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Historical Account of Ocean Acidification and Contemporary Repercussion

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Abstract— The Paleocene–Eocene Thermal Maximum represents a quantifiable and measurable loss of biodiversity as a result of carbon absorption in the earth through several sources. The impact on earth systems using ice core samples, geological footprints as well as fossils gives us an accurate image of the type of background extinction rates as well as atmospheric composition during the roughly 170,000 year period of the PETM. This paper looks at the PETM as an event to compare modern day repercussion and impact due to anthropogenic carbon emissions and ocean acidification.

Index Terms— Anthropogenic emission, Carbon absorption, Climate systems, Geoscience, Oceanography, Ocean acidification, Paleocene–Eocene Thermal Maximum, Carbon emission

1 Introduction

The nature of anthropogenic influence on Earth has been relatively recent, considering humans have only had the ability to make an impact in the past two centuries. Before this, the conscious workings of mankind to shape and change nature is dull in comparison to the natural order of the Earth itself. The Earth has the capacity to move an insurmountable amount of gasses and rock, terraforming the planet slowly over time. However, when relying on the one source life cannot sustain without – that is – the hydrosphere, it is imperative to monitor and to ensure the continuing health of the world's oceans. Today's oceans are saturated with respect to carbon based elements such as calcium carbonate which is an important attribute to a calcification process most marine life go through, but an increase in atmospheric carbon dioxide (CO_2) due to burning of fossil fuels is depositing large amounts of carbon into the ocean, reducing pH values and which are directly proportional to calcium carbonite saturation. As this acidification of the ocean continues, we will see a decrease in key marine organisms such as coral, plankton and pteropods[1]. Ocean acidification is caused by the dissolving of CO_2 with H_2O to form a chemical reaction that increases hydrogen ion concentrations [H^+] which lowers pH as follows:

$$CO_{2\,(aq.)} + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO^{3-} + H^+ \leftrightarrow CO_3^{2-} + 2H^+$$

This reaction yields carbonic acid (H_2CO_3), bicarbonate (HCO^{3-}), carbonate (CO_3^{2-}) as well as hydrogen ions (H^+) which are responsible for the future acidification of the ocean[2]. This translates as a direct impact on the food chain that humans all around the world heavily depend on. In order to assess a computational model for the expectancy as well as degradation of marine life, this paper will explore previous historical exploits of carbon and simulate the repercussions and impact to human industries today.

2 Effects

2.1 History

The historical atrocities of nature on the biosphere are well-known and documented. For millennia, the planet Earth has evolved to better deal with its carbon-based life forms, allowing an environment to sustain life, and to promote it. However, on numerous occasions – some extra-terrestrial – life on Earth has faced extinction on a planetary scale. The most famous of these extinction is indubitably the Cretaceous-Tertiary (K-T) extinction, or the mass extinction of the dinosaurs. A less notable but equally significant event is the Paleocene-Eocene Thermal Maximum (PETM), which refers to drastic climate event that began at the temporal boundary between the Paleocene and Eocene epochs nearly 56 million years ago (10 million years after the K-T extinction). This singularity has been the focus of substantial geoscience research as it provides us with the best past data set by which to understand and compute global climate change and of particular interest, ocean acidification and its effect of marine life[3].

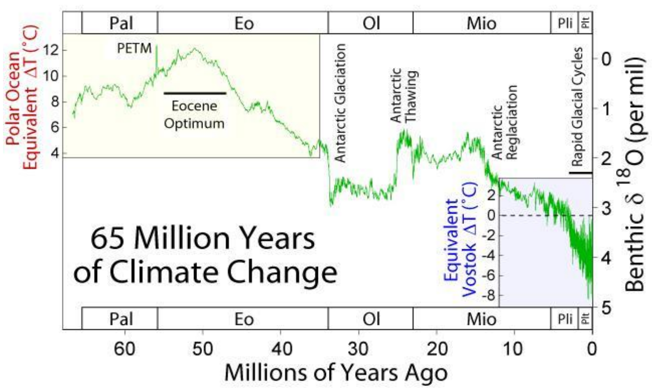
During the estimated 170,000 years that this change lasted, the Earth saw a global temperature increase of 5°C and extreme changes in the carbon cycle. This, when paired with the slightly undersaturated carbon deposit, caused a systematic absorption of oceanic carbon. This was marked by a prominent negative excursion in various carbon stable isotopes from around the globe. This essentially caused a mass extinction in any basin with excessive carbon, and up to 50% of organic species during a 25,000 year time period were facing extinction. This anomaly provides us with a 'case study' of the effects of global warming and massive carbon deposits into the ocean and how it influences organic life.

Figure 1.0[4] shows a progressive change in climate for the past 65 million years. It provides scientists with data concerning global geologic shifts in ocean temperature, atmospheric composition and change in temperature denoted by the ΔT. This shows local temperature recovered from ice cores as well as geo-samples. The spike that occurs roughly in the 55 million marker shows the PETM event, and the quick and abrupt spike to temperature. It is not possible to tie these temperature changes with any of the other variables present when discussing climate change, but it provides evidence for two separate phenomena:

- There was a period in the 55 million year mark where there was a clear change in global climate activities, and

- the Earth routinely goes through global cyclical climate oscillation with or without animal or human activity[5].

