HUMAN IMPACT ON EARTH'S TEMPERATURE AND CHRISTIAN DILEMMA

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ABSTRACT

Contrary to conventional thinking, human signatures of carbon dioxide input to atmosphere began much before the industrial revolution in the mid-18th century. Christians who advocate the the 'young earth theory' (Intelleigent Design scholars) dismiss flatly the findings of modern geology. This paper, essentially, focuses on the acceptance of scientific consensus on the prehistoric climate change in geologic time. Some new ideas are discussed to explain the exact causal relationship between temperature and greenhouse gases over the past 800,000 years. This article also throws light on the so called "Milankovitch Cycles", caused by variations in orbital positions of the earth in relation to sun. The second part of this paper deals with global warming as the "Three Thoughts of A Geologist": (A) Climate change before the dawn of human (B) Warming and cooling in relation to carbon dioxide and (C) Evidence of greenhouse gas concentrations never before Coenozoic Ice Age reached levels as high as they are today.

Introduction -Human Influence on Global Climate

Despite humanity's relatively short presence on the planet, our use of Earth's natural resources and space has had and continues to have profound affects on our planet's ecosystems. Mounting evidence suggests that humanity's ecological footprint and global environmental influence has not been merely limited to the advanced environmental degradation we have caused since the industrial revolution. The first arrival and increased ecological pressure (e.g. hunting) of humans in North America and Australia is now strongly linked to the extinction of these continents' Pleistocene megafauna (large animals) between 50,000 and 10,000 years ago (Barnosky et al. 2004). Agricultural expansion resulting in increased forest clearing and new innovations in crop cultivation such as rice farming might be responsible for observed anomalous pre-industrial increases in atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2) and methane (NH_4), respectively (see summary and discussion in Ruddiman 2003). We generally associate local and global environmental pollution caused by chemical, organic, and ultimately nuclear materials with the onset of the industrial revolution in the mid-18th century, however, resource acquisition and processing, particularly the mining of metals has a much longer history of environmental degradation (Paula and Geraldes 2003). It seems that with humanity's unequaled ability to manipulate and shape its environment also came the potential to do (long-lasting) grievous harm to the planet's ecosystem. For a more detailed summary of humanity's long environmental impact on our planet see Zalasiewicz et al. (2008).

The fact that humans can have a long-lasting, and potentially dangerous, global environmental impact on the entire planet remains a philosophically challenging view to accept for many (see discussion in Malin 2005). After all, for much of our historical memory we have always seemed to be at the mercy, rather than in control, of the natural world. Images of natural catastrophes, from the destruction of the cities of Pompeii and Herculaneum by volcanic eruption in 79 A.D. (de Boer and Sanders 2001) to the terrible destructive power and global reach of the 2004 Indian Ocean tsunami (Lay 2005, Titov 2005), provide us with humbling reminders that humans are shockingly helpless in the face of natural forces. Humanity's power seems to pale compared to the scale and magnitude of natural systems and events. This is perhaps particularly the case with how we view our atmosphere. A natural system that can bring forth devastating winter storms, furious tornados, and immense hurricanes could readily be believed to be indifferent to human influence However, unfortunately, the evidence (see discussion by George, 2012, paper in this '*Theoecology Journal*'') suggests that climate change has caused threats to shell bearing animals in the seas because of ocean acidification and in the last 250 years humanity has reached an environmental footprint sizeable enough to alter even our planet's global climate (IPCC 2007).

Humans have become important agents of change on our planet. Some scientists have even argued that humans are now *the* dominant agent of change in the environment, for example as sculptors of the landscape (Hooke 2000; Wilkinson 2005). This ecological dominance has led to the suggestion that we should denote and recognize a new geological epoch, the "Anthropocene." Indeed, the sudden rise in atmospheric greenhouse gas concentrations beginning with the industrial revolution in the latter part of the 18^{th} century has been suggested as marking the beginning of this new epoch (Curtzen 2002; Zalasiewicz et al. 2008). Despite the recognition of humanity's global impact, particularly on the Earth's climate, by the scientific community, many laypeople are still puzzled by why human-induced climate change is viewed as such a potentially dangerous threat. After all, hasn't the Earth's climate changed dramatically throughout Earth history? Were there not periods of time during which the globe was even warmer than it is today? There is some evidence to show that in the Ordovician Ice age the atmospheric CO2 was 4,400 ppm and today it is 380 ppm. And why should global warming, even if anthropogenic, be viewed with any more worries than these other prehistoric changes in climate? The geological record provides us with a wealth of information on how our planet's climate has changed throughout its long history. What follows is a survey of some of the more important events and their causes since the formation of the planet. The history of the last 65 million years of climate evolution are covered in greater depths as they provide an important comparative background by which to view modern, anthropogenically-induced climate change.

