The Changing Earth

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Table of Contents

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Introduction

We live to exist; and by living we exist; but why do we exist? This question is the fundamental quandary of the philosophical belief system of existentialism. All systems of philosophy and religion are belief systems. All philosophical and religious adherents pose unanswerable questions concerning the meaning and experience of what we call life. Science alone stands aloof of philosophy and religion. Science alone does not attempt to explain existence in terms of what we believe, but instead attempts to describe reality in terms of observable facts and their rational consequences.

This does not mean to imply that all adherents of science eschew belief systems (although some do, just as some philosophers and religionists disdain science – and atheists and theists are here included in the belief systems of religion).

Science has come under criticism for its deconstruction approach to grappling with complex systems. Anti-science adherents accuse science of being deficient because the decomposed sub-systems it models do not add up to explain the whole of nature. Directing this blame indicates a complete misunderstanding of what is science. Science is not a personification. Science per se does not advocate for any particular human view point. Science does not have opinions or beliefs. Science does not go to church on Saturday or Sunday. Science does not convene councils or govern societies. Science does not ponder life and death. Science is a tool. It is a rational and methodical thinking process. It is not a belief system nor is it a government or economic system.

We live on a piece of reality that we call Earth. Just as our ephemeral bodies have a beginning and an end (we are all born, and we all eventually die). The Earth had a beginning in the dimly seen extreme past, and it will eventually succumb to the ravages of time in the as yet veiled (to us) distant future. Science, and not philosophy, will best guide us in how to make our sojourn in this reality as beneficial to our species (and others) as possible.

The beginning of the methodology of science can be traced back to Galileo Galilei, a Florentine thinker born on 15 February 1564 in Piza, and dying on 8 January 1642 in Arcetri, near Florence. Isaac Newton was born in the same year that Galileo died, on 25 December. A contemporary portrait[1] of Galileo is shown in Figure 1.

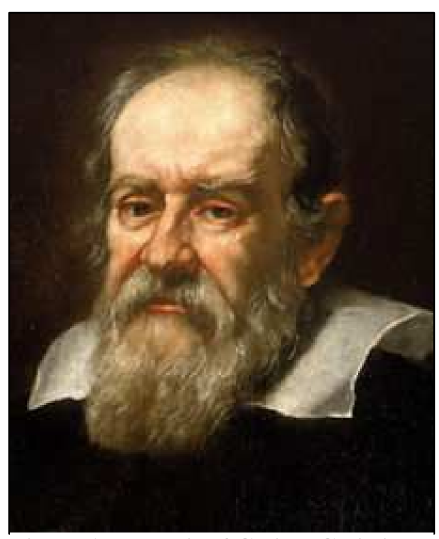

Figure 1: Portrait of Galileo Galilei by Giusto Sustermans.

Instead of philosophising that a lead ball would fall faster than a feather in a vacuum, Galileo actually conducted a physical experiment and demonstrated that they both fall at the same rate. He introduced a method of observation and

[1] Giusto Sustermans (also known as Justus Sustermans) was a Flemish painter in the Baroque style. He was born in Antwerp in 1597, and died in Florence in 1681 (Wikipedia, 2008).

verification that had not been previously considered. Instead of debating physical questions and deciding them on intellectual and (mostly) intuitive consensus, he dared to actually conduct physical tests.

The Roman Catholic religious dogma of the time held that the Earth was the centre of the Universe, and did not move! Galileo was able to demonstrate that the Earth moved relative to the Sun. In 1632, with the consent of the Pope, he published a book that described his discovery, titled *Dialogue Concerning the Two Chief World Systems* (The Dialogues)(Crew & de Salvio, 1914). As a result of this publication he was brought before the Catholic Congregation for the Doctrine of the Faith (the Inquisition), charged with heresy, and threatened with torture and death unless he recanted his assertion. This he did, and spent the remainder of his life under house arrest. It is said that following his recantation he said as an aside, "Never-the-less, it moves."

The Dialogues was placed on the Catholic Church's list of proscribed texts in 1633. Although the Catholic Church permitted the Dialogues to be reprinted in 1821, Galileo's published works remained on the Church's Index of Prohibited Books until 1835. It was not until 1981 that the Church officially forgave Galileo of his supposed crime.

The principle objective of science is to explain what nature *does*, not what it *is*. Although philosophy and religion have roles to play in providing those who need such support with feasible explanations concerning our existence (and hence that of the cosmos), they have, by virtue of being *belief* systems, no rational basis for justifying those explanations. Throughout history, philosophical and religious beliefs have played a catch-up game with science. Philosophers and religionists speculate, ponder, invent and pray (and often prey on the gullibility and susceptibility of the populous), while scientists examine, experiment, theorise, and explain. If, as a result of that scientific explanation, some existential relevance is elucidated, then it is a by product, not a goal, of the scientific method.

The Earth is not static; it changes over time. The Earth is dynamic. It is not the centre of the Universe. The Earth does not exist to house us. We exist because the Earth is as it is. There have been times in the past when this was not so. There will be times in the future when it is not so.

In this paper the author will outline various changes to the Earth that scientists have observed and attempted to provide rational scientific explanations for since the time of Galileo, over the last 360 years or so. Although the observations have taken place in a few scant centuries, they reveal to us an Earth that has been changing for the past several thousand million years[2]. It is changing now, and will continue to change for thousands of millions of years into the future.

[2] The often used term *billion* is ambiguous, and has no world consensus meaning. In the United States of America it is used to represent one thousand million or 10^9, In France, Britain (and hence Australia), and Europe in general, it legally represents one million million or 10^{12}. The author eschews its use in scientific literature as being meaningless.

