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History of Earth evolution

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Abstract. The paper delves deeply into crucial subjects spanning the birth of our solar system to humanity's ascendancy on Earth. It aims to enable humankind to gain a deeper understanding of our own origins and the Earth's genesis and evolution. Given that Earth is our sole habitat, we must gain insights into the conditions necessary for it to sustain life or identify potential terrestrial planets suitable for human habitation. Throughout its history, Earth has weathered countless encounters with meteorites, comets, and asteroids, dating back to the formation of the solar system. These events, though rare, played a pivotal role in shaping our planet's atmosphere, magnetic field, and unique environmental characteristics. Perhaps the most extraordinary aspect of Earth's history is the emergence of life itself—a true marvel. Starting with single-celled protists, life evolved into complex multicellular organisms. Yet, a pivotal moment in Earth's history came with a momentous global extinction event triggered by the rise of oxygen. This event reshaped the planet's natural ecosystem, leading to the extinction of many species and the emergence of new ones. Humanity's own journey, navigating the depths of history, eventually led to our dominance over the Earth.

Keywords: Solar system, Habitable zone, Food chain, Primitive ocean, Cyanobacteria.

1. Introduction

1.1. The formation of the solar system

The solar system has evolved over such a long period of time, 4.6 billion years [1], and has endured incredibly complicated physical changes. The solar system was initially nothing more than a massive nebula of high-energy molecules [2]. Once the center region has amassed sufficient mass, gravitational collapse causes the core temperature to grow. When this temperature reaches roughly 10 million K, the hydrogen near the core will spark nuclear fusion [3].

Following nuclear fusion, the intense heat radiation generated initiates thermal expansion, countering the force of gravitational collapse and halting the inward compression of materials. Consequently, a delicate balance is struck between gravitational collapse and the thermal expansion driven by the energy liberated through nuclear fusion. Within the core, the hydrogen element begins to stabilize the fusion process, leading to the gradual enlargement of the Sun.

Light radiation will be absorbed, released, and gradually lose energy when the sun starts nuclear fusion. By the time it reaches the surface, it has changed from 1500W high-temperature radiation to 5770K black body radiation (thermal radiation produced by high temperature) [4]. The sun's surface is covered in thick plasma from the core outward. In the form of black body radiation, photons take a very long time to fuse from the sun's core to its surface. The core's nuclear processes create neutrinos that radiate freely into space.

Once the Sun ignites, the emitted radiation and solar wind swiftly disperse the surrounding gas, effectively averting its gravitational collapse into the Sun's core. Consequently, the Sun's mass begins to stabilize, and an accumulation of material commences in its outer layers. As shown in the Figure 1. This process is marked by a reduction in the available gas reservoir due to the solar wind's expulsion of inner gases, which contributes to the formation of certain terrestrial planets. However, in the case of Jupiter, which lies farther from the Sun, a significant reservoir of gas is retained within its orbital domain. This allows Jupiter to accumulate an ample supply of dust and gas, eventually condensing into the majestic gas giants we observe. As the solar system took shape, it closely resembled its current configuration, with the planets having cleared their orbital paths, establishing the planetary arrangement we recognize today.

