Drastic Changes in Atmospheric CO_2 Concentration Led to Biological Mass Extinction and Explosion

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Abstract: When the area of polar ice caps expands to a certain threshold, a positive feedback effect will occur. Due to the strong reflection of sunlight by ice and snow, the global climate will become cold and dry. CO_2 in the atmosphere will be rapidly sequestered in the seabed and permafrost through the biological carbon pump, thereby affecting plant photosynthesis, reducing NPP and the nutritional value of plants. This leads to the selective extinction of species that are large in size and those that are small in size but have high metabolic rates. Conversely, when the area of polar ice caps shrinks to a certain threshold, a positive feedback effect will also occur. Permafrost and the seabed will rapidly release CO_2 into the atmosphere, leading to a rapid increase in NPP, plant nutritional value, and species diversity. Therefore, through geoengineering to reduce the warm currents entering the Arctic Ocean, it is possible to inhibit glacier melting and global warming.

Keywords: Dinosaur Extinction Theory; Atmospheric CO_2; Net Primary Production; Ecological Niche; Biological Mass Extinction; Biological Explosion; Global Warming; Geoengineering

Highlights

1. A cold and dry climate will cause CO_2 in the atmosphere to be rapidly sequestered in the seabed and permafrost through the biological carbon pump.

2. Under conditions of CO_2 deficiency, NPP and nutritional value of plants will decrease, leading to the selective extinction of species that are large in size and those that are small but have high metabolic rates.

3. Under conditions of sufficient CO_2, NPP and nutritional value of plants will increase, thereby enhancing the body size and species diversity of organisms.

4. Reducing the warm currents entering the Arctic Ocean through geoengineering can prevent the melting of Arctic Sea ice and control global warming.

Introduction:

The journal Science has published the world's most cutting-edge 125 scientific questions, one of which is: "Why were there species explosions and mass extinctions?" In the history of life on Earth, there have been five major mass extinctions [1], and each has been followed by a species explosion. The most spectacular of these was the Cretaceous-Paleogene (K-Pg) extinction event, which saw the demise of the dinosaurs. As a result, over 100 hypotheses have been proposed to explain why the dinosaurs went extinct. Therefore, this article focuses on discussing the causes of the dinosaur extinction. Here, we first evaluate the feasibility of several major hypotheses regarding dinosaur extinction and find that they all have significant flaws. Subsequently, we propose a new hypothesis for mass extinctions and explosions. This hypothesis suggests that mass extinctions and explosions are associated with dramatic changes in atmospheric CO_2 concentrations. Based on this hypothesis, we also discuss how to address the issue of global warming.

I The feasibility argument of species mass extinction hypotheses

A correct theory should not allow for a single flaw, but taking the dinosaur extinction hypotheses as an example, numerous flaws have been identified.

1. Asteroid Impact on Earth [2]: Because this hypothesis is described in a very spectacular manner, it has become a hot topic. However, there are many flaws in this hypothesis, which will not be listed one by one here. For example, the dust ejected by an impact can only produce a brief "nuclear winter" [3]. Even if corrected to soot, the duration of the nuclear winter is only a short 3 to 5 years [4], which is not sufficient to cause long-term climate change. Moreover, fossil evidence shows that after the asteroid impact on Earth, dinosaurs continued to survive for another 700,000 years before becoming completely extinct [5] . The nuclear winter hypothesis also fails to explain why cold-intolerant Mesozoic relict species such as crocodiles, turtles, Komodo dragons, and tree ferns (Cyatheales) are still able to survive to this day. Additionally, the asteroid impact on Earth cannot account for why the CO_2 concentration at the end of the Cretaceous Period dropped to only 229 ppm [6].

2. Super Volcanic Eruptions [7]: Research indicates that dust produced by asteroid impacts and volcanic eruptions would not lead to a nuclear winter [8]. Moreover, during the Cretaceous period, around 120 and 110 million years ago, there were two super volcanic eruptions: the Ontong Java Plateau volcanic province and the Kerguelen Plateau volcanic province. Both were larger in scale than the Deccan Traps volcanic province at the end of the Cretaceous period, yet dinosaurs continued to thrive. During the mid-Cretaceous Period, there were a series of volcanic eruptions larger in scale than the Siberian Traps, such as the Ontong-Java, Madagascar, Caribbean, and High-Arctic large igneous province eruptions, yet no mass extinction events occurred.

