life forms need to survive. But the Sun is only one part of the equation. Variables that affect life include temperature, the presence or absence of water and the quality of soil, to name a few.

Exactly how the organic molecules of the early oceans evolved into the myriad forms of life we see today is a topic of continual debate, and beyond the scope of this manual. It will suffice to explore the reasons why Earth provided favorable conditions for the emergence of life, and to examine the implications of life on our planet.

The Goldilocks Zone – Too Hot, Too Cold, and Just Right

Theoretically, the terrestrial planets Venus, Earth, and Mars all exist within the “habitable” region of the solar system. That is, all other factors being equal, the amount of solar radiation reaching these planets could provide for the range of temperatures necessary for the existence of liquid water, a prerequisite for life as we know it. But in reality, all other factors are not equal on these planets. Like Earth, Venus and Mars progressed through stages of differentiation, flooding, cratering, and evolution. As they developed, variations in size, atmospheric composition and temperature resulted in conditions

which were not favorable to life on Venus and Mars. Some scientists colorfully describe the range of conditions within the habitable region as the “Goldilocks zone”.

At an average distance from the Sun of 67.2 million miles, Venus is at the inner edge of the Goldilocks zone. On Venus, as on Earth, volcanoes released large amounts of carbon dioxide, water vapor, and nitrogen during the flooding stage. But because of its proximity to the Sun, temperatures on Venus remained too high for the condensation of water vapor. Oceans never formed on Venus. On Earth, oceans provided a means for the removal of carbon dioxide from the atmosphere; on Venus, carbon dioxide constitutes over 96% of the atmosphere. This heavy concentration of carbon dioxide has resulted in a greenhouse effect “run amok” on Venus. With an average surface temperature of 869°F, liquid water cannot occur on Venus. Life Goldilocks first taste of porridge, Venus is “too hot” for life.

Mars, at an average distance of 141.6 million miles from the Sun, lies on the outer edge of the Goldilocks zone. Because of its small size and mass, Mars has significantly less gravity than Earth. Earth’s gravity is strong enough to hold on to the gases which make up its atmosphere; Mars’ is not. Gases released during Mars’ flooding stage have slowly drifted off into space over time, resulting in a very thin atmosphere. Water does exist on Mars as ice, but the thin atmosphere affects the viability of liquid water, and any prospects for life, in three ways. First, although Mars’ atmosphere consists primarily of carbon dioxide (over 95%), there is so little of it that the greenhouse effect is almost non-existent. So, while Mars experiences seasons much like Earth, with summer temperatures as warm as 72° F, the thin atmosphere allows most of the heat radiated from Mars surface to escape into space. As a result, the average surface temperature on Mars is -67° F., below the freezing point of water. Second, the low air pressure exerted by the Martian atmosphere would allow any liquid water that might occur during the Martian summer to evaporate almost immediately. Third, Mars atmosphere offers little protection from the Sun’s ultraviolet radiation. If organic molecules did manage to appear on Mars’ surface, they would be damaged or destroyed. Following the Goldilocks analogy, Mars is “too cold” for life.

Earth, at an average distance of 93 million miles from the Sun, is right in the middle of the Goldilocks zone. With an average temperature of 59° F, and a protective layer of ozone in the stratosphere, Earth is “just right” for life.

GLOSSARY

| | |
|---------------------------|---|
| Accretion: | An increase in size by gradual external additions. |
| Asthenosphere: | A layer of the Earth's interior, just below the lithosphere, over which the surface plates slide. |
| Air pollution: | Harmful particles and gases that have been added to the air. |
| Atmosphere: | The layer of air above the Earth |
| Bar: | A long ridge of sand or other material near or above the surface of a body of water. |
| Bedrock: | Unbroken solid rock covered in most places by soil or rock fragments. |
| Biosphere: | The part of the Earth's crust, waters, and atmosphere where living organisms exist. |
| Carbon dioxide: | A colorless, odorless gas present naturally in the atmosphere. |
| Chlorofluorocarbon (CFC): | A synthetic gaseous compound made of carbon, hydrogen, fluorine and chlorine, used mainly as a refrigerant. |
| Collision zone: | A boundary where a continental plate collides with another continental plate, creating mountain ridges. [See plate tectonics] |
| Comet: | An object in the solar system consisting of frozen gas, ice and dust. |
| Condensation: | The change of gas into a liquid. |
| Continental drift: | The theory that the continents were once part of one large continent called Pangea, which broke into pieces that moved apart. |
| Core: | The hot, bell-shaped center of the Earth. |

