

Evolutionary Biology
(Unit-8)
Sem 6 Hons (CC-6-14-TH)

One of the defining features of life is the modification of organisms through adaptation and genetic mutation. Evolution has shaped millions of years of variation, from the original single-cell structures to the enormous diversity of life we see today. The spectacular expansion of life forms makes it hard to believe that all life on Earth is related. But in fact all life seems to have originated with just one type of cell that emerged about 3.5 billion years ago: the Last Universal Common Ancestor. It is generally thought that original cell was much simpler than anything in existence today. Last Universal Common Ancestor was preceded by rudimentary molecular arrangements that hardly met the criteria for a cell, and it has been assumed that ancient Last Universal Common Ancestor contained just enough moving parts to function as a cell. The discovery in all microbes of a very primitive internal structure called an organelle (for storage of a polyphosphate) has raised the possibility that Last Universal Common Ancestor was more complex than scientists had thought.

Charles Darwin, one of the greatest minds in the history of science, was so fearful of the antagonism his theory of evolution was certain to provoke that he delayed publication for more than a decade. Only when another great naturalist, Alfred Wallace, shared his very similar findings with Darwin, did Darwin finally publish *Origin of Species* in 1859. And indeed, the theory met with bitter rejection. This was a period still governed by the notion that the Earth and all life was the work of a divine Creator, and that the creation had taken place over six days. Even today when the evidence for evolution is undeniable, there is still resistance among some religious groups. In the United States, which is probably the most conservative of the world's developed nations, between 40-50 percent of the adult population questions evolution.

In the mid-1800s when Darwin and other scientists were trying to understand the reasons for the physical changes that could be seen in generations of creatures and the obvious relationship between some species, the means for doing so were very limited. Darwin and others experimented with mutations on birds and other animals, but they knew nothing about DNA and almost nothing about the cell. Even the methods for collecting and analyzing fossils were very limited.

Extinction –

Although life is amazingly resilient, in the long history of the planet, almost all life forms have become extinct - 95 percent or more at some time. Fortunately, life always seems to rebound, and so far each rebound has brought significant increase in biological complexity and diversity. For example, the Cambrian era starting some 500 million years ago, followed what was possibly the greatest extinction in the history of the Earth. But the Cambrian introduced a huge variety of creatures, and most important the basic body structures that shaped the morphology of all living creatures today. We trace the complex eye, teeth, the bilateral body (eventually with limbs) and many other physical structures to this period.

Some 65 million years ago the extinction of the dinosaurs presented an evolutionary opportunity to the tiny mammals that co-existed with the giant creatures. The mammals, previously insignificant, developed from a relatively few groups to a huge variety of species that filled the many niches that were suddenly –in geological terms—available: animals that could live in trees, on grassland, in water.

When a species disappears, biologists say that the species has become extinct. By making room for new species, extinction helps drive the evolution of life. Over long periods of time, the number of species becoming extinct can remain fairly constant, meaning that an average number of species go extinct each year, century, or millennium. However, during the history of life on Earth, there have been periods of

mass extinction, when large percentages of the planet's species became extinct in a relatively short amount of time. These extinctions have had widely different causes.

About 541 million years ago, a great expansion occurred in the diversity of multicellular organisms. Paleobiologists, scientists who study the fossils of plants and animals to learn how life evolved, call this event the Cambrian Explosion. Since the Cambrian Explosion, there have been five mass extinctions, each of which is named for the geological period in which it occurred, or for the periods that immediately preceded and followed it.

The first mass extinction is called the Ordovician-Silurian Extinction. It occurred about 440 million years ago, at the end of the period that paleontologists and geologists call the Ordovician, and followed by the start of the Silurian period. In this extinction event, many small organisms of the sea became extinct. The next mass extinction is called Devonian extinction, occurring 365 million years ago during the Devonian period. This extinction also saw the end of numerous sea organisms.