3. Super Pandemics: It is even less likely that a pandemic could have wiped out all the dinosaurs. For example, in 1950, Australia launched a bacterial warfare campaign to exterminate the overpopulated rabbits. Although 99.8% of the rabbits died that year, the surviving 0.2% quickly reproduced and their population rebounded soon after.

4. Multiple Event Convergence: This hypothesis suggests that dinosaurs became extinct due to a series of successive disasters. However, the intervals between major catastrophes, such as asteroid impacts, are typically very long, providing survivors with ample time to recover their population density. If a single disaster cannot eradicate all dinosaurs, the survivors would quickly rebound to their original numbers. It is similar to how land scorched by a wildfire is covered with greenery again the following year. After a virulent epidemic, survivors would also reproduce rapidly.

5. Food Poisoning: Toxic angiosperms (flowering plants) did not appear suddenly, so dinosaurs had sufficient time to adapt through evolutionary processes. For example, cows generally cannot overconsume the toxic leaves of Acacia trees. However, in Weizhou Island, Beihai City, Guangxi, China, local yellow cows can consume large quantities of these leaves without being poisoned. The reason is that their rumen contains microorganisms capable of breaking down the toxins [9].

6. High-Energy Radiation: This includes hypotheses such as supernova explosions, super solar flares, and geomagnetic reversals. However, these hypotheses cannot explain why ichthyosaurs and other species that lived in seawater capable of shielding radiation also went extinct. Moreover, geomagnetic reversals occur every few hundred thousand years, which cannot account for the mass extinctions that happen once every few tens of millions of years.

7. Climate Change: These include freezing, overheating, and desiccation. However, climate changes on a geological timescale take at least hundreds of thousands of years. Therefore, dinosaurs had ample time to migrate to latitudes with suitable climates. The hypothesis that dinosaur flatulence caused a greenhouse effect leading to their extinction is also invalid, because methane (CH_4) cannot be considered a dominant greenhouse gas in this context [10].

8. Competition for Survival: The existence of competitors not only fails to lead to the extinction of the other party but can also have mutually beneficial effects. For example, in Australia, the rampant breeding of rabbits led to the mass starvation of sheep. In an attempt to eliminate the rabbits, people resorted to shooting, poisoning, and biological warfare, but these efforts proved ineffective. Eventually, the introduction of wolves successfully controlled the rabbit population to an acceptable level, allowing rabbits, sheep, and wolves to coexist and reproduce. Similarly, the hypothesis that mammals eating dinosaur eggs led to the extinction of dinosaurs is also invalid, because birds also frequently prey on sea turtle eggs and hatchlings, yet sea turtles have not gone extinct as a result.

There are many more absurd hypotheses, but they will not be listed one by one here.

II Essential Factors for Mass Extinctions

To cause the extinction of dinosaurs that were distributed globally, it is necessary to achieve a global, no-dead-end extinction in a very short period of time; otherwise, survivors would quickly reproduce and repopulate. Since the atmosphere permeates every corner of the Earth's surface, the only factor that could achieve a comprehensive and global extinction of such a widespread species is a change in the composition of the atmosphere.

III Common Characteristics of Mass Extinctions

1. All five known mass extinctions involved significant geological and climatic changes, including alterations in the layout of oceans and continents, large-scale volcanic eruptions, orogeny, and sea-level fall [11].

2. Among the eleven major extinctions, the Precambrian, Ordovician, Devonian, Cretaceous, and Eocene periods all show that polar continental glaciers were highly developed and sea levels declined [12-13].

3. During these “glacial periods,” atmospheric CO_2 concentrations plummeted dramatically [14-15].

4. The five major mass extinctions are related to increased marine carbon burial and rapid

input or output of carbon [16-18].

Based on the above clues, mass extinctions and explosions of species may be caused by a common factor.

So, why does the global temperature drop sharply? Why does a cold climate lead to a sharp decline in atmospheric CO_2 concentrations? And why does a sharp decline in atmospheric CO_2 concentrations result in mass extinctions?