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| Coriolis Effect: | The deflection in the motion of objects due to the Earth's rotation. |
| Crater: | A depression on the surface of the planet or moon, caused by collision with interplanetary matter. |
| Cratering Stage: | The second stage of Earth's development, in which collisions with planetesimals added to the planet's mass. |
| Crust: | The outer or top layer of the Earth. |
| Currents: | Flows of moving air or water. |
| Density: | The amount of mass an object has for its volume. |
| Differentiation: | A process by which materials are distributed according to their density. The differentiation stage was the first stage of Earth's development. |
| Electromagnetic spectrum (EMS): | The complete range of all wavelengths of electromagnetic radiation. |
| Electrons: | Tiny negative electric charges that move around the nucleus of an atom. |
| Endangered Species: | A population with very few living members. |
| Energy: | The ability to do work. |
| Evaporation: | The change of a liquid to a gas. |
| Exosphere: | The topmost layer of the atmosphere |
| Extinction: | The loss of an entire population. |
| Extrusive rocks: | Igneous rocks formed on the Earth's surface. |
| Felsic: | Material consisting of light-colored silicate minerals, as in igneous r rock. |
| Flooding Stage: | The third stage in Earth's development, in which radioactive decay in the planet's interior led to the volcanic release of magma and gases. |
| Fusion: | The combining of two or more atomic nuclei to produce a nucleus of greater mass. Fusion releases tremendous amount of energy. |

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| Gamma Ray: | An electromagnetic wave of very high frequency. |
| Global Warming: | The warming of the Earth's surface and atmosphere as a result of the greenhouse effect. |
| Greenhouse effect: | An absorption and retention of infrared energy by the atmosphere, resulting in a warming of the surface. |
| Greenhouse Gas: | A gas that absorbs and retains infrared energy in the atmosphere, carbon dioxide, chlorofluorocarbons, methane, nitrous oxide and water vapor are the major greenhouse gases in Earth's atmosphere. |
| Habitable zone: | An area around a star where a planet could have a surface temperature between the freezing and boiling points of water. |
| Igneous rock: | A rock produced by solidification from a molten state. From the Greek igneus – from fire. |
| Infrared: | Electromagnetic radiation with wavelengths ranging from approximately .0001 to .000001 meters. |
| Intrusive Rocks: | Igneous rocks formed deep inside the Earth. |
| Ion: | A charged particle. |
| Ionosphere: | The upper region of the thermosphere containing loose electrons and positive ions. |
| Island: | A small area of land surrounded by water. |
| Jovian Planet: | The four gaseous planets of our solar system: Jupiter, Saturn, Uranus, and Neptune. |
| Lava: | Liquid rock that has reached the Earth's surface. |
| Leap year: | A year containing 366 days. |
| Lithosphere: | The solid part of the Earth, consisting of the crust and the upper mantle. |
| Lower Mantle: | The portion of the mantle consisting of the asthenosphere and the mesosphere. |
| Lunar Eclipse: | An event where the Moon passes through the Earth's shadow, temporarily darkening its surface. |