Two Important Scientific Concepts

Although *speculation* and *insight* are important tools in any good scientist's cupboard, all scientists must never lose sight of the fact that their findings must be *rational*, *objective*, *explain all of the known facts*, and be *reproducible*. Whilst speculation and insight can be valuable tools to provide a *starting point* to a scientific investigation, in the end that speculation and insight must be replaced with rational, dispassionate, and demonstrable fact.

At the basis of these scientific concepts are the related fundamental notions of *accuracy* and *precision*. These are two concepts without which any investigation is non-scientific. In the final scientific analysis speculation and insight must be put back in the cupboard, to await the dawning of another idea.

Some may suggest that I am 24 years old. They would be right; to a certain extent, and I thank them for their kindness, but that type of statement is not very accurate.

I hear that you are a scientist.

Yes; and I'm only 59 years old (give or take 40 years)!

(Art credit: Adrienne Wall, © 2008 www.artinterface.com.au, used with permission from the artist.)

It is a fact that I was born in 1949. It is also a fact that it is now 2008. That means I am about 59 years old; but that figure is only *accurate* to a *precision* of plus or minus a half a year (i.e. accurate to within 0.85% of the true value). I am also 24 years old; but that figure is only *accurate* to a *precision* of plus or minus 25 years (i.e. an accuracy within 42% of the real value, hence my observation that it is not very accurate)! Stating my age in either of these manners is scientifically justifiable. It is objective, it explains all of the known facts, and (given the initial facts) anyone can reproduce those results with equal accuracy and precision.

If I now give you a further fact we may be able to improve on both the accuracy and precision of my *approximate* age. If I told you that I was born in April 1949, and that it is now June 2008, we can now determine that I am aged 59 years and two months plus or minus one month (i.e. 59.17±0.08 years, an accuracy within 0.14% of the true value). So we see that by gleaning additional *factual* information we can improve on the scientific findings[3].

All scientific findings must be interpreted taking into account the accuracy and precision of those results. It would be foolish to accept that I am 24 years old without knowing how accurate and how precise that figure is. However, it may be useful for a vain person to use that reasoning to state their age – and also convince themselves on pseudo-scientific grounds that they are only telling a white lie. Be aware, however, that the astute rational thinker will see through your prevarication.

It is a fact that all scientific results are only *approximations* of reality. A valid scientific fact is stated with certain accuracy, within certain bounds of precision.

Human Existence from an Earth Perspective

Sophisticated cultures throughout the World assert a heritage of ancient existence. Based on these assertions ethnic tribes and nations lay claim to land and resources. Wars erupt over trivial territorial disputes, based on claims of prior possession. As a species we beguile ourselves into thinking that we have existed since time immemorial; and yet the scientific evidence leads us to a very different view. As a species we humans have only practiced our cultures a miniscule fraction of the age of the Earth.

If we relate the estimated age of the earth to a 100 km length of straight road, we, as a species, have only been travelling over that road for the last four and a half meters! A previous humanoid species travelled this same road for at least 40 metres, and then became extinct before we came on the scene. We have been here for about 4.5 thousandths of a percent of the age of the Earth!

The Age of the Earth

The oldest rocks so far discovered on Earth were found in north western Canada near Great Slave Lake. These rocks have been reliably dated to within a few percent of 4.03 thousand million years ago (Ga)[4]. Rocks found in West Greenland have been dated to between 3.7 and 3.8 Ga. Well-studied rocks nearly as old have been found in the USA (3.5 to 3.7 Ga), in Swaziland (3.4 to 3.5 Ga), and in Western Australia (3.4 to 3.6 Ga). A number of radiometric methods have been used to date these ancient rocks ensuring that the results are accurate, and are precise to within a few percent. It is also clear from scientific studies that the rocks were formed from lava flows and sediments deposited in shallow water, not from primeval star-dust. This is an indication that the Earth's history began well before these rocks were deposited. In Western Australia, ancient zircon crystals with radiometric ages of as much as 4.3 Ga have been found in younger sedimentary rocks. This makes these tiny crystals the oldest minerals to have been found on Earth so far. (USGS 2007)

[3] The author was in fact born on the ninth day of April 1949. He leaves it as an exercise for the reader to determine his approximate age down to a precision of plus or minus 12 hours, and determine its accuracy.

[4] Geological time scale of one thousand million years ago is designated by Ga, which means Giga annum. Giga is the ISO metric multiplier for one thousand million.

The oldest dated moon rocks have ages between 4.4 and 4.5 Ga. More than 70 meteorites of different types have radiometric ages between 4.53 and 4.58 Ga. These calculations result in an age for the Solar System, and therefore the Earth, of 4.54 Ga with an uncertainty of less than 1 percent.[5] This is consistent with current calculations of 11 to 13 Ga for the estimated age of the Milky Way Galaxy and the estimated age of 10 to 15 Ga for the age of the Universe. (USGS 2007a)

The Age of the Human Species

The age of the human species is estimated to be in the order of 200 thousand years. There is general scientific acceptance that the precursor species Homo erectus was active some 1.7 Ma (million (Mega annum) years ago), and persisted almost unchanged until as recently as 700 thousand years ago (ka). Evidence of modern Homo sapiens characteristics is found about 130 ka, with a world-wide expansion of the species only about 90 ka (Templeton, 2002). Turney et al (2001) have demonstrated that Homo sapiens were present in Australia some time prior to about 48 ka.

Development of the Earth

Scientific evidence indicates that the earth formed by natural means. Although specific details concerning the earliest natural development of the Earth are uncertain to a degree, the known evidence implies a general trend that is universally accepted in the scientific community. A concise explanation of the Earth's formation, from the earliest times through to the present, is captured by major milestones in that development. The University of Michigan's web site, *Earth's Early Years: Differentiation, Water and Early Atmosphere*, gives an excellent description of the earth's early development (University of Michigan, n.d.). Much of the information contained in this section is derived from that source.