The largest extinction took place around 250 million years ago. Known as the Permian-Triassic extinction, or the Great Dying, this event saw the end of more than 90 percent of the Earth's species. Although life on Earth was nearly wiped out, the Great Dying made room for new organisms, including the first dinosaurs. About 210 million years ago, between the Triassic and Jurassic periods, came another mass extinction. By eliminating many large animals, this extinction event cleared the way for dinosaurs to flourish. Finally, about 65.5 million years ago, at the end of the Cretaceous period came the fifth mass extinction. This is the famous extinction event that brought the age of the dinosaurs to an end.

In each of these cases, the mass extinction created niches or openings in the Earth's ecosystems. Those niches allowed for new groups of organisms to thrive and diversify, which produced a range of new

species. In the case of the Cretaceous extinction, the demise of the dinosaurs allowed mammals to thrive and grow larger.

Scientists refer to the current time as the Anthropocene period, meaning the period of humanity. They warn that, because of human activities such as pollution, overfishing, and the cutting down of forests, the Earth might be on the verge of—or already in—a sixth mass extinction. If that is true, what new life would rise up to fill the niche that we currently occupy?

The species alive today are only a tiny fraction of all those that have ever lived. The vast majority of species in the history of the planet have become extinct. The fossil record indicates that the average "lifespan" of a species, from its origin to its extinction, is between 1 and 5 million years. The process of fossilization itself, however, suggests that this is probably a substantial overestimate, and the lifespan of many species is much shorter, on the order of thousands of years. This means that in the grand sweep of the history of life, extinction is occurring all the time. Extinctions affecting one or a few species and occurring in one locality rather than globally belong to a pattern known as background extinction.

The fossil record, however, describes sudden, global extinctions that affect many species. These dramatic events are known as mass extinctions. Some populations seem more vulnerable than others: tropical forms of life have been drastically affected, while land plants tend to be highly resistant to mass extinctions. Ammonites and trilobites were vulnerable, but snails seem to pass through mass extinction events relatively unscathed.

There have been at least five mass extinctions, and maybe many more, but the fossil record is unclear. The two biggest extinctions were at the end of the Permian Period, about 250 million years ago, and at the end of the Cretaceous, some 65 million years ago. The Permian extinction saw the loss of 80 to 96 percent of all marine species. In the Cretaceous event, perhaps 60 to 75 percent of marine species disappeared.

Major causes of extinctions

Loss of food source. After massive fires, floods, droughts, and other events, organisms may lose their food source. Organisms that are unable to move or to change their diets, or to obtain adequate nourishment are likely to perish.

Loss of habitat. Climate change and natural disasters can destroy habitat. But one of the leading causes today is human population. The intrusion on natural habitats by agricultural expansion, together with human diversion and pollution of water and increasing urbanization, all put tremendous pressure on organisms. Many large animals, including elephants, buffalo and the predator cats, cannot adapt to their shrinking territories. Some species are able to move to new territories, but many are perishing.

Ecosystem imbalance. All organisms live within an system of interdependent relationships with other species. The loss of one key species within the system can bring about a disastrous elimination of others. For example, the loss of top predators such as sharks (killed for their fins) causes an imbalance that leads to the elimination of one or more species within their particular ecosystem.

Catastrophe. All sorts of catastrophic events can cause extinctions. Massive volcanic eruptions have, at times in Earth's history, made the atmosphere so toxic and hot that many organisms could not survive. The great meteor that struck Earth 65 million years ago destroyed much of the life on the planet at that time. Some scientists have even argued that gamma rays from a few supernova explosions around 41,000 years ago may have penetrated Earth's atmosphere (information based on radioactive potassium in tusks and human artifacts from between 34,000 and 13,000 years ago, a period of massive extinctions).