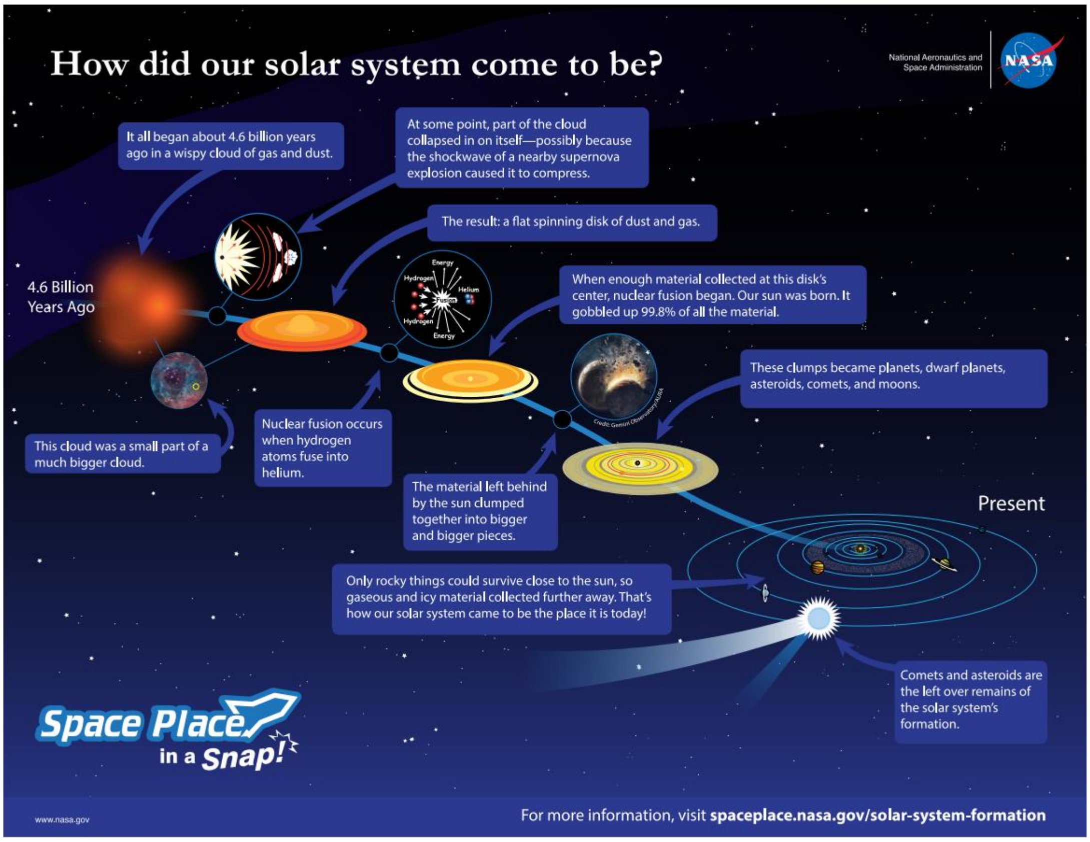

Figure 1. The very beginning of the universe.

1.2. *The importance of the habitable zone for life on Earth*

Humans and all other living things on Earth have only ever known life on Earth, and they have not yet discovered life beyond. There are five fundamental requirements, both internal and external, for life to exist on earth. There are two external conditions. The first is stable light or the sun. As the primary celestial body in the solar system, the sun continuously emits solar radiation into space. Although only one solar photon in every 2.2 billion hits the Earth, the solar radiation is very stable, which is crucial for the evolution of life on Earth over billions of years. A safe working environment is the second external need. In the solar system, the Earth's orbit around the sun is particularly safe since it intersects and complements the orbits of the other eight planets, preventing collisions between them [5].

The first is the right temperature range. The earth's average temperature is 15°C, between 0°C and 100°C, which ensures that water can exist in liquid temperature conditions, which is a very important

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condition for the evolution of life. The second and third conditions are inside the earth (itself). The fact that the Earth is only 150 million kilometers from the sun and receives just the right amount of solar radiation energy is the primary reason for the planet's suitable temperature range. Mars and Jupiter, on the other hand, have uncomfortably low temperatures, while Mercury and Venus are overly warm compared to the Earth.

The presence of liquid water is the second internal need, and its existence is guaranteed by the earth's average temperature of 15°C. The "hydrosphere" of the earth is the substantial volume of water that covers its surface. Oceans encompass 71 percent of the earth's surface. Water is the essential element that ensures the survival of all life on Earth. The earliest life on Earth was nurtured in the ocean, and it evolved from the sea to the land.

The Earth boasts a moderately thick atmosphere, which results in moderate atmospheric pressure. In stark contrast, Venus possesses an atmosphere considerably denser than Earth's, with a surface atmospheric pressure a staggering 92 times that of our planet. It's noteworthy that while most celestial bodies have atmospheres of varying thicknesses, these atmospheres exhibit a wide range of compositions, with some being thin and others notably dense.

Diving deeper into atmospheric composition, we find that many planets' atmospheres are dominated by gases such as carbon dioxide, argon, helium, methane, and others, rendering them inhospitable to sustaining life as we know it on Earth. For instance, Venus' atmosphere primarily comprises carbon dioxide, making it a particularly harsh environment. As shown in the Figure 2. In contrast, Earth's atmosphere primarily comprises nitrogen, accounting for 78.1% of its composition, closely followed by oxygen at 20.9%. This unique composition is essential in creating the conditions necessary for supporting life as we find it on our planet.