Figure 1.0



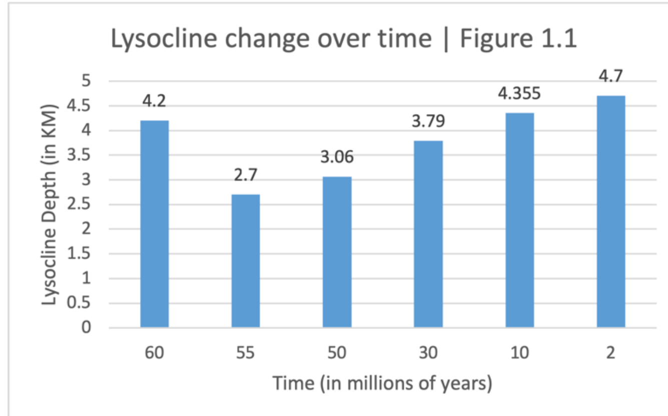
Using this as a benchmark, the PETM stands out over the existing climate oscillations that have historically played an important role in the fluctuation of the Earth's climate systems. So this establishes the PETM as an anomaly in the geological timeframe of the Earth. It is because of this anomaly that scientist have devoted so many resources attempting to decipher the mystery of the massive carbon input in the oceans. This ocean acidification also inferences evidence for global warming. For the average global temperature to rise by nearly 6°C within a range of 25,000 years, it has clear effects on plant, vegetation as well as the entire biosphere. The timing of the addition of carbon into the ocean and the rise in global temperature is not a coincidence.

2.2 PETM and marine life

The Earth operates by dynamically connecting all the different 'spheres' (biosphere, hydrosphere, lithosphere etc.) into one cohesive system. When one of these systems are changed, it will alter all the other connecting systems. Since this paper focuses on the ocean acidification, the hydrosphere is going to be at the centre of discussion pertaining to the PETM.

We have evidence of the lysocline level of the PETM. The lysocline is the depth at which carbonate starts to dissolve, which means that any depth above the lysocline, carbonite is oversaturated[6]. Carbonite levels in the ocean are required for calcification of shellfish and other marine organisms that have to calcify their exoskeletons. The higher dissolve rate of carbonite greatly impairs the ability for such organisms to repair their shells – so carbonite saturation is directly linked to marine health as most of these organisms are at the bottom of the food chain. Roughly 2000 x 10^9 metric tons of carbon in the form of methane was deposited to the ocean[7]. This caused the lysocline to be at a depth of 2 kilometres (km), which means any marine at a greater depth of 2 km will suffer reduced shell restoration functions. This is partly one of the reasons marine life saw a dramatic and abrupt extinction rate. Today, this depth is at 4km, which shows if current carbon deposits continue, this depth will start to shallow. Using the data provided in research[8], figure 1.1 shows the depth of the lysocline.

As is apparent from figure 1.1, the lysocline depth



underwent a dramatic change between 60-55 million years where the PETM occurred. Since the PETM, the lysocline depth has reverted back to a more stable and marine-friendly 4.7 km. This event saw a change in geochemical composition of sea-floor carbonate dissolutions, which greatly impacted the biosphere by relation. This deep water acidification can be seen and has been analyzed in ocean cores. So the lysocline rose by an average of 2 km within a domain of a few thousand years. This 35-50% mass extinction due to the lysocline is greater with respect to time than the extinction of the dinosaurs. While the source input of CO_2 is still largely debated, it is clear that the ocean acidification caused a catastrophic failure in global temperature systems as well as marine life which most other forms of life depend on. It is speculated that a combination of volcanic activity, a possible comet as well as large methane releases is what caused this carbon to be inputted into the atmosphere and ocean[9].

This becomes increasingly important in the contemporary context. It is significant to note the events that transpired in the PETM gives researchers and scientists the data to predict future events concerning ocean acidification as well as the impact it will have on the anthropogenic population. So how will the continual anthropogenic emission of CO2 and other carbon based elements affect the lives of humans?

2.3 Ocean Acidification

Figure 1.2[10] shows the expected change of ocean pH levels from a more alkaline to a more acidic pH value. The ratio of concentrated elements shows how they are responsible for the variation in pH levels, for example, the CO_2 green line shows the more acidic the pH value, the higher the concentration of carbon dioxide. The same is true for the red bicarbonate ($HCO3^-$) line as well as the black carbonate ($CO3^{2-}$) line. This shows that higher concentrations of CO2 will cause a lower pH number. Also, figure 1.2 also shows the expected change of pH value, that we are going through a process of ocean acidification. Of the extra carbon dioxide, some remains as dissolved carbon dioxide, the rest is used to generate additional bicarbonate and carbonic acid. There is