The Earliest Times

The earliest Earth probably consisted of an unsorted conglomeration of minerals and elements contributed by detritus of the Solar System formation. These materials would have been mostly of silicon compounds, native iron, as well as iron and magnesium oxides, and smaller amounts of the remaining natural compounds and elements. Bombardment of the proto-Earth by minor solar planetoids, comets and meteorites over hundreds to thousands of millions of years caused the Earth to grow bigger. This led to four different heating effects that culminated in the basic internal structure that the Earth now exhibits:

One heating effect was that caused by accretion. As impacting bodies bombarded the Earth their kinetic energy was converted into heat. It is highly likely that an early collision of a very large object caused the formation of the Moon from a large portion of the Earth.

Heating was also caused by self-compression. As the Earth got bigger the additional gravitational force caused the hot, uneven and plastic mass to contract into a smaller

[5] This age actually represents the last time that lead isotopes were homogeneous throughout the inner Solar System. It tells us how long ago lead and uranium was incorporated into the solid bodies of the Solar System.

spherical volume. This compression produced heat just like the compressed air from a bicycle pump will get hot when you pump up a tyre.

Differentiation of the Earth's core also caused heating. As the more dense materials were drawn under gravity to the Earth's centre, conversion of gravitational potential energy to heat occurred.

The remaining source of heating was from the decay of radio-isotopes. As short-lived isotopes decayed to daughter elements they radiated energy as alpha, beta and gamma rays. The surrounding materials absorbed the energy released in this radioactivity, causing them to heat up. This heat source persists even today, and will persist for thousands of millions of years into the future.

At some time within the first few hundred million years the surface of the Earth down to about 500 km became so hot that the plentiful iron melted. This molten iron formed into pools and, being denser than the silicon, magnesium, and other minor elements, began to sink under its own weight. It is estimated that about one third of the primitive planet's material sank to the centre. The resulting release of gravitational energy caused the heating rate to increase. As a consequence, most of the planet was turned into a liquefied or plastic state.

During the liquid and plastic phase the Earth differentiated into concentric spheres.

The formation of a molten iron core was the first stage of the differentiation. The Earth was converted from a relatively homogenous body, with about the same kind of material at all depths, to a layered body. At the centre was a dense iron core. On the surface was a crust of less dense materials with relatively lower melting points. Between the solid crust and the molten core was the plastic mantle.

Over several hundred million years, due to incredible compressional forces, and despite the exceedingly high temperature, the centre-most part of the Earth's core solidified to form the inner core.

It is in this differentiated form that the Earth now exists (See Figure 6 on page 9).

The Early Atmosphere

The primitive Earth had no atmosphere. The release of gases trapped in the interior of the early Earth, particularly during the differentiation phase, formed the first atmosphere. This process still goes on today as volcanoes spew gasses into the atmosphere (See Figure 2). Volcanoes that are active today typically exude about 94% to 96% of their gasses as steam and water vapour. The balance of volcanic gasses is made up

Figure 2: Chile's Chaitin Volcano erupting on 3 May 2008 (Photograph by Carlos Gutierrez). Note the lightning caused by the dynamic cloud of ash and gas. This lightning is a principal catalyst for the formation of gas compounds, including ozone.

mainly of Carbon, Sulphur, Chlorine, and Hydrogen compounds.

Extreme volcanism occurred during the differentiation phase. It is likely that the bulk of the atmosphere was derived from degassing early in the Earth's history.

It was from the gas compounds provided by volcanism that free Oxygen was derived. Water gas and vapour was a major component of the early atmosphere. Once the earth's surface had cooled sufficiently liquid water formed on the surface and pooled into lakes and oceans. This would have resulted in further reduction of Carbon dioxide. The atmosphere at that time was dominated by nitrogen. There was no oxygen in the early atmosphere.

Figure 3: Stromatolites in Hamelin Pool, Shark Bay, Western Australia (Source: USC Sequence Stratigraphy Web, 2006)

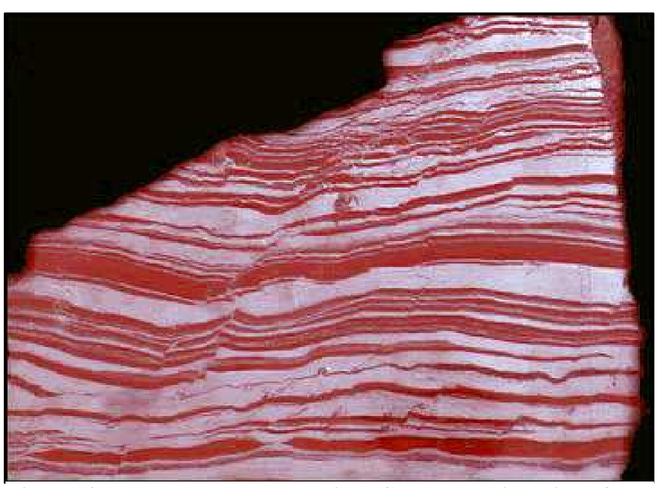

Figure 4: Banded Iron Formation (Source: University of Michigan, n.d.,)

It was in this liquid water environment where the first evolution of living organisms occurred. The advent of photosynthetic algae had a major impact on the atmosphere. Blue-green algae fed off atmospheric carbon dioxide and crustacean shells and converted much of it into oxygen and marine sediments. Over time the sediments were converted into rocks known as stromatolites, remnants of which still exist (See Figure 3).

For hundreds of millions of years the oxygen released from gas compounds did not build up in the atmosphere. It was taken up by rocks; in particular in banded iron formations (See Figure 4) and continental ion oxide deposits. Even today, the majority of the Earth's oxygen is locked up in iron and other metal oxide formations. It was probably about a thousand million years ago when the reservoirs of oxidised rock became saturated and free oxygen started to accumulate in the air.