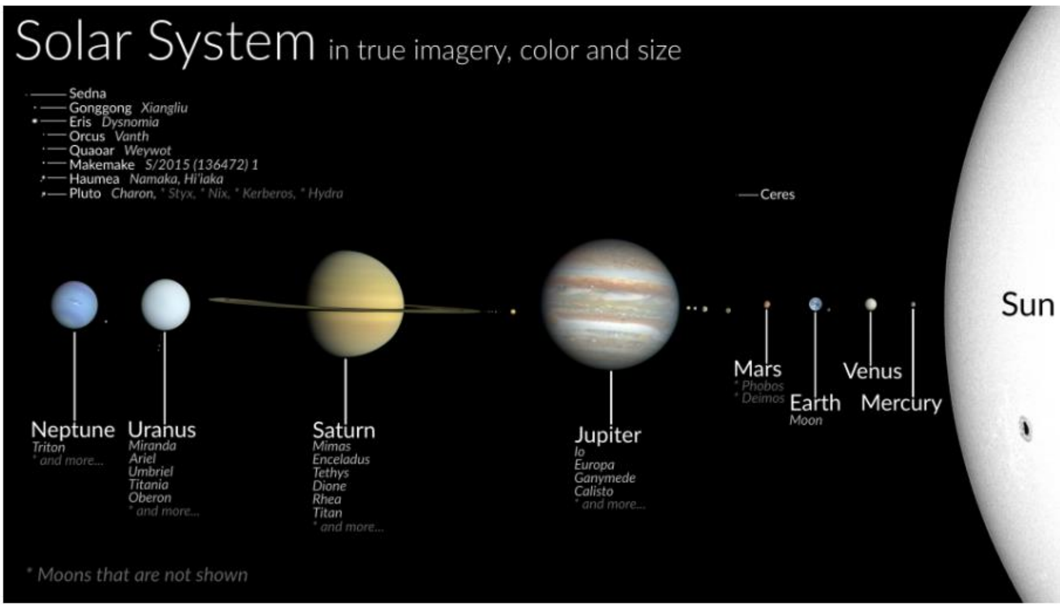

Figure 2. The structure of the solar system and the eight planets.

2. The formation of the primitive Earth

The Earth's atmosphere exhibits a moderate thickness, leading to a balanced atmospheric pressure. In contrast, Venus, in stark contrast, boasts an atmosphere denser than Earth's, with a surface atmospheric pressure a staggering 92 times that of our planet. While most celestial bodies sport atmospheres of varying thickness, their compositions diverge significantly, some featuring thin atmospheres while others host denser ones.

Exploring the atmospheric makeup further, we discover that many planets' atmospheres are predominantly composed of gases like carbon dioxide, argon, helium, methane, and various others, rendering them unsuitable for sustaining life as we know it on Earth. Venus, for instance, is primarily characterized by its carbon dioxide-rich atmosphere.

On the other hand, Earth's atmosphere stands out with its unique composition, consisting of nitrogen as the dominant gas at 78.1%, closely followed by oxygen at 20.9%. This distinctive mix is crucial in creating the life-sustaining conditions we enjoy on our planet. During the early phases of Earth's formation, the surface was dominated by environmental hot persimmons. Still, over time, the constant influx of stellar meteorites circulating within the solar system has played a pivotal role in shaping the Earth's surface by depositing abundant water and other essential resources. Furthermore, the collision of dust particles within the atmosphere generates significant heat energy, contributing to the Earth's warming and facilitating its ongoing development. Later, after the formation of the primitive Earth, an ancient dwarf planet named Theia was hypothesized to have existed in the early solar system. According to the Giant Impact, about 4.533 billion years ago, Theia deviated from its original position and collided with the early Earth [6]. The two planets melted into one to form the present Earth. A portion of the early Earth's mantle and crust was torn apart by the impact and catapulted into a stable orbit around the Earth, eventually re-accreting to form the Moon. As shown in Figure 3.