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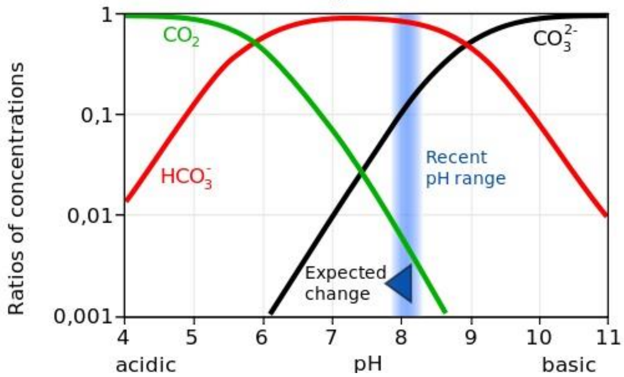
an equilibrium that exists, and currently, that is being threatened by unaccounted carbon input into the ocean[11]. This equilibrium exists when the minerals are neither forming nor dissolving. This reverts back to the previous

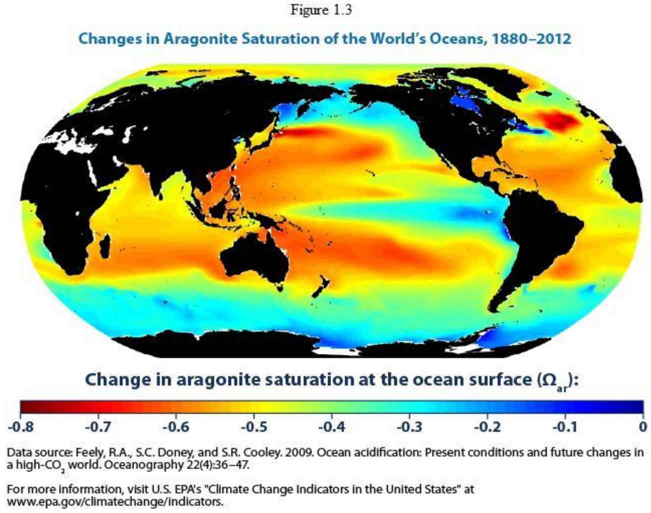
Figure 1.2



section regarding lysocline.

This increase in acidity has serious consequences for marine life such as depressed metabolic rates in jumbo squid[12]. It is alarming that we can see and study these changes now, as opposed to the thousands of years it took the PETM to produce the same effects in ocean acidity and lysocline levels. This shows that in the brief period of modern civilization, humans have changed the composition and cyclical processes that the ocean operates on within the last 200 years. Figure 1.3 (source given below picture) shows the change in aragonite saturation at the ocean surface from 1880- 2012. Aragonite is a form of calcium carbonate that many marine organisms use to calcify and build exoskeletons and shells. This is in direct comparison to the research seen before with lysocline levels. As seen in figure 1.3, there is a negative methodical change in the aragonite composition in the ocean. This can translate as a higher CO_2 input from anthropogenic sources. If left unchecked, it can lead to a shallower lysocline depth, in which we will start to see the same results as the PETM extinction.

Figure 1.3



This is a threat to the foundations of most of the food chains that humans rely on. Thus, while the production of industry and burning of fossil fuels may initially seem beneficial to us, it is clearly having a negative effect on elements that we need to survive which we could not predict before. This threat of acidification includes a decline in commercial fishers, since many fishes feed of plankton and pteropods which need aragonite to survive. The acidification is harming the calcifying organisms from which most food webs use as their base. Pteropods shells dissolve with increasing acidification and the brittle stars lose muscle mass when re-growing appendages[13].

These changes are happening so rapidly that it calls to question for global climate discussions and talks. However, little is being done to protect the pteropods and plankton on which most marine life depend on for sustenance.

"Due to their aragonitic shell, thecosome pteropods may be particularly vulnerable to ocean acidification driven by anthropogenic CO2 emissions. This applies specifically to species inhabiting Arctic surface waters that are projected to become temporarily and locally undersaturated with respect to aragonite as early as 2016"[14].

3 Conclusions

Clearly the effects of anthropogenic sources will diminish marine life production as soon as 2030, which is much faster than the orderly change nature went through in the PETM. By affecting the bottom of the food chain in the ocean, we are risking the higher predators such as fish, birds and whales which directly affects humans as over a fourth of the world's population relies on seafood to survive. This not only has an impact on us on an environmental level, but on a commercial and economic level as well. Fisheries all across the world are producing lesser yields than they did 30 years ago. Approximately 470-870 million of the poorest people in the world heavily rely on the ocean for food, jobs, tourism and revenue to make a living, these changes in the ocean are going to impact them first[15].

It is absolutely vital to curb this drastic change that we are experiencing first handed going into the 21st century. Fortunately, there are measures we can do today to account for and prevent another PETM from happening within our lifetimes. The evidence is conclusive, we know how plants and animals will be destroyed with a higher ocean acidification. We have seen it 55 million years ago with the PETM. It is important to acknowledge the change that is happening due to anthropogenic sources and to mitigate some of the non-essential elements. There are many climate conservatives that suggest that these changes are far too early for humans to make, and other climate extremists that suggest that we will experience another PETM-like event within the next decade. We have to keep everything in perspective when dealing with the only home we will ever know.

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