Once free oxygen diatomic molecules became available in the atmosphere, lightning and ultraviolet light rearranged some of them into triatomic ozone molecules to develop an upper atmospheric ultraviolet shield. It was only after this that living organisms moved out of the oceans and started breathing the air.

Cratonisation and Plate Tectonics

The Earth's continents are made up of rock that was formed when molten lava was extruded through fissures in the primeval surface crust. At different places over the Earth's surface these extruded rocks began to form islands of material that was less dense than the mantle and crust from which they came. Being less dense they floated in the crust, and, like a cork on water, could not be reclaimed by the mantle. These islands of floating rock are called *cratons*, and they are the cores on which all of the Earth's continents were built.

The Kaapvaal craton in southern Africa and the Pilbara craton of northwestern Australia are the largest regions on Earth to have retained relatively pristine rocks that have been dated to 3.0 to 4.0 Ga (de Wit & Hart, 1993).

Over hundreds of millions of years the original cratons coalesced with neighbouring cratons. As more and more cratons joined together the size of the continents grew until they too joined together to form one world continent that we now call Pangaea (See Figure 5).

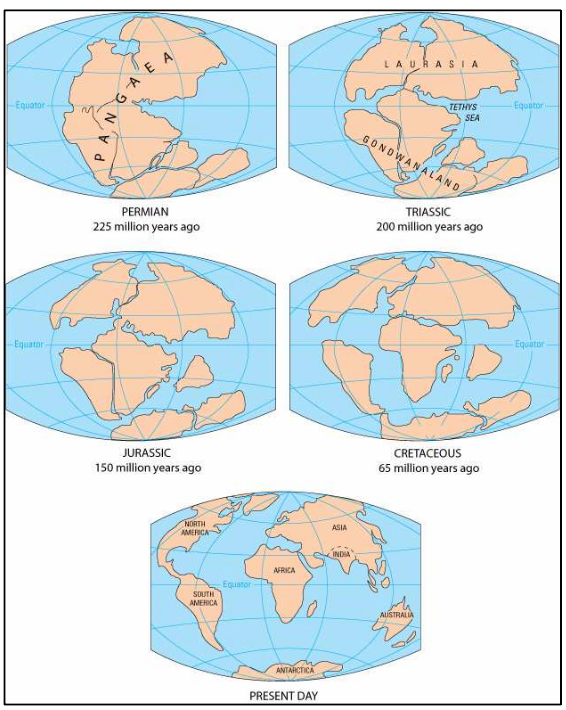

Figure 5: The formation of the continents (Source: USGS, 2007b)

Some time between 225-200 Ma Pangaea began to break up; slowly separating into the continents as we know them today (USGS, 2007b). About 200 Ma Pangaea divided into two continents, Laurasia, and Gondwanaland. Laurasia went on to form Europe, North America and Asia; and Gondwanaland divided to form South America, Africa, India, Australia, and Antarctica (USGS, 2007b).

As shown in Figure 6, the continental crustal *plates* are about 40 km thick on average, and up to 200 km thick in places (de Wit & Hart, 1993; SCIGS, 1998). They are floating on the plastic mantle, which in turn is floating on the molten outer core. The Earth's molten outer core encloses a solid inner core.

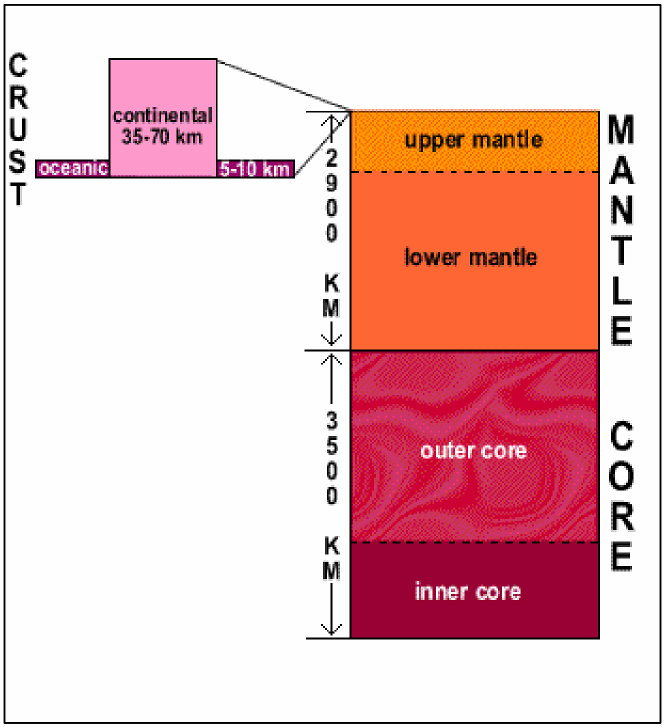

Figure 6: Cross section of the Earth, not to scale. (After SCIGS, 1998)

Between the continents, and beneath the oceans, the earth is covered by a relatively thin oceanic crust. This oceanic crust is very different in composition from continental crust. The principle difference is that the oceanic crust has not yet cratonised; that is, it is still sufficiently dense to be reclaimed by the earth's mantle from time to time.

The oceanic crusts around the World are, in general, closely bound to their neighbouring continental crusts. Where the continental plates go, their associated oceanic appendages tag along also.

Within the Earth's molten core there is a heat gradient. It is hotter towards the centre than it is near the mantle. The core heat is derived from two principle sources.