IV The causes of a significant drop in global temperatures

The factors driving glacial and interglacial cycles may be related to astronomical factors [19] or/and continental drift of the Earth itself [20]. For example, because the continental plates on the Earth's surface are floating on the slowly flowing fluid of the "upper mantle," the plates are constantly drifting and colliding with each other. This results in a continuous cycle of convergence and separation among continents. It is known that among the seven such cycles, five are associated with glacial periods. Plate collisions not only cause volcanic eruptions but also lead to the uplift of high mountain ranges and the compression of ocean areas. They redistribute land and sea, alter ocean currents and atmospheric circulation patterns, and thus cause significant climate fluctuations. This may be one of the primary reasons for the alternation between glacial and interglacial periods.

The specific heat capacity of seawater is more than four times that of sand and rock. The reflectivity of the ocean is approximately between 10% and 20%, while the reflectivity of ice and snow is as high as 80% to 90%. The reflectivity of sea ice surfaces is around 40% to 65%. Therefore, when the ocean area decreases to a certain threshold, the heat exchange between low-latitude and high-latitude ocean currents is reduced to a certain threshold [21], and the land area at the poles increases to a certain threshold, ice will begin to form at the poles. When the area of polar ice caps expands to a certain threshold, a positive feedback effect will occur. Due to the strong reflectivity of ice and snow, temperatures will continue to drop, a large amount of water will freeze into glaciers, and as a result, sea levels will decline. The decrease in temperature also reduces the rate of seawater evaporation, making the climate colder and drier. Since cold surface seawater has a higher density, it will sink to the ocean floor and then be transported to the low-latitude tropical seafloor through "deep ocean currents," resulting in the entire ocean's bottom water being in a cold state.

V How does a cold climate cause a rapid decline in atmospheric CO_2 concentrations?

The atmospheric CO_2 concentration was 2,132 ppm during the Late Triassic of the Mesozoic Era, but by the end of Late Cretaceous, it had dropped to only 229 ppm [6]. According to Antarctic ice core records, CO_2 concentrations over the past 650,000 years have fluctuated between 180 ppm during glacial periods and 300 ppm during interglacial periods. In the early warm period of the Carboniferous, CO_2 concentrations exceeded 8,000 ppm, but during the Late Paleozoic Ice Age, the lowest CO_2 concentration in the Earth's atmosphere was around 100 ppm [14]. Fischer et al. found that during each glacial-to-interglacial transition over the past 500,000 years, atmospheric CO_2 concentrations increased 400 to 1,000 years after the temperature rise [22]. Petit et al. discovered that during the glacial periods of the past 420,000 years, atmospheric CO_2 concentrations decreased only after the temperature decline [23].

In summary, it is noteworthy that a drop in temperature precedes a decline in CO_2 concentration, and vice versa.

The soil organic carbon storage in the global permafrost regions is approximately 2.4 times the amount of CO_2 in the atmosphere [24]. Methane (CH_4) can form a crystalline structure known as "methane hydrate" or "combustible ice" under high pressure and temperatures between 2°C and 5°C [10]. Combustible ice can be stored in permafrost and the seafloor. The carbon stored solely in seafloor methane hydrates is estimated to be 4 to 5 times the amount of CO_2 in the atmosphere.

The soil organic carbon storage in the global permafrost regions is approximately 2.4 times the amount of CO_2 in the atmosphere [24]. Methane (CH_4) can form crystals with water under high pressure and at temperatures of 2–5°C, known as “methane hydrate” or “combustible ice.” Combustible ice can be stored in permafrost and the seafloor. The carbon stored solely in seafloor methane hydrates [10] is estimated to be about 4–5 times the amount of CO_2 in the atmosphere. Historical data indicate that during the warm periods of the Cretaceous, the bottom water temperature of the ocean was 15°C, which is not conducive to the formation of stable methane hydrates. According to research by scientists from the British Geological Survey and others, glaciers may still have formed at the Earth's poles during the greenhouse conditions at the end of the Cretaceous Period. Geologists have found that in the mid-Cretaceous, the average temperature in the equatorial region of the Atlantic Ocean reached 42°C, but by the late Cretaceous, it dropped to as low as 2.2°C. Therefore, the conditions for storing methane hydrates (combustible ice) in the seafloor and polar permafrost were already in place. Terrestrial coal formation is a relatively slow process for carbon fixation. Therefore, during warm climatic periods, the concentration of CO_2 in the atmosphere does not affect plant photosynthesis, and flora and fauna have sufficient time to adapt through evolutionary processes. As a result, mass extinctions are unlikely to occur.