Climate Change in Deep Time – The Christian Dilemma

Any discussion that involves the last 4.5 billion years of geological time represents a unique challenge for a scientist seeking to reach out to the Christian community. Many Christians, particularly among American conservative evangelicals, deny the vastness of geological time and instead subscribe to an Earth with a relatively short history measured in thousands, not billions of years (see for example Morris & Morris 1996). The reasons for dismissing the findings of modern geology are complex (see testimonies in Ashton 2001), and beyond the scope of this paper. The literature written to specifically counter the geological claims of "scientific creationism" is extensive (for a sample see Godfrey 1984; Walker 1984; Strahler 1990; Wise 1998; Cuffey 1999; Manger 1999; Isaak 2007, Young & Stearley 2008). The dilemma is that Christians who do not accept an ancient Earth are likely to dismiss any discussions of climate change throughout deep time as well. This is unfortunate because an understanding of past climatic conditions provides not only an important historical context in which to study and understand modern climate change but provides us with unequaled insight on what conditions on a much warmer future world might be like. At best, Christians skeptical of modern geological findings should nonetheless be motivated to embrace environmental stewardship simply based on present-day observations of global warming, species extinction, increased deforestation, pollution, and scriptural authority (Greenberg 2003; Braaten 2003) and genuine conerns of creation care (Wilson, 2006, George, 2009 & 2010) . The approach here does not seek to simply dismiss the concerns that conservative Christians bring to a discussion of geological ages. However, for the sake of brevity and to keep the focus on environmental stewardship, the following discussion will assume an acceptance of the scientific consensus with regards to geological time and prehistoric climate change.

From Ice Ages to Global Warming

As mentioned earlier in the paper, continuous measurements of atmospheric concentrations of the greenhouse gas carbon dioxide began in 1957 at the Mauna Loa Observatory in Hawaii (Revell & Suess 1957). The "Keeling Curve", as it became known, indicates that the concentration of atmospheric carbon dioxide in the Northern hemisphere has been steadily increasing since measurements began. The small annual increases and decreases are due to seasonal uptake and release of carbon dioxide by photosynthetic organisms (Keeling 1960; Pales & Keeling 1965; Keeling et al. 1995; Keeling & Whorf 2004). But how do we know that this upwards trend is n't part of some larger natural cycle? It is possible that carbon dioxide levels have been increasing at the observed rate (Keeling & Whorf 2004) of about 1.3 ppm (parts per million per year) for much longer than humans have had a chance to affect this concentration.