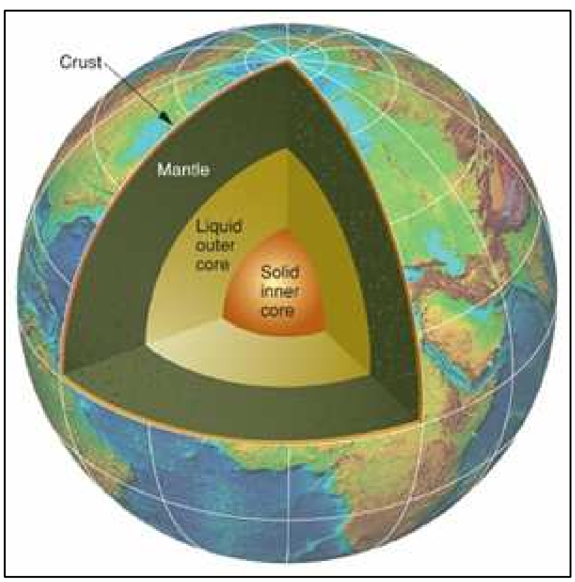

Figure 7: Cutaway view of the Earth (Source: Anuta, 2006).

Remnant heat from the original formation of the Earth contributes about 5 to 10 % of the Earth's current heat (Anuta, 2006). However, up to 90% of the Earth's heat comes from radioactive decay. Throughout the molten core various elemental radio-isotopes are mixed in with the other components. The radioactivity of those elements radiates alpha, beta and gamma rays, which heat up the surrounding materials. Radioactive potassium, uranium and thorium are thought to be the three main sources of heat in the Earth's interior, with potassium being the major contributor (UCBerkleyNews, 2003). The heat gradient in the molten core sets up global convection currents, which in turn distribute the core heat to the plastic mantle. The mantle heat is then transferred upwards to the Earth's crust, principally by very slowly moving convection within the plastic mantle.

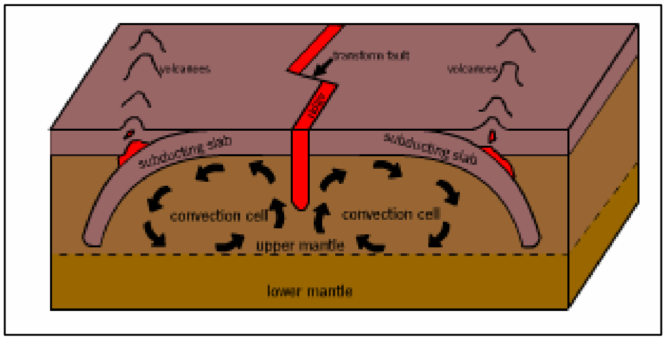

Figure 8: Mantle convection motion (Source: SCIGN, 1998)

It is the mantle convection movement that drives the global distribution of the crustal tectonic plates (See Figure 8).

Major Change Events in the Earth's History that have an influence on Human Existence.

Some of the Earth's major change events, such as original formation, differentiation, terraformation, oceanisation, cratonisation and the formation of continents, have already been described. However, there have been other equally important change events that have taken place in the past – and which continue to this day. These recurring change events are of vital importance to all living species that inhabit the Earth. There is some scientific evidence that the technological activities of we humans is contributing to one of those major changes. It may be that we are fouling our own nest.

There are many major global events that have the potential to have an influence on human existence. Only two major recurring events will be briefly described here; they are the global extinction events, and global temperature change. Emphasis will be given to the latter because of the current global warming interest.

Extinction Events

From the time when living species started evolving on Earth through to the present time there has been a process of waxing and waning of different species. Charles Darwin (1809-1892) explained some of the non-catastrophic natural means by which speciation occurs (Darwin C., 1859).

Paleobiologist Doug Erwin of the Smithsonian Institutions National Museum of Natural History considers there to be five major global species extinction events. He describes them as follows, with estimates of extinction rates provided by the late John J. Sepkoski at the University of Chicago. (Siegel L., 2000)

> ***Cretaceous-Tertiary extinction**, about 65 million years ago, probably caused or aggravated by impact of several-mile-wide asteroid that created the Chicxulub crater now hidden on the Yucatan Peninsula and beneath the Gulf of Mexico. Some argue for other causes, including gradual climate change or flood-like volcanic eruptions of basalt lava from Indias*[sic] *Deccan Traps. The extinction killed 16 percent of marine families, 47 percent of marine genera (the classification above species) and 18 percent of land vertebrate families, including the dinosaurs.*
>
> ***End Triassic extinction**, roughly 199 million to 214 million years ago, most likely caused by massive floods of lava erupting from the central Atlantic magmatic*

province -- an event that triggered the opening of the Atlantic Ocean. The volcanism may have led to deadly global warming. Rocks from the eruptions now are found in the eastern United States, eastern Brazil, North Africa and Spain. The death toll: 22 percent of marine families, 52 percent of marine genera. Vertebrate deaths are unclear.

***Permian-Triassic extinction**, about 251 million years ago. Many scientists suspect a comet or asteroid impact, although direct evidence has not been found. Others believe the cause was flood volcanism from the Siberian Traps and related loss of oxygen in the seas. Still others believe the impact triggered the volcanism and also may have done so during the Cretaceous-Tertiary extinction. The Permian-Triassic catastrophe was Earths worst mass extinction, killing 95 percent of all species, 53 percent of marine families, 84 percent of marine genera and an estimated 70 percent of land species such as plants, insects and vertebrate animals.*

***Late Devonian extinction**, about 364 million years ago, cause unknown. It killed 22 percent of marine families and 57 percent of marine genera. Erwin said little is known about land organisms at the time.*

***Ordovician-Silurian extinction**, about 439 million years ago, caused by a drop in sea levels as glaciers formed, then by rising sea levels as glaciers melted. The toll: 25 percent of marine families and 60 percent of marine genera.*

From the five major extinction events, three principle causes can be identified: external impact events; volcanic/tectonic episodes; and, major global temperature changes. There is nothing that we can do to *prevent* any of these three trigger event episodes from occurring; and it is questionable whether we can successfully mitigate conditions if any of them occur now or in the future. Of the three triggers, there is only one that our human activity *may* have an influence over. It may be that we can have a major effect on the global temperature – indeed, it is considered highly probable that we may have already done so! (Hergerl et al, 2007)

Global Temperature Change

Evidence obtained from analysis of ocean floor sediment and Antarctic ice cores (Petit et al, 1999; Lisiecki & Raymo, 2005) allows us to estimate the variation in Antarctic temperatures for at least the past 5.5 million years (See Figure 9).