During cold and dry climatic periods, tropical rainforests transition from wetlands to drylands, which is unfavorable for continental weathering and coal formation. However, the dry climate facilitates the transport of dust containing phosphorus and iron by wind to the oceans and permafrost regions, effectively fertilizing them and thereby increasing their Net Primary Production (NPP) [25-26]. Subsequently, large amounts of organic matter, carbonates, CO_2, and CH_4 are sequestered in the cold seafloor and permafrost, leading to a rapid decline in atmospheric CO_2 concentrations [14, 27-28].

VI The Relationship Between Atmospheric CO_2 Concentration and Mass Extinctions and Explosions of Species

Under relatively low CO_2 concentrations, plants not only experience a decline in Net Primary Productivity (NPP), but also a decrease in the nutritional value per unit mass of dry matter. Therefore, when CO_2 concentrations drop to a certain threshold, large-bodied species with high food intake and high metabolic rates are likely to be selectively driven to extinction.

1. The concentration of CO_2 is positively correlated with NPP and the nutritional value of plants.

Considering adaptive evolution, Cretaceous plants were primarily composed of C_3 plants that required higher CO_2 concentrations [29], and they likely needed even higher CO_2 levels than modern C_3 plants. Fiona Gill et al. [30] simulated the climate of the dinosaur era by raising CO_2 concentrations in greenhouses to 2000 ppm and grew various Mesozoic plants. Calculated by dry matter, a 30-ton sauropod dinosaur would only need to consume 51 kg of plants per day, which is more than half less than plants grown at 1200 ppm CO_2. This suggests that increasing atmospheric CO_2 concentration can enhance NPP and the nutritional value of plants, promoting the evolution of larger-sized flora and fauna. This may explain why most plants and animals during the Carboniferous and Cretaceous periods were extremely large. Conversely, a decrease in atmospheric CO_2 concentration would reduce NPP and the nutritional value of plants, leading to the elimination of larger-sized flora and fauna. A rapid decline in atmospheric CO_2 concentration could cause mass extinctions, while a rapid increase could lead to species explosions. Since Cretaceous plants adapted to high CO_2 concentrations, the rapid decline in atmospheric CO_2 at the end of the Cretaceous [6,31-32] would have led to a swift reduction in NPP and the nutritional value of plants on land and in the ocean, resulting in global mass extinctions of terrestrial and marine species.

2. NPP is positively correlated with ecological niche.

In low latitudes, tropical rainforests have the highest NPP and the greatest species diversity, while tropical deserts have the lowest NPP and the fewest species. Both terrestrial and marine NPP decrease with increasing latitude, and species diversity also declines with increasing latitude. This suggests that NPP is positively correlated with the number of available "ecological niches." Therefore, when NPP declines, excess species will inevitably be eliminated.

If NPP drops rapidly in a short period, it can lead to mass extinctions. Conversely, if NPP rises rapidly in a short period, it can lead to species explosions.

Because NPP is positively correlated with ecological niches, even though high-latitude marine fish evolve faster than those in the tropics, they also go extinct more quickly [33]. This may be the primary reason why species richness in high-latitude marine and terrestrial ecosystems is lower than that in low-latitude regions.

3. NPP and the nutritional value of plants are positively correlated with species body size and metabolic rate.

Under conditions of abundant and high-nutritional-value food, animals tend to evolve towards larger body sizes or higher metabolic rates [34] and vice versa. [35-37]. For example, the red kangaroo, which lives in the arid and infertile inland grasslands of Australia, has adapted to the sparse and low-nutritional-value vegetation by evolving a body size that is only one-third that of horses or camels on other continents, and a basal metabolic rate that is only half that of sheep. Since species with higher metabolic rates have a greater probability of extinction [38-39], during the decline of NPP and plant nutritional value, species with large body sizes and those with small body sizes but high metabolic rates are selectively driven to extinction [40-41].

4. NPP is positively correlated with the nutritional value of plants.

When NPP is low, plants evolve to become coarse, spiny, indigestible, and of lower nutritional value to prevent overgrazing by animals. The significant reduction in dinosaur body size at the end of the Cretaceous and the evolution of hadrosaurs with teeth adapted for grinding food [42] also indicate that NPP was low and vegetation had become coarse and indigestible with greatly reduced nutritional value, leading to mass extinctions. The extinction of the European wild horse was due to drought that made the grass coarse and difficult to digest, and it was replaced by bison with stronger digestive capabilities.