During the gradual formation of a habitable planet, the Earth was subjected to various large and small asteroids, comets, and other celestial bodies colliding. Historically, hundreds of small impacts (including fireball explosions) have been recorded that caused death, injury, and property damage in specific areas. After a long period of meteorite and comet impacts, the Earth's rotation increased the cooling rate of the lava ocean. As meteorite impacts intensified the surge of Earth's lines, the continuous volcanic eruptions released large amounts of greenhouse gases, ensuring that water vapor from the surface of the Earth did not escape into space. Over the course of a few years, the lava ocean cooled, and materials of different densities rose and sank, forming the crust, mantle, and core. Water vapor from the surface fell to the surface in the form of precipitation due to cooling temperatures and gradually formed the most primitive ocean.

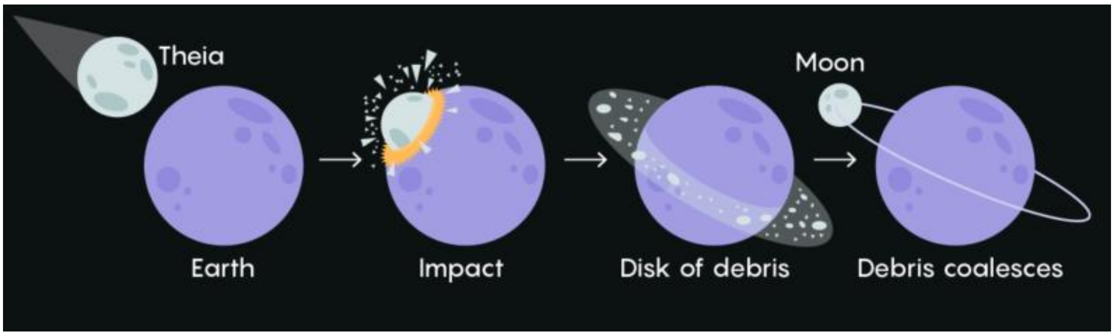

Figure 3. One of the hypotheses for the moon's formation: the impact of the planet Theia.

3. Primordial oceans give rise to life

3.1. Early anaerobic single-cell life formation

About 3.5 billion years ago, the earliest life was born in the primitive ocean, single-celled organisms - cyanobacteria, single-cell is a simple organism separated by only a membrane from the outside world, belonging to the lowest and most primitive organisms. Algae is one of them, in this period in the history of life, evolution is called the algae era [7]. As the number of algae grows, so does the amount of oxygen in the atmosphere.

3.2. Cyanobacteria bloom and Prokaryotic life appears

Around 3.8 billion years ago, as life emerged in the Earth's oceans, the atmosphere held a mere 0.02 percent oxygen. It wasn't until approximately 2.4 billion years ago that algae proliferated rapidly, releasing substantial quantities of oxygen. Prior to this period, Earth lacked free oxygen, and it was the advent of life that ushered in this vital element, leading to a dramatic rise from negligible levels to nearly

1% of today's atmospheric oxygen. It was during this time that eukaryotic life forms made their debut on Earth's stage. As shown in the Figure 4. The moniker "the lungs of the Earth" is aptly applied to cyanobacteria and plants, as they not only generate oxygen but also sustain the planet's habitat. Initially, the oxygen produced by cyanobacteria didn't significantly augment the free oxygen content in the atmosphere. Over time, however, oxygen levels on Earth gradually increased due to its cumulative release. It's worth noting that this transformation took roughly half of Earth's history to transition from its original oxygen-free or reducing environment. While this development proved advantageous for the emergence of aerobic life forms, it posed a dire challenge for anaerobic life that had previously thrived. The momentous event known as the Great Oxidation Event, which transpired around 2 billion years ago, marked the Earth's first mass extinction, resulting in the extinction of over 99.5% of life forms that previously inhabited our planet.