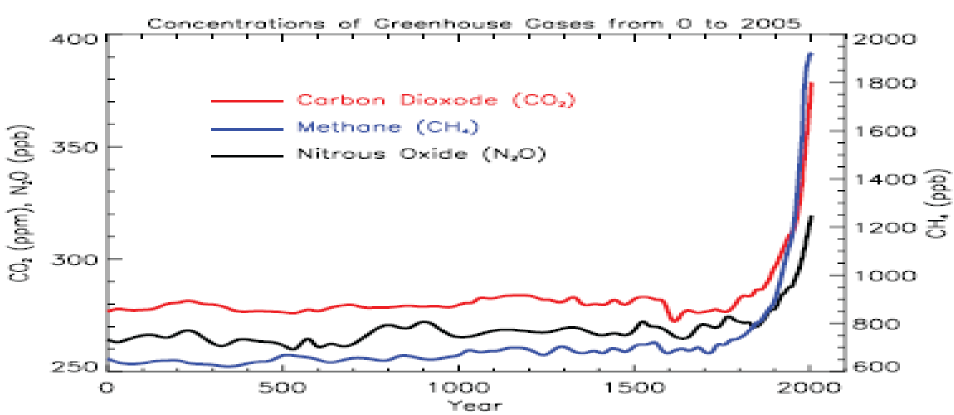
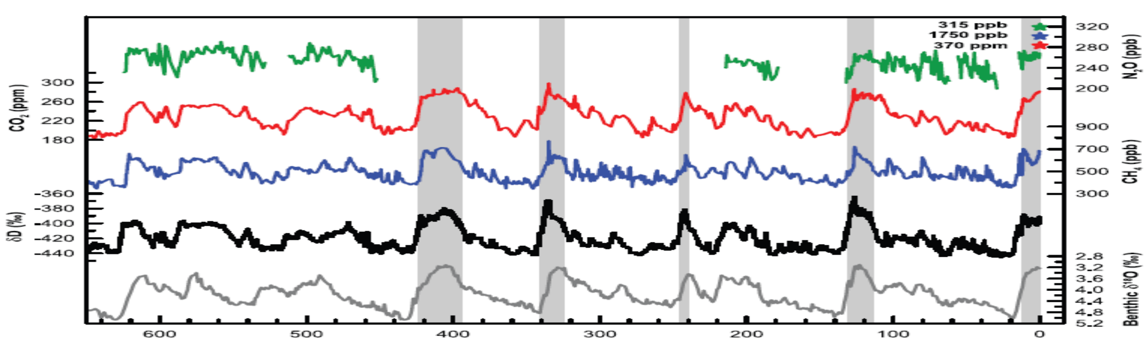


Figure 1 Adapted from the IPCC 2007 report

To place the "Keeling Curve" into context, Figure 1 shows the atmospheric concentrations of the three important greenhouse gases carbon dioxide, methane, and nitrous oxide for the past 2000 years (IPCC 2007: 135). This data represents a compilation of measurements taken from cores of glacial ice and firn (an intermediate between loose snow and glacial ice) in Antarctica. For a complete list of references upon which this graph is based see IPPC (2007: Figure 6.4, p. 448). Tiny air bubbles trapped inside the ice allow reconstruction of atmospheric gas concentrations with a resolution of between 20-200 years, depending on local annual snow accumulation rates and how well-preserved the ice layers are at each site (IPCC 2007: 448). All three atmospheric gases begin to increase dramatically between 1700 and 1800. Indeed, all of the gases' concentrations varied comparatively little prior to the late-1700s. Hence, the high rate at which carbon dioxide concentration is seen to increase in the "Keeling Curve" appears to be a new phenomenon at most ~250 years old. The same can be said for measured concentrations of nitrous oxide and methane. If the recently (last ~250 years) observed increases in gas concentrations are part of some natural cycle, it must be a cycle that is at least 2000 years long.

Fortunately, our data of the atmospheric concentrations of these three gases (CO_2, CH_4, and NO_x) can now be reconstructed (using air bubbles trapped in Antarctic ice cores) back to at least 650,000 years ago for methane and nitrous oxide (Petit et al. 1999), and 800,000 years ago for carbon dioxide (Spahni et al. 2005). Figure 2 shows the measured concentrations of each gas as well as oxygen isotope data gathered from the skeletons of fossil marine benthic foraminifera (small microscopic calcareous organisms that live in or on the seafloor) and variations in deuterium, an isotope of hydrogen (Lisiecki & Raymo 2005a, 2005b; Siegenthaler et al 2005). These two latter measurements record fluctuations in global ice volume and local paleo-temperature respectively (for an explanation of how this works see Houghton 2004: 67; Libes 1992: 562-566; Faure 1991:301-310). The concentrations of all three atmospheric greenhouse gases have varied dramatically throughout the last 650,000 to 800,000 years. However, this variation is not completely random and there are some important trends in this data.

First, shorter periods of higher gas concentrations (marked in light red) alternate with longer periods of lower gas concentrations (marked in light blue). This is particularly visible during the past 450,000 years.