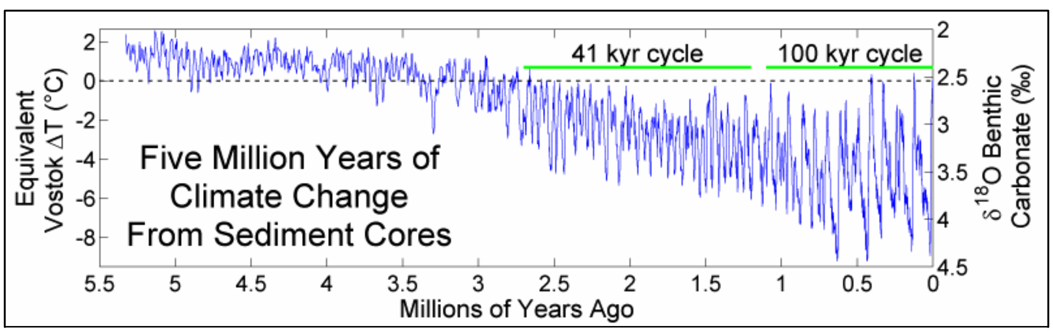

Figure 9: Global temperature change over the past 5.5 million years (Image by Robert A. Rohde for Global Warming Art. Source: GWArt, 2007a)

The record shows us that major cyclical variation in the Earth's surface temperature has been occurring over the past 5 million years, with a consistent cooling trend. From 3 million to 1 million years ago the peaks of the cooling episodes were on average about 41 thousand years apart. For about the past 1 million years the peaks have been on average about 100 thousand years apart.

Figure 10 shows a detailed view of the extrapolated global temperature variations that have existed from the present back to about 400 thousand years ago (Petit et al, 1999)

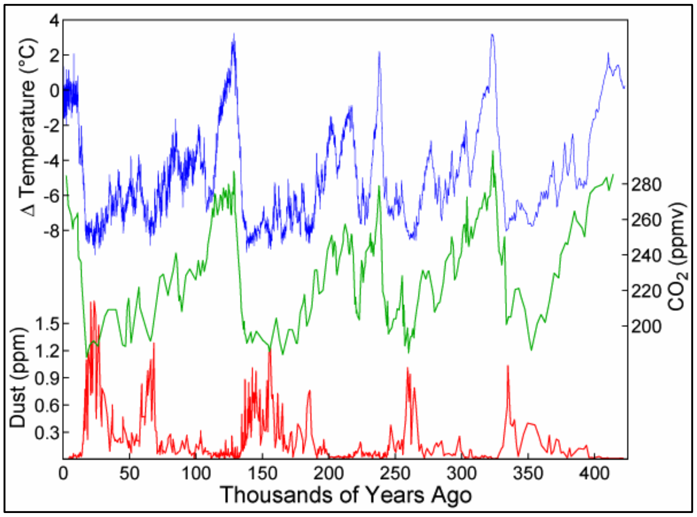

Figure 10: Variations in surface temperature CO_2 and dust over the past 400 thousand years (Image by Robert A. Rohde for Global Warming Art. Source: GWArt, 2007b)

Figure 10 also shows the variation in CO_2 levels over the past 400 thousand years. There is an obvious positive correlation between the CO_2 levels and the temperature; however, apart from scientific speculation, there is no evidence to confirm that the variations in temperature were caused by the variations in CO_2 level. It is just as possible that the variations in CO_2 level were caused by the variations in temperature, or that there were other correlated causal effects that have not yet been identified.

While it is difficult to explain why the Earth's atmospheric CO_2 level would intrinsically vary in 125 thousand year cycles, there are very plausible explanations as to why the Earth's surface temperature would do so. However, the strongest evidence that it was not an increase in CO2 levels that precipitated the glacial periods is found from examining the timelines associated with the last five interglacial periods (See Figure 11)[6]. Examination of the timelines for temperature and CO_2 build-up during the onset of the last five interglacial periods shows that the rises in temperature preceded the rises in CO_2 levels (EPICA community members, 2004).

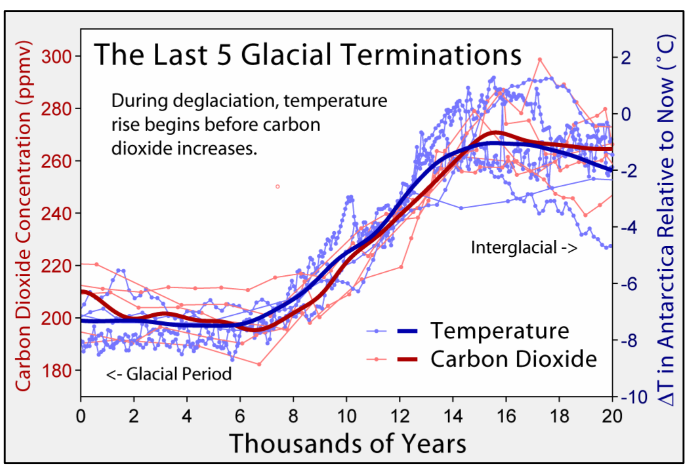

Figure 11: Temperature/CO2 timelines for the last 5 interglacial onsets. (Image by Robert A. Rohde for Global Warming Art. Source: GWArt, 2007c)

[6] Note that the timeline shown in Figure 11 goes from left to right as time approaches the onset of the interglacial period.