Climate or atmospheric change. Periodic natural climate changes have sometimes occurred too rapidly for some organisms, bringing death to those that have not been able to move or adapt. A great many species

became extinct in the last great ice age, and in many cold-adapted creatures were unable to adapt to extreme warming. Atmospheric changes such as the increase in oxygen when plants began their rapid evolution led to the extinction of almost all other life, for which oxygen was toxic. Similarly, the sudden increase in methane in the deep past wiped out a great deal of life. And today, we are in the midst of another great extinction, this one due in part to the sudden increase in CO₂ and in part to toxins introduced by human industry.

Extermination. The abrupt demise of one or more species may come about from predation –either from other animals or from humans. Some massive animals such as the mastodons in North America may have been eliminated by stone age humans. In the past two centuries, humans have exterminated many species of mammals, birds, fish and plants by hunting or deliberate elimination.

Disease. Many types of diseases –from fungi, viruses, bacteria—spread and kill faster than the antibodies and other defenses can adapt. The Tasmanian wolf is a modern example: a fungus is spreading rapidly in this isolated population of animals, and the prospects of species survival are poor.

A remarkable feature of the history of life is that so many successful species have died out. Many of the extinctions recorded in the fossil record are of species or large groups of species that were ecologically tolerant and occurred in great numbers in all parts of the world. If these extinctions were caused by slow declines over long periods of time, as Darwin thought, they might be explicable in terms of the cumulative effect of very slight deficiencies or disadvantages. But it is becoming increasingly clear that successful species often die out quickly. This is best documented for the K-T mass extinction because of the extensive field work inspired by the controversy over the cause of that event. Several important biologic groups, including the ammonites and dinosaurs, now appear to have existed at full diversity right up to the K-T boundary.

For a species to survive for several million years, as many do, it must be well adapted to the physical and biological stresses normal in its environment. Tree species, for example, that can withstand, or even benefit from, forest fires have presumably evolved this ability because forest fires are common in their environment. It may well be that most species have evolved ways of surviving anything that their environment can throw at them, as long as the stress occurs frequently enough for natural selection to operate. This implies, in turn, that likely causes of extinction of successful species are to be found among stresses that are *not* experienced on time scales short enough for natural selection to act.

The recent Pleistocene glaciation produced very few complete extinctions of species. To be sure, extinction rates during the last deglaciation were high among large mammals and some bird groups. A reasonable explanation is that although the glaciation was associated with marked shifts in climatic regimes, most species were already equipped to cope with the changes by natural physiological tolerance, by having populations in refugia, or by having the ability to migrate to more favorable areas. This appears to be especially true in the marine realm.

In view of the foregoing, recent hypotheses for extinction caused by the catastrophic effects of extremely rare physical events (e.g., asteroid or comet impact, global volcanism) have great appeal.

Patterns of Extinction:

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What caused these immense die-offs? No one process has been implicated, but there are many suspects, including the most dramatic: asteroids crashing into Earth. This was first suggested in 1980 when a layer of iridium was found in rocks laid down at the Cretaceous/Tertiary, or K/T, boundary. Greeted with skepticism at first, the impact hypothesis has gained strength as more evidence supporting it has emerged. A crater of the right size and age, known as the Chixulub crater, was found off the coast of Yucatan, along with rocks known as shocked quartzes and tektites, which suggest a high-velocity collision. An impact big enough to create the Chixulub would certainly have had dramatic effects, throwing up global dust clouds, perhaps enough to render the planet dark and sunless for some time. Other possible consequences have also been suggested, including acid rain, massive volcanic eruptions, and climatic heating.

It is now widely accepted that an impact occurred at the time of the K/T extinction, but whether it was the primary cause of the extinction event is still the subject of debate. Some fossil evidence suggests that many

organisms, including dinosaurs, were declining in numbers well before the K/T event. Other factors, less dramatic and sudden than an asteroid impact but potentially just as devastating in their effects, were operating, too. Sea levels were dropping, causing changes to climate and vegetation that would severely affect large herbivores, including many dinosaurs.