Carbon dioxide in ppm (from IPCC Report)

Second, whenever gas concentrations were high, paleo-temperatures were high (see δD curve) and glacial ice volumes were low (the lower the $\delta^{18}O$ the less ice was present). The opposite is also observed. This suggests that there is an important relationship between the amount of atmospheric greenhouse gases and global temperatures, namely, when there are high concentrations of greenhouse gases, the global climate is warmer. Indeed, the periods during which gas concentrations were low correlate with glacial periods, informally known as "Ice Ages" (see Imbrie & Imbrie 1986; Macdougall 2006), during which significant parts of the higher latitudes were covered by continental glaciers. However, the exact causal relationship between temperature and greenhouse gases over the past 800,000 years is more complicated than it first appears (see discussion below).

Third, and perhaps most important to this discussion, the maximum recorded historical levels for each gas prior to the industrial era are significantly lower than present-day concentrations. In other words, compared to the last 650,000-800,000 years of Earth history, the rapid increase in the concentrations of carbon dioxide, methane, and nitrous oxide that began in the 18^{th} century is an *anomaly* that cannot be explained in terms of the natural cyclicity between glacial and interglacial periods. Indeed, a recent study (Tripati et al. 2009) demonstrated that the last time atmospheric carbon dioxide concentrations were high as they are today was roughly 15 million years ago. The dramatic implications this latest finding has for our understanding of global warming will be discussed later in the paper.

As discussed above, there is a close relationship between atmospheric gas concentrations and global temperature. The current scientific consensus is that the current warming observed since the industrial revolution is dominantly driven by the human emission of heat-capturing greenhouse gases such as carbon dioxide (IPPC 2007). However, detailed comparison between carbon dioxide concentrations and paleo-temperature over the past 450,000 years show that gas concentrations initially follow temperature variations – not the other way around. In other words, temperature is observed to change first, followed by changes in carbon dioxide (Mudelsee 2001; Caillon et al. 2003). Perhaps not surprisingly, this has led to claims by the global warming denying community that temperature rise *causes* increased concentrations of greenhouse gases rather than the other way around (e.g. Idso & Idso 1998). Climate scientists are well aware of this phenomenon and have studied it in great detail (see for example Fischer et al. 1999; Shackleton 2000; Mudelsee 2001; Monnin et al. 2001; Cuffey and Vimeux 2001; Caillon et al. 2003; Stott et al. 2007). The simple answer to this apparently contradictory and puzzling phenomenon is that carbon dioxide, or greenhouse gases in general, are not the only drivers of climate change. The reoccurrence of the glacial-interglacial cycle has long been seen as the result of variations in the magnitude of incoming solar radiation (Hays et al. 1976; Berger 1977, 1978; for a recent perspective see Kawamura et al. 2007). However, unlike the short-term solar variations such as the 11-year sun spot cycle (see discussion by George 2012), these fluctuations, commonly known as Milankovitch cycles, are caused by long-term variations in the orbital position of the Earth relative to the sun (see IPCC: 445, 449-450). The most important of these cycles include changes in the shape of the Earth's orbit (its eccentricity, ~100,000 year cyclicity), the degree to which the Earth's axis is tilted (~41,000 year cyclicity), and a slow rotation (its precession, ~23,000 year) of the direction in which the Earth's axis points (see diagrams in Imbrie & Imbrie 1986; Zachos et al. 2001; Macdougall 2006). Changes in these parameters influence how much solar radiation reaches different parts of our atmosphere. As solar radiation increases, global temperatures rise and ice sheets retreat. Kawamura et al. (2007) were able to demonstrate that at least the last four glacial terminations of the last 360,000 years were triggered by changes in solar radiation that are consistent with Milankovitch cycles.