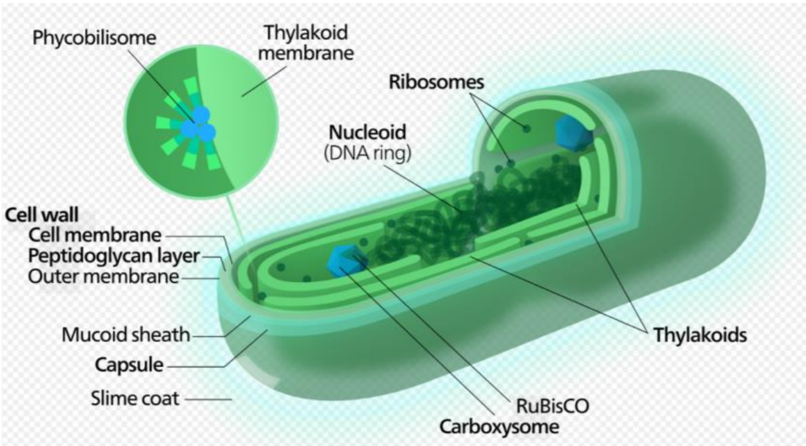

Figure 4. Cell structure.

4. Changes in the Earth's surface

4.1. Supernovae explode, global temperatures drop, sea levels drop

Fields, a professor of astronomy at the University of Science and Technology in Illinois, the United States, after a large number of data analyses, led the scientific research team that the second mass extinction of life occurred 359 million years ago may be related to a supernova explosion [8]. During the transition period between the Devonian and Carboniferous periods, the second mass extinction occurred on Earth, and the Marine life on Earth ushered in a catastrophe. As shown in Figure 5.

However, after the second mass extinction, the Earth entered a new era of rapid species evolution. The Devonian period was the "Age of Fish" on Earth. The ancestors of both reptiles and amphibians appeared in the Devonian period. In previous archaeological studies, scientists have found that China's climate during the Earth's Devonian period was very wet and warm. Even in the polar regions, there is spring all year round. Strangely, however, at the end of the Devonian period, the Earth suddenly "changed its face." The climate and environment of the entire planet have changed dramatically. There was a catastrophe coming.

At the end of the Devonian period, about 65 light-years from Earth, there was a supernova explosion, and the energy it released reached Earth [9]. Caused serious damage to the earth, the earth's ozone layer has also been destroyed. After a long period of time, the earth was subjected to various types of radiation that increased and also caused the global temperature to drop, the original sea level would also drop, and the falling temperature led to the polar regions of the temperature drop sharply, the formation of glaciers. Eventually leading to a mass extinction of life on Earth. It wasn't until about 100,000 years later that the Earth began to gradually return to health.

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Figure 5. Hypothetical models of supernova explosions.

4.2. Polar glaciers were formed, ancient continents were formed

Over the course of its remarkable 4.6 billion year history, Earth has undergone profound transformations, giving rise to seven continents and four oceans. The dynamic movement of tectonic plates plays a pivotal role in shaping the planet's geological features and is closely intertwined with the emergence and evolution of life on Earth. Approximately 600 million years ago, during the Cambrian and Ordovician periods, Earth assumed its place as the third planet in the solar system, captured by the gravitational pull of the Sun. With this celestial positioning, the Sun commenced its role in supplying vital heat to the planet's cooling surface. As Earth journeyed through the solar system, it embarked on a rhythmic revolution and autobiography, bestowing upon it the cycle of seasons, the passage of days and nights, and the nuances of cold and warmth. Beneath the Earth's surface lies a dynamic core or inner sphere, tilted in a direction contrary to the pull of the Sun's gravity, creating a fascinating interplay of forces. This autobiographical dance of the Earth influences the movement of its crust from east to west, giving rise to diverse topographical features such as mountains, plateaus, valleys, and plains. Gradually, guided by the Earth's ongoing rotation, scattered continents converged, forming the first supercontinent, Pangaea, in a majestic geological symphony.

4.3. The continuous eruption of prehistoric volcanoes caused the continents to divide

Looking back, about 165 million years ago, our present continent, in that prehistoric time, was called "Pangea"[10]. And it was still one. One day, all of a sudden, massive volcanic eruptions began, and all of a sudden, the Earth was filled with fires and rivers of fire. After that, with the end of the volcanic eruptions, Pangea began to disintegrate, and by the late Jurassic, the Earth's central Atlantic region had split into a narrow ocean, separating not only North America from eastern North America but also East Gondwana from West Gondwana. By about 140 million years ago. The continent of Gondwana began to break up and break up again, including the continuing division of the South Atlantic Ocean, which happens to separate our present-day South America from Africa. Of course, India and Madagascar have also begun to drift away from Antarctica together, Causing the eastern Indian Ocean on Australia's western edge to crack. But now, because the South Atlantic has not been completely opened, it has led to the Atlantic Ocean like an unzipper, gradually opening from south to north, which is why it is relatively wide today.