5. The cause of extinction is not starvation, but rather the impact on reproductive rates.

Experiments have shown that chickens, when malnourished, lay eggs with thin shells or may not lay eggs at all. Due to the decline in NPP and the indigestibility of plants, herbivorous dinosaurs would have suffered from malnutrition, leading to the laying of thin-shelled eggs that could not hatch, or even the cessation of egg-laying altogether, ultimately resulting in the extinction of dinosaurs. The discovery of many thin-shelled dinosaur egg fossils at the end of the Cretaceous is evidence of malnutrition. Studies on carbon isotope ratios ($^{12}C/^{13}C$) in the K/T boundary layer during the dinosaur extinction indicate that NPP was very low for both terrestrial and marine plants at that time. At the Cretaceous-Paleogene boundary, terrestrial plants were relatively shorter and sparser compared to before [43], and land animals became much smaller in size [44]. This supports the idea that the rapid decline in NPP and plant nutritional value may have been the cause of the mass extinction [33-34].

6. A rapid increase in CO_2 concentration will first lead to small-scale species extinctions, followed by a large-scale species explosion.

When the area of polar ice caps shrinks to a certain threshold, the loss of the strong sunlight reflection from ice and snow will trigger a positive feedback effect. This will cause the carbon fixed in permafrost and the seafloor to be rapidly released into the atmosphere as CO_2 [45-46]. This process will lead to a small-scale species extinction, as some species are unable to adapt to the climate characterized by high temperatures, high humidity, and high concentrations of CO_2. Subsequently, NPP on land and in the ocean will also increase rapidly. As mentioned above, a rapid increase in NPP over a short period can lead to a species explosion. Since atmospheric CO_2 concentration is positively correlated with sea level, oxygen content, and NPP, rising sea levels are thus associated with species explosions [47].

With key components such as engines, wheels, and steering wheels, it is convenient to assemble a variety of transportation vehicles in different shapes. Similarly, when organisms evolve to possess genes for critical organs like eyes, muscles, bones, and livers, and combine these with Hox genes [48] (which act as the architects of animal body plans, and even minor mutations in these genes can lead to significant changes in animal structures), an abundance of food and an arms race between predators and prey can lead to the rapid emergence of species with diverse shapes and functions over a short period. For example, when the unicellular alga *Chlamydomonas reinhardtii* is cultured together with the ciliate *Paramecium*, which can only prey on *Chlamydomonas reinhardtii*, approximately two-fifths of the unicellular algae evolve into multicellular forms within just 50 weeks [49].

VII Strategies for Controlling Global Warming

The first summer when nearly all Arctic Sea ice melts may occur in 2027 [50]. When the area of the Arctic ice cap shrinks to a certain threshold, a positive feedback effect will be triggered. Due to the loss of the strong sunlight reflection from ice and snow, glaciers and permafrost will melt rapidly, causing sea levels to rise and an increase in water vapor. The seafloor and permafrost will then release large amounts of CO_2. The climate will become similar to that of the Mesozoic Era: characterized by high temperatures, high humidity, and high concentrations of CO_2. Many mammals will be unable to adapt to this climate. The global ecosystem will collapse rapidly, and mass extinction events will be repeated. Therefore, the issue of preventing the melting of Arctic ice is urgent. Many geoengineering solutions proposed to control global warming have significant drawbacks, including extremely high costs, large side effects, and lack of long-term effectiveness. To address this, we propose a simple form of geoengineering: installing hydroelectric turbines, rock-fill dams, or building water gates at locations where ocean currents pass between low and high latitudes in the polar regions [51]. When the flow of warm currents entering the polar regions is reduced, the sea ice area will expand [21], and temperatures will not rise above the irreversible tipping point. Compared to the proposal by Moore JC et al. [52] in 2018 to build giant underwater dams along the seabed in front of Antarctic glaciers to prevent warm seawater from eroding the glaciers, our method is more cost-effective and feasible.

VIII Conclusion

In summary, the initial driving factors for mass extinctions and radiations are related to dramatic changes in atmospheric CO_2 concentrations, which are driven by astronomical factors or/and factors inherent to the Earth itself, causing glacial and interglacial periods.

Conflicts of Interest：

BH is the founder and Chief Scientific Officer of Rejuvenation Biotech, a biotech R&D company.

Author contributions:

BH researched and completed writing of the manuscript. BH has read and approved the current version of this manuscript and has agreed to its submission.

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