The initial lag of between 200 and 1000 years (Fischer et al. 1999; Caillon et al. 2003) of carbon dioxide concentrations behind temperature is in part explained by Milankovitch-type orbital forcings. Orbital parameters initiate the end of a glacial period by allowing for more solar radiation in the southern hemisphere (after all our data comes from Antarctic ice cores). As southern temperature rises, the atmosphere and the oceans begin to absorb more heat. The latter is important as a warming ocean can more readily release carbon dioxide into the atmosphere than a cool ocean. As the Southern Ocean warms it begins to release more carbon dioxide due to changes in solubility as well as biological productivity (Martin et al. 2005). For the first 200-1000 years, gas release lags behind, but thereafter gas concentrations and temperature rise synchronously. As gas concentrations increase, the planet begins to warm further causing more carbon dioxide to be released in turn. Ultimately, mixing of carbon dioxide through the atmosphere takes time, which probably explains why temperature in the tropics lags behind Antarctic temperature increase by ~1000 years (Cuffey and Vimeux 2001; Stott 2007). In summary, the observed lag in carbon dioxide concentrations behind temperature in Antarctic ice core records is the result of the interaction between variations in orbital parameters, atmospheric and oceanic temperature, and the global carbon cycle. For a more detailed discussion of the "lag phenomenon" in laymen's terms see Severinghaus (2004), Brahic & Le Page (2007), Steig (2007), and Cook (2007). Although changes in orbital parameters and positive feedback in the global carbon cycle play an important role in glacial-interglacial cycles, they are by no means the only variables (see summary in IPCC 2007: 446).

The initial lag of gas concentrations behind temperature in prehistoric times is of course *not* what has been observed in recent times. Indeed, since the industrial revolution, greenhouse gas concentrations have rapidly been outrunning temperature increases. The dominant driver of global warming since the 18th century is the radiative forcing caused by greenhouse gases (IPCC 2007: 23). The cycle of glacial and interglacial periods has been going on for nearly the last 3 million years (MacDougall 2006). According to the "normal" variations of greenhouse gases concentration of the last 650,000-800,000 year (see Figure 2) our current interglacial period would last at least another 30,000 years (Loutre & Berger 2002; Berger & Loutre 2003; Epica 2004). However, greenhouse gas concentrations have risen to such anomalous levels that the next glacial period will likely be delayed even further into the future (Loutre & Berger

2000; Archer & Ganopolski 2005). For a perspective on the 1970s media-fueled fear of an impending ice age, see Henson (2008: 247-248). Human activity is not only affecting the current state of our planet but is altering a natural equilibrium that has ruled our planet's climate for at least 800,000 years, and potentially as much as the last 3 million years.

Global Warming Before Humans

Over the last 800,000 years atmospheric carbon dioxide concentrations have fluctuated between 180 and 280 ppm. Only since the industrial revolution in the late 18th century have concentrations spiked to the current anomalous high of ~388 ppm in 2009 (Tans 2009). Tripati et al (2009) demonstrated that the last time our atmosphere had correspondingly high levels was in the middle Miocene epoch, roughly ~15 million years ago (see also Lowenstein & Demico 2006). The fact that greenhouse gas concentrations have been as high or higher in the past can be surprising and confusing to the non-scientist. The conclusion readily (but falsely) drawn from this knowledge is that current global warming is simply recreating a previous natural state and is therefore nothing to worry about – after all the ecosystem has experienced this before and will cope, perhaps even thrive (e.g. Idso & Idso 1998). However, this outlook fails to take into account that during this "previous natural state" the world was an average of 3-6ºC warmer and global sea levels were 25-40 meters (80-130 feet) higher than today (Tripati et al. 2009). It would mean a return to an ecosystem and shoreline that our species has *never* before experienced during its short 195,000 years on Earth. More significant however is that this change is occurring at a rate that is expected to be detrimental, perhaps catastrophic, to our already stressed and fragmented ecosystem (see IPPC WG2: 213).