About 55 to 50 million years ago, North America and Greenland began to drift away from Europe, and the Indian plate also began to hit the Asian continent due to the continuous drift [11], so we formed the Tibet plateau and the Himalayas. Then, after the Cenozoic era, the land of Australia, which had been connected to the Antarctic continent, gradually drifted northward and struck the Indonesian islands in today's Asia. Therefore, since the eruption of the volcano, the earth has not only fortunately not been destroyed, but also because of the continuous fragmentation and movement, forming the outline of the world today. As shown in Figure 6.

Figure 6. A real volcanic eruption.

5. Animal evolution

5.1. Fish come ashore and become amphibians

Amphibians were the first terrestrial vertebrates to breathe air, and fossils suggest they appeared in the late Devonian period 360 million years ago [12]. Evolved directly from fish, these animals represent a transition from aquatic to terrestrial. Amphibians begin their lives with gills, which gradually evolve into lungs as they grow into adults. The evolution of amphibians completed the transition process from aquatic to terrestrial and from gill breathing to lung breathing, which was also a major change in the evolutionary history of amphibians. But there are also imperfect features, such as the reproductive process is inseparable from water, the heart function is not perfect, the skin assisting breathing, and so on. In recent years, many fossils have provided evidence for the evolution of amphibians and have given rise to new theories about the evolution of different tissues and organs.

In the realm of circulatory anatomy, amphibians, and fish chart divergent paths. Amphibians, for instance, possess a heart comprising two atria and a singular ventricle. However, the mixing of oxygen-rich and oxygen-poor blood within this ventricle leads to a relatively inefficient respiratory system in amphibians. To compensate for this limitation, they have evolved mechanisms to augment oxygen uptake through their skin and oral epidermis. This skin-based respiration resembles the gills of fish, which rely on dissolved oxygen in water for breathing. Consequently, amphibians need to maintain constant moisture levels to facilitate this skin-based respiration, akin to the aquatic environment necessary for fish with gills. Amphibians also have a unique reproductive habit, which is that the young develop in water and breathe with gills, and the adults breathe with lungs [13]. This allows them to forage and find shelter on land. When amphibians reach sexual maturity, they return to the water to reproduce. They mate in the water, and the females lay their eggs on the branches of aquatic plants. Except for species of axolotl and Mexican walking fish, which spend their entire lives in the water as juveniles, breathing through their gills and body surfaces and occasionally swallowing air into their lungs. The axolotl has four limbs, but because these limbs cannot support the movement of its body, the species usually lives in water. As shown in Figure 7.

Figure 7. A hypothetical picture of a fish becoming an amphibian.

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5.2. Dinosaurs go to the top of the food chain

The dinosaur ecosystem can be broadly categorized into two fundamental aspects: the food chain and the ecological niche. The food chain elucidates the intricate web of dietary relationships among these prehistoric creatures, encompassing herbivores, carnivores, and scavengers. Within this intricate tapestry, some dinosaurs emerged as apex predators, exemplified by the formidable Tyrannosaurus Rex, known for preying on fellow dinosaurs. Conversely, other dinosaurs assumed the herbivorous role, typified by species like the Diplodocus and Sauropods, which subsisted on plants. Additionally, there were omnivorous dinosaurs, such as Ceratops and Ankylosaurs, capable of consuming vegetation and small animals.

The concept of ecological niche pertains to the distinct roles and positions dinosaurs occupy within the ecosystem. Diverse species carved out unique ecological niches, each fulfilling a specialized role. For instance, herbivorous dinosaurs occupied the plant-centric niches, drawing energy from their plant-based diets. In contrast, predatory dinosaurs perched atop the food chain as apex hunters, preying on other dinosaurs to sustain themselves. Tyrannosaurus Rex, a name that resonates across the annals of paleontology, stands as a symbol of awe and intimidation. This colossal creature, measuring an astounding 13 meters in length and weighing a staggering 7 tons, possessed the formidable ability to shatter bones with ease. As the largest terrestrial carnivore ever to roam the Earth, Tyrannosaurus Rex reigned supreme among dinosaurs. Its lineage traces back to the Jurassic period, around 170 million years ago, when early members of the Tyrannosaur family were relatively diminutive and agile, employing their elongated forelimbs for hunting. Over the subsequent 80 million years, the Tyrannosaurs experienced minimal evolutionary alterations while persisting as formidable denizens of their prehistoric world. As shown in Figure 8.