This implies that it may have been the rises in temperature that caused the rises in CO_2 observed over the past 400 thousand years, not the other way around.[7]

Glacial Events

The variation in global surface temperature depicted in Figure 10 exemplifies the nature of world wide glacial episodes that have been occurring for at least the last million years. It is characterised by long periods (about 105 thousand years) of relative cold, with ice covering much of the earth, interspersed with short periods of warm (about 20 thousand years); the so named interglacial periods.

It is clear from the world temperature records that we are currently in an interglacial period. The most recent glaciation, the so called *Ice Age*, finished as recently as 10 thousand years ago, when our current warm period began. The evidence also strongly suggests that we have passed the *normally expected* peak of that relatively brief warming period.

What may be surprising to some are the relatively rapid time periods over which the changes between glacial and interglacial regimes may occur.

> *Until a few decades ago it was generally thought that all large-scale global and regional climate changes occurred gradually over a timescale of many centuries or millennia, scarcely perceptible during a human lifetime. The tendency of climate to change relatively suddenly has been one of the most suprising*[sic] *outcomes of the study of earth history, specifically the last 150,000 years … . Some and possibly most large climate changes (involving, for example, a regional change in mean annual temperature of several degrees Celsius) occurred at most on a timescale of a few centuries, sometimes decades, and perhaps even just a few years. …*
>
> (Adams et al, nd)

If the long term global temperature variations over the past 5 million years are an indicator of future expectations then, unless some global event to the contrary occurs, within the next 5 thousand years our future generations will see the sudden onset of the next glacial period.

Normal Global Warming

The temperature line in Figure 10 exhibits a characteristic of a well-known repetitive phenomenon that is common in nature. In electronics the characteristic is exhibited by what is known as a *relaxation oscillator*. Hydraulic hammer pumps make use of the same phenomenon when a column of water is allowed under gravity to strike a spring loaded valve flap. The characteristic feature of the relaxation phenomenon is a short trigger event followed by a longer relaxation event. In Figure 10 the short interglacial warming events are occurring with periodic regularity, and are always followed by longer glacial events. If the analogue with other natural relaxation processes is to be assumed, then it appears that the glacial periods are triggered by the brief interglacial warming events.

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[7] It should not be inferred that this statement implies that an intrinsic increase in global CO_2 level may not cause an increase in the global surface temperature.

It has been well known for about a century that the global climate patterns are driven principally by two world-wide systems. The most obvious of these systems, one that we all see every day, is the radiated energy we receive from the Sun. Heat energy from the Sun warms the atmosphere and partially drives the short term global wind system. It also warms the surfaces of the oceans and the continents, which additionally drives the short term global wind systems. However it is not the global wind system that controls the longer term global climatic system; that is driven by the Great Ocean Conveyor Belt (Science@NASA, 2004).

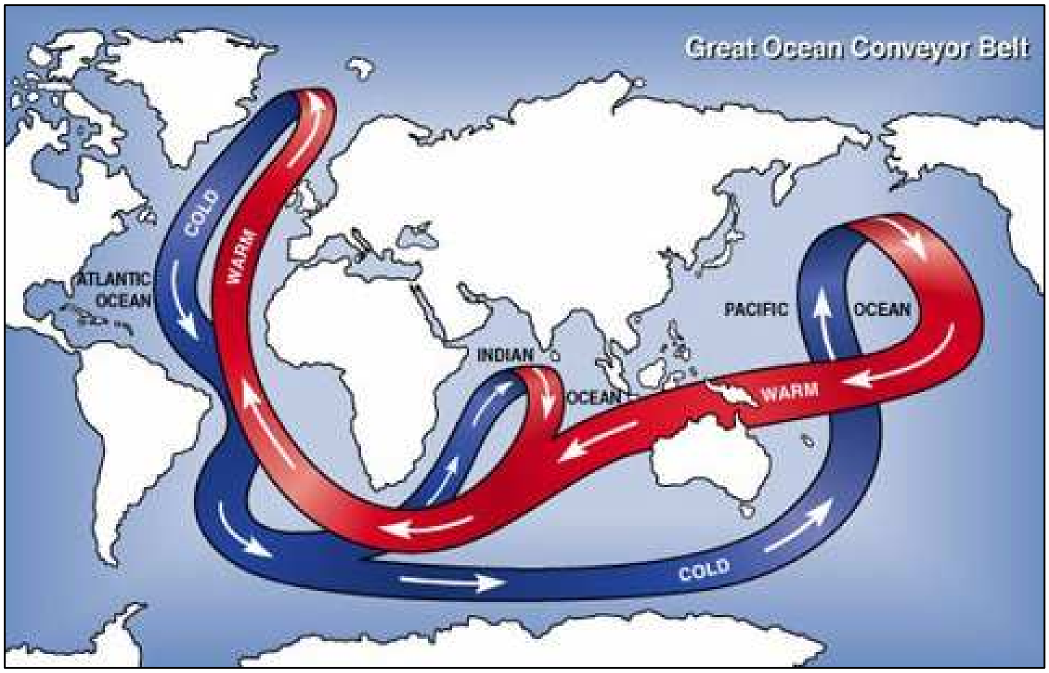

Figure 12: The Great Ocean Conveyor Belt global current (Source Science@NASA 2004).

The Great Ocean Conveyor Belt, also referred to as the thermohaline circulation, picks up deeper, colder water from the Great Southern Ocean. This cold water is transported to the North Pacific Ocean where it is brought to the surface. The water then travels west-ward through the tropical regions north of Australia where it is warmed. The warm water passes below Africa, and then northward via the North Atlantic Ocean to the Arctic Ocean. Here it starts to cool again.

During the warm travel path the surface water evaporates. By the time it reaches the turn-around path in the North Atlantic and it is rapidly chilled, the southward water is much denser than the north-going stream. When the return stream meets the warm Atlantic steam it dives beneath the latter under the force of gravity; and it is this gravitational impetus that keeps the Great Ocean Conveyer Belt flowing.