The climatic conditions that serve as the backdrop to the glacial-interglacial swings of the past ~3 million years are in themselves the result of long-term climatic cooling that began ~50 million years ago. Although direct measurements of atmospheric gas concentrations are limited to the last 800,000 years as recorded in ice cores, proxy data can be used to reconstruct a relative temperature scale of deep ocean waters for much older time intervals (Zachos et al. 2001; Billups et al. 2002; Bohaty and Zachos 2003; Lear et al. 2004). Figure 3 depicts relative changes in $\delta^{18}O$ (read: "delta O 18") values inside fossil skeletons (calcite or $CaCO_3$) of deep sea benthic foraminifera for the past 65 million years (the Cenozoic era). The $\delta^{18}O$ value of the fossil calcite skeleton depends on the temperature of the surrounding seawater in which the test (skeletal body) was originally precipitated, as well as the $\delta^{18}O$ value of the seawater itself. When the $\delta^{18}O$ of seawater remains unchanged, any temporal changes in the $\delta^{18}O$ of the foraminiferal skeleton reflects changes in surrounding seawater temperature (Faure 1998: 308-310). Unfortunately, for the past ~35 million years, $\delta^{18}O$ of seawater changed as a result of the waxing and waning of continental glaciers. This is because ocean waters become enriched in ^{18}O as lighter isotopes of oxygen are removed through evaporation and deposited on land as glacial ice (see Houghton 2004: 67). Hence, paleo-temperatures (relative to today) can only be reconstructed until late in the Eocene. Younger variations of $\delta^{18}O$ are influenced by both changes in seawater temperature *and* ice volume (Zachos et al. 2001). Either way, changes in $\delta^{18}O$ values of skeletal calcite provide an important record of global climatic changes over the last 65 million years. A brief survey of the most important events provides a lens through which to view modern climate change.

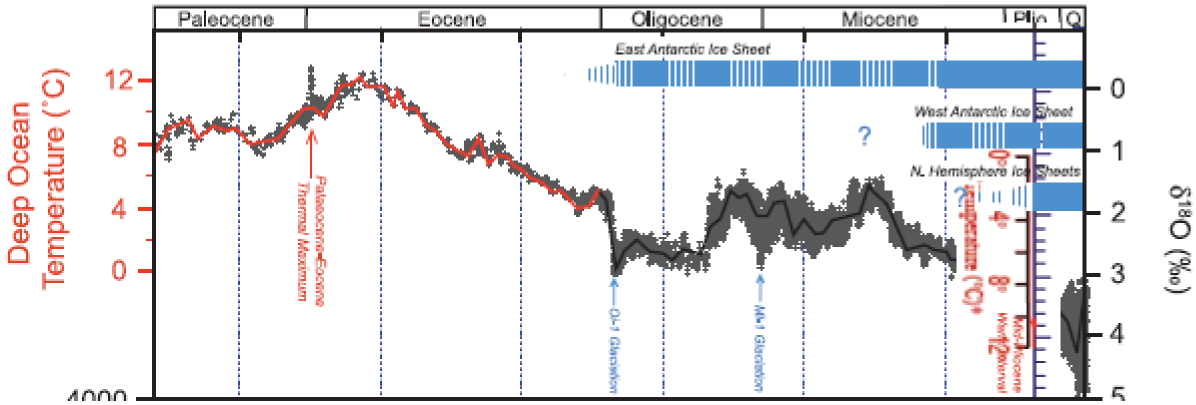


Figure 3 Deep-Sea Temperature from Geologic Past

The Mesozoic era, and with it the age of the dinosaurs, came to a relatively abrupt end ~65.5 million years ago. Following the geologically short-lived climatic perturbation caused by the end-Cretaceous asteroid impact, the first ~13 million years of the Cenozoic era experienced the last major warm period on Earth (Berggren et al. 1998). This “hothouse world” reached its zenith, or the “Eocene Climatic Optimum”, between 52 and 50 million years ago (Zachos et al. 2003). During the Eocene, warm temperatures extended well into the higher latitudes. Fossil sites throughout the Arctic bear the remains of fauna limited to much warmer latitudes today, including alligators, monitor lizards, and even primates. This bizarre faunal collection is matched by the floral components. Fossil plants from Northern Europe consist of palms, and other tropical shrubs found only in the warm lower latitudes today. Plant life must have thrived in these higher latitudes as evidenced by Eocene coal beds. Indeed, the average annual Eocene temperature in southern England was around ~25ºC, roughly 15ºC more than it is today. For more information on this lush Eocene world, see Prothero 1998.