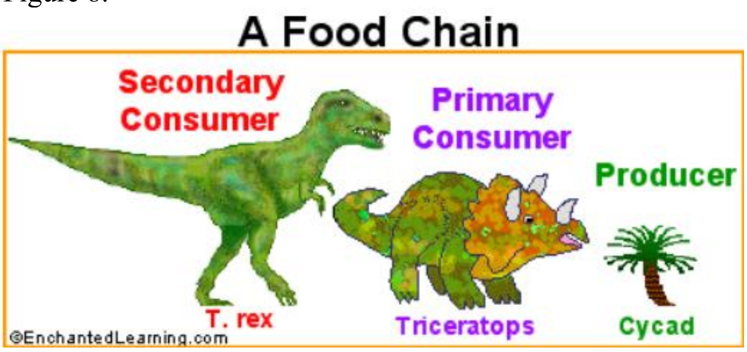

Figure 8. The food chain in the age of dinosaurs.

In their relentless pursuit of prey, these early tyrannosaurs underwent significant evolutionary adaptations, developing advanced brains and heightened sensory organs. Little did they know that these remarkable abilities would prove pivotal some 80 to 90 million years ago when the extinction of Allosaurus left a conspicuous void atop the food chain. It was then that their exceptional intelligence and acute senses propelled Tyrannosaurs into an unstoppable position, propelling them to the forefront of apex predators. Gradually, these Tyrannosaurs, an amalgamation of human-like intelligence and equine swiftness, underwent astonishing transformations, evolving into colossal behemoths that surpassed the length of a bus and weighed more than a ton. Their brains evolved into formidable weapons of predation, while their once-significant forelimbs became reduced to diminutive, almost vestigial, appendages. Around 80 million years ago, these colossal Tyrannosaurs came to dominate the landscape of what is now North America and Asia, extending their reign across nearly every terrestrial ecosystem. In doing so, they outcompeted smaller predators and asserted their prowess as the apex predators, hunting with impunity and preying upon their chosen creatures.

5.3. A series of asteroids hit the Earth, killing off the dinosaurs

The prevailing theory behind the extinction of dinosaurs centers on a catastrophic asteroid impact. Scientists have unearthed compelling evidence from an exceedingly thin layer of iridium found at the boundary between the Cretaceous and the Paleogene periods, coinciding with the mass dinosaur extinction event. Iridium is a rarity within the Earth's crust but is abundant in asteroids and comets, strongly suggesting a celestial object struck our planet. Through rigorous geological and astronomical analyses, scientists have pieced together critical details, such as the object's size, velocity, angle of impact, and impact location. This cataclysmic event resulted in the formation of a colossal crater, measuring approximately 180 kilometers in diameter and plunging to depths of 30 kilometers. Beyond asteroids, comets represent another plausible source of celestial impact on Earth, with Comet 4 being a notable example. Comets, composed of ice, dust, and rock, trace elliptical orbits around the Sun. As they draw nearer to the Sun, comets experience the effects of solar wind and radiation pressure, forming distinctive luminous tails. Occasionally, comets collide with other celestial bodies or are perturbed by the gravitational forces of the Sun, altering their trajectories and potentially bringing them into collision courses with Earth. The repercussions of a comet impact on our planet parallel those of an asteroid impact, resulting in a colossal release of energy and substantial environmental upheaval. However, it's essential to note that the likelihood of comet impacts on Earth is considerably lower than that of asteroid impacts. Furthermore, there is no conclusive evidence pointing to a comet impact as the trigger for the end-of-Cretaceous extinction event.

6. Conclusion

In the long evolution of the earth, the probability of human presence in every step of the evolution of the earth is extremely small. Understanding and studying the changes of the whole earth can better help human beings understand their own origin, realize the further continuation of human civilization, protect the homeland of human beings, and achieve long-term sustainable development.

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