The direction of the Great Ocean Conveyer Belt shown in Figure 12 is as it currently is; during the onset phase of a typical warm interglacial period.

Recent research indicates that a reversal of the Great Ocean Conveyer Belt can be triggered by global warming (Science@NASA, 2004). There is good evidence available to indicate that once the global temperature reaches some critical value the water density difference in the North Atlantic Ocean is insufficient to drive the

Conveyor in the counter clockwise direction. Scientists at the Scripps Institution of Oceanography (2006) have demonstrated how increased global warming will most likely cause the conveyor to reverse in direction, and thus trigger the next glacial period. It has also been demonstrated that deep-sea warming in the southern hemisphere is the process that gradually relaxes the conveyor and stimulates it into the brief interglacial regime (Stott et al, 2007). Stott et al (ibid.) also demonstrate that the global temperature build-up occurs about 1000 years *before* the build-up of atmospheric CO_2.

Anthropological Global Warming?

It has been amply demonstrated that the interglacial warm periods are not caused by a natural build-up of intrinsic atmospheric CO_2. However, it is a relatively simple matter to demonstrate that introducing excess CO_2 into a horticultural greenhouse will indeed cause the temperature within the greenhouse to rise above what it would do in the absence of the excess CO_2. This analogy is the source of the often quoted and sometimes misused term "greenhouse effect" when referring to global warming. It is also the source of the term "greenhouse gas" to refer to CO_2 and other gasses that produce a similar effect.

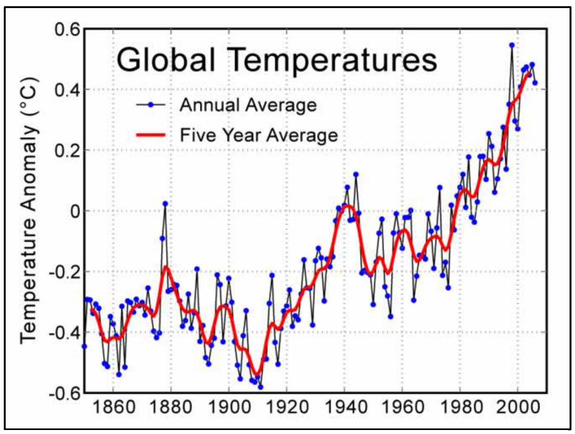

Figure 13: Annual global temperature since 1850 (Image by Robert A. Rohde for Global Warming Art. Source: GWArt, 2007d)

It is clearly evident that the Earth's average surface temperature is rising at a steady rate. Data made available by the Intergovernmental Panel on Climate Change (IPCC) (Hegerl et al, 2007) indicate that over the past 100 years the average global surface temperature has risen about 0.6ºC to 0.8ºC. Information released by the IPCC also speculates that, if the level of atmospheric CO_2 does not rise adversely, this trend of a moderate rise in temperature will most likely continue for the next 100 years.

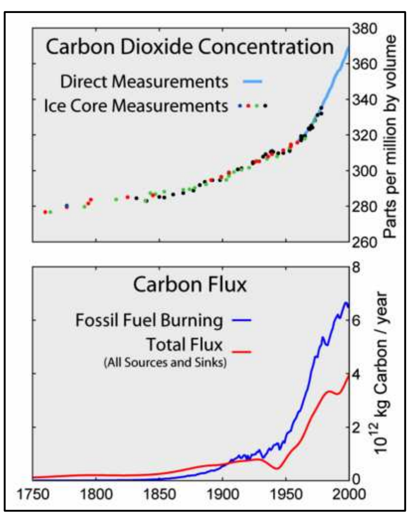

Figure 14: Annual global CO2 concentration (Image by Robert A. Rohde for Global Warming Art. Source: GWArt, 2007e)

There has been considerable recent scientific and political speculation that the rise in global temperature over the past 100 years has resulted from the increased concentration of atmospheric CO_2 released during and subsequent to the Industrial Revolution by the anthropological burning of fossil fuels. However, there is a lack of real evidence to support this speculation. For instance, despite an unprecedented rise in anthropological CO_2 and other greenhouse gas levels over the past five decades, the rate of global warming has not changed (see Figures 13 & 14). It is unclear what effect, if any, the observed rise in atmospheric greenhouse gas concentration will have on future global temperatures.

This does not mean, however, that we should be complacent about the way we use our finite fossil resources. Quite the contrary, we need to be circumspect about such matters. It does not make good political or social sense to continue polluting the atmosphere with such unnatural concentrations of gasses that may have the potential to severely and adversely affect the Earth on which we live. Whether it causes anthropological global warming or not, we have to stop pouring greenhouse gasses into the atmosphere.

Conclusion

In the introduction it was stated that the principle objective of science is to explain what nature *does*, not what it *is*. It is important that practicing scientists and science teachers remember this principle. Unless science students are taught this principle there is an increasing likelihood that scientists and scientific findings will be misused for political and commercial purposes.

With judicious use of the Internet and the ready availability of reliable scientific literature it is not a difficult task to conduct personal research into all claims couched in a scientific terms. It will always be the case that unscrupulous or ignorant organisations or individuals will misconstrue information to serve their own purposes. The commercial adage of "caveat emptor" (let the buyer beware) is just as valid in consuming information as it is when purchasing a home. If as scientists and science teachers we do nothing more than train our students in rational consumption of information, then we have served the future generations well.

The Earth is continually changing. We exist because the Earth is as it is. There have been times in the past when this was not so. There will be times in the future when it is not so. However, if in 200 thousand years time the human species no longer exists, it is historically certain that the Earth will be just as pristine as it ever was – but our progeny will not be there to enjoy it.

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