The Eocene is of particular interest to those wishing to understand modern day climate change. Why was the early Cenozoic so unusually warm? Although multiple factors come into play when talking about climate drivers over a 13 million year period, the evidence is converging on extremely high concentrations of greenhouse gases being the dominant factor (Zachos et al. 1994, 2001, 2008; Lowenstein & Demico 2006; Fletcher et al. 2008; Smith et al. 2008). Analysis of unusual minerals that formed in Eocene lakes demonstrates that atmospheric carbon dioxide levels during the Eocene were at least 1125 ppm (Lowenstein & Demico 2006). Although this is nearly 3 times greater than today’s levels of ~388 ppm (Trans 2009), it is only a little higher than the uppermost limits of concentration our current atmosphere is projected to reach by 2100 (IPPC 2007: 750). Long-term (by 2400) carbon-dioxide concentrations will be even higher (Zachos et al. 2008). Subsequently, paleoclimatologists have paid the Eocene increased attention. Understanding Eocene climate might provide us with a look at how our own near future climate might look.

A particular subject of study is a sudden excursion in the $\delta^{18}O$ record that has become known as the Paleocene-Eocene Thermal Maximum (PETM). This excursion records a sudden increase of global sea surface temperature between 5º and 9ºC in less than 10,000 years with warming lasting about 170,000 years (Zachos et al. 2005). Evidence from carbon isotopes (see Zachos et al. 2003) suggest that this event was accompanied by rapid addition of ~2000 gigatons of carbon (in the form of CO_2) into the Earth's atmosphere and ocean, although some put the number as high as ~5000 gigatons (Higgins & Schrag 2004). The exact source of this carbon remains the subject of debate but potential culprits are volcanically-liberated sedimentary methane (Svenson et al. 2004), the release of frozen sedimentary methane (e.g. gas clathrates) from the seafloor (Dickens 2003), and/or terrestrial carbon sources such as peat (Kurtz et al. 2003). Higgins and Schrag (2003) provide a comprehensive discussion of these and other potential sources of greenhouse gases during the PETM.

Because the PETM was the result of a sudden release of greenhouse gas into the atmosphere and ocean it is perhaps the best ancient analog for today's global warming caused by industrial emissions. Higgins & Schrag (2003) point out that the observed temperature rise during the PETM suggest an increase of about 4ºC for every doubling of atmospheric carbon dioxide concentrations, which lies near the upper end of projections provided by modern climate models (see IPPC 2007: 749). In other words, our computer models are likely *underestimating* the magnitude of future warming if emissions continue to rise as they have since the industrial revolution.

Around 50 million years ago, the early Cenozoic hothouse came to an end when $\delta^{18}O$ values began to increase (a relative downturn on the graph in Figure 3) and continue to do so relatively evenly until the Eocene-Oligocene boundary. This change in $\delta^{18}O$ values is generally interpreted to be evidence of continuous global cooling (Zachos et al. 2001; but also see findings by Pearson et al. 2007), a trend that, with some important perturbations (see discussion below), continued until the ice age world of the last ~3 million years. A widely held hypothesis is that this long-term cooling is driven by the formation of the Himalayas which initiated in the mid-Eocene (Raymo & Ruddiman 1992; but also see more recent perspective on this view by Kerrick & Caldera 1999). An efficient means to decrease atmospheric carbon dioxide concentrations is to remove it through the weathering reactions with silicate rock (see West et al. 2005; Smith et al. 2008). The general model suggests that mountain uplift and resulting increases in weathering rates (mountains expose large amounts of rocks) significantly reduce atmospheric carbon dioxide concentrations. The Himalayas might have played the role of a giant natural atmospheric carbon dioxide "scrubber" for the past 50 million years (Raymo et al. 1988).

The sudden rise in $\delta^{18}O$ at the Eocene-Oligocene boundary marks a crucial event in the history of our Cenozoic climate and has therefore received much attention by the scientific community (Prothero & Emery 1996; Prothero 1998; Prothero et al. 2003). The event coincides with the final tectonic separation of South America and Australia from the Antarctic continent resulting in the formation of the Drake Passage and Tasmanian Seaway around 35 million years ago. This marked the final step in the ~200 million year long tectonic break-up of the supercontinent Pangaea, which had existed since the Carboniferous/Permian periods (see Scotese 2002). As a result, global ocean circulation fundamentally changed as the newly developed southern circumpolar current effectively isolated Antarctica from warm tropical surface waters. Antarctica experienced the first built up of vast ice sheets whilst cooler global ocean waters caused the extinction of many warm-water species (Zachos et al. 1992; review in Ivany et al. 2003) The world that emerged from this tectonically-driven climate change is ultimately the core of our own modern global earth system, with similar atmospheric, oceanic, and biological components and structures (Ivany et al. 2003).