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| Mafic: | Consisting of dark-colored minerals, mainly magnesium and iron, as in igneous rock. |
| Magma: | Liquid rock beneath the Earth's surface. |
| Mantle: | The layer of Earth found in the lower mantle. |
| Mesosphere: | (a) A layer of the Earth found in the lower mantle. (b) The layer of the Earth's atmosphere from about 50 to 90 km above the surface of the Earth. |
| Metamorphic rock: | Rocks that have been changed by heat, pressure, chemical actions, or a combination of them. |
| Meteor: | A small piece of space rock or dust that becomes attracted to the Earth and burns up in our atmosphere. |
| Microwaves: | Electromagnetic radiation with wavelengths ranging around .001 meters. |
| Molecules: | Two or more atoms joined together. |
| Moon: | A small body in orbit around a planet. |
| Ozone: | A molecule consisting of three oxygen molecules (O ₃). |
| Ozone layer: | A region in the Earth's upper atmosphere where small concentrations of ozone absorb ultraviolet radiation. |
| Pangea: | The large continent that broke into the continents seen today. |
| Phases: | The part of the Moon seen from Earth. |
| Photosynthesis: | The process by which plant cells make carbohydrates by combining carbon dioxide with water, releasing oxygen. |
| Planet: | A large, rotating body that orbits a star. |
| Planetesimal: | A small body found in a protoplanetary disk which eventually becomes part of the planet. |
| Plate Tectonics: | The theory that many of Earth's features are caused by the movement of plates of the Earth's crust. |
| Plates: | Large sections of the Earth's crust. |

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| Pollutants: | Unwanted matter added into air or water which changes its composition and could deteriorate its quality. |
| Precipitation: | Water that falls from the atmosphere to the Earth's surface. |
| Protons: | Positive electric charges within the atom's nucleus. |
| Protoplanetary disk: | A mass of gas and dust rotating around a star, believed to contain material necessary for planet formation. |
| P-waves: | Primary waves. Compression waves released by earthquakes which can travel through solids and liquids. |
| Radiation: | The transfer of energy by waves. |
| Revolution: | The motion of a heavenly body around another; an orbit. |
| Rotation: | The spinning on an axis. |
| Satellite: | An object that revolves around a planet. |
| Seasons: | Changes in the average temperature and length of day that result from the tilt of the Earth's axis with respect to the plane of its orbit. |
| Sedimentary rock: | Rocks made of layers of sediments that have been fused together. |
| Silicate: | A compound containing silicon, oxygen and a metal. |
| Smog: | A mixture of smoke and fog. |
| Soil: | The part of the Earth which is in a condition to support plant life. |
| Solar nebula: | A cloud of gas and dust surrounding a forming star. |
| Spit: | A point of land projecting into the sea. |
| Spreading zone: | A boundary in which two plates diverge. [See plate tectonics] |
| Stratosphere: | The part of the Earth's atmosphere above the troposphere, up to an altitude of about 50 km. |
| Subduction zone: | A boundary in which an oceanic plate collides with another oceanic plate, or with a continental plate, pushing the less dense plate down into the mantle. |
| Subsoil: | Light-colored soil that does not contain much organic material; the |

layer below the top soil.

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| Surface evolution: | The fourth and present stage of Earth's development. Changes to the Earth's surface through constructive (volcanic) and destructive (erosion) forces. |
| S-wave: | Secondary wave. Shear waves released by earthquakes which cannot travel through liquids. |
| Terrestrial planet: | Any of the four solid planets of the inner solar system, including Mercury, Venus, Earth, and Mars. |
| Thermosphere: | The layer of the Earth's atmosphere above 90 km from the surface. |
| Topsoil: | The upper soil surface containing many nutrients and minerals. |
| Transform boundary: | A boundary in which two continental plates slide past one another. |
| Troposphere: | The part of the Earth's atmosphere from the surface to about 15 km. |
| Ultraviolet: | Electromagnetic radiation with wavelengths ranging from approximately .0000001 to .00000001 meters. |
| Upper mantle: | The portion of the mantle that combines with the crust to form the lithosphere. |
| Venus: | The second planet from the Sun and the Earth's closest planetary neighbor. |
| Visible light: | Electromagnetic radiation with wavelengths ranging from approximately .000000004 to .000000007 meters. |
| Water cycle: | The process of water constantly circulating from oceans to lakes, land, air and living organisms. |
| Wavelength: | The distance from one wave crest to the next (or one trough to the next). |
| x-rays: | Electromagnetic radiation with wavelengths ranging from approximately .00000001 to .0000000001 meters. |