The continuous global cooling that connects the Eocene-Oligocene boundary with our modern ice-age era (last ~ 2.6-3 million years) was punctuated by one last brief warming period, the Mid-Miocene Climatic optimum (14-17 million years ago). This event has been linked to an increase in atmospheric carbon dioxide levels. The source for all of this carbon dioxide can probably be found among the extensive, million-year-scale volcanic activity of the Columbia River flood basalts in the Pacific Northwest and volcanic activity in Central Europe (Hodell & Woodruff 1994; Böhme 2003; Kürschner et al. 2008).

Global Warming in Light of Deep Time: Three Thoughts of a Geologist

The above look at climate changes over the last 65 million years places modern global warming into its geological context. Several conclusions can be drawn from this comparison.

First, climate changes, both gradual (e.g. Eocene cooling) and rapid (e.g. Paleocene-Eocene Thermal Maximum), have occurred "naturally" before the dawn of humans. Since the beginning of our planet, changes in ocean circulation and atmospheric composition have been wrought by tectonic activity, both as continents slowly shift their relative positions, and as volcanic activities wax and wane. On one hand it is assuring to know that our planet has experienced dramatic climatic upheavals in the past, however the fossil record leaves one with little comfort about how ecosystems were affected by the more climatic changes. The Paleocene-Eocene Thermal Maximum, perhaps the most rapid example of Cenozoic global warming before modern day climate change coincides with the decimation of deep sea benthic foraminifera as well as a fundamental restructuring and turnover of the terrestrial mammal fauna (see papers in Wing et al. 2003). The Eocene-Oligocene climatic transition records similarly extensive turnovers and extinctions in the marine habitat and terrestrial ecosystem (see summary in Ivany et al. 2003). Climate change, even when it is natural, has always had significant effects on the ecological make-up of our planet.

Second, geological evidence shows us that climatic change, be it warming or cooling, is closely linked with atmospheric greenhouse gas concentrations, particularly carbon dioxide. The Eocene hothouse, the PETM, and the Mid-Miocene Climatic Optimum have all been linked to increased levels of the potent greenhouse gas carbon dioxide. Our current levels of carbon dioxide have reached levels similar to what they were in the Miocene and projections place future concentrations (perhaps as early as 2100 or as late as 2400) into comparative levels last seen during the Eocene hothouse. The Eocene and Miocene saw global average temperatures that might have been between 10º and 5ºC degrees higher than they are today respectively. Needless to say, the distribution of plant and animal life, as well as climatic zones was very different in those times.

Third, the rise in greenhouse gas concentrations responsible for the warming we have seen since the industrial revolution is an anomaly that cannot be explained in terms of natural climatic cycles that have been present on our planet for at least the last 2.6 to 3 million years. Greenhouse gas concentrations have fluctuated prehistorically between glacial and interglacial periods but never before in the Cenozoic ice age era have they reached levels as high as they are today. Indeed, these high levels will likely have lasting affects on the glacial-interglacial cycle and postpone any future glacial periods.

Humans are not the first organisms throughout Earth history to have a profound impact on global climate. Indeed, the composition of our very own atmosphere is in large part due to the evolution and activity of the earliest photosynthetic bacteria and later terrestrial flora (Schopf, 2001). However, humans are the first organisms who are willfully affecting the environment. With our newfound power to either care for or destroy the environment comes a profound responsibility. We have a choice to make. Humanity should weigh its options carefully – if there is anything that geology teaches us, it is that profound changes have profound consequences. In the long-term, the Earth will ultimately recover from human-induced climate change, however the ecosystem that will emerge will very likely be very different, and initially much poorer in composition of the biota and biodiversity

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