Changes in sea level, in fact, accompanied each of the five mass extinctions, while only the K/T event has been persuasively linked to an asteroid impact. Among the causes that have been suggested for the other mass extinctions are volcanism, climate changes (mostly cooling), changes in the shorelines of continents as crustal plates shifted and coalesced, and changes in the circulation and chemistry of the oceans. The question of mass extinctions and their causes is an area of vigorous research.

Extinctions in deep time

Throughout most of deep time, extinctions have occurred at a fairly constant rate, with the average lifetime of a species spanning 1–10 Mya (Million Years Ago). The causes of these ‘background extinctions’ are difficult to determine, but plausibly include: (i) being outcompeted or predated upon by newly arriving forms; (ii) failing to adapt to long-term environmental change, and (iii) being reduced in abundance by stochastic disturbance events and subsequently failing to recover to a viable population size. However, the crucibles of extinction research in palaeontology have been the five great extinction events, when 65–95% of species were lost. The two most well studied of these mass kills occurred at the end of the Cretaceous (66 Mya) and Permian (250 Mya). The scientific consensus is that the End-Cretaceous extinctions resulted from both the immediate and lingering after-effects of a collision of the Earth with a 10 km wide bolide. The cause of the Permian extinction remains a topic of intense research (and debate), with candidate hypotheses including extreme volcanism, a massive dose of hypoxia driven by a release of marine clathrates or some combination of drivers.

Irrespective of the specific causes, these events share important commonalities: (i) they caused catastrophic loss of global biodiversity, (ii) they unfolded rapidly (at least in the context of evolutionary and geological time), (iii) taxonomically their impact was not random, and (iv) survivors were often not previously dominant clades. The physiognomy of past extinction events is clearly relevant to the current biodiversity crisis, often termed the sixth extinction, which might eventually rival the 'big five' in scale.

The Role of Extinction

Despite many uncertainties, we can formulate a reasonable statement of the probable role of extinction, containing the following elements.

(i) Extinction of a widespread species, or a widespread group of species, requires an environmental shock (physical or biological) which is not normally encountered during the geological life spans of such species or groups, and the shock must be applied rapidly enough over a broad geographic area to prevent adaptation by natural selection or escape by migration. If the most effective extinction mechanisms are beyond the experience of the victims, a high degree of apparent randomness should be expected. Survivors are most likely to be those organisms which are fortuitously preadapted to an "unexpected" stress.

(ii) The most intense episodes of extinction, like the Big Five, produce major restructuring of the biosphere. Three-quarters, or more, of the standing diversity is removed, and diversification of the surviving lineages yields a global biosphere very different from that before the extinctions. Previously successful clades are lost, and unlikely

survivors expand. Although the extinction does not, by itself, make a creative contribution to the evolution of complex structures such as wings or limbs, it may be decisive in sustaining or eliminating such structures. The pterosaurs died out in the latest Cretaceous, and reptiles never again achieved powered flight. Did this foster the Tertiary radiation of bats? What further adaptations might pterosaurs have evolved had they survived? Seen in this light, the major extinctions have a profound influence on the future course of evolution, sometimes constructive and sometimes destructive.

(iii) At lower levels of extinction intensity, Darwin-style selectivity may be relatively common, but except for a few spectacular cases, including Jablonski's studies of the effects of larval development and geographic range, we do not have enough hard evidence to claim that low-level extinction has anything approaching the importance given it by Darwin. Further studies in this area, under the rubric of species selection, are sorely needed.

The role of extinction in evolution –

The extinction of species is not normally considered an important element of neodarwinian theory, in contrast to the opposite phenomenon, speciation. This is surprising in view of the special importance Darwin attached to extinction, and because the number of species extinctions in the history of life is almost the same as the number of originations; present-day biodiversity is the result of a trivial surplus of information, cumulated over millions of years. For an evolutionary biologist to ignore extinction is probably as foolhardy as for a demographer to ignore mortality. The past decade has seen a resurgence of interest in extinction, yet research on the topic is still at a reconnaissance level, and our present understanding of its role in evolution is weak. Despite

uncertainties, extinction probably contains three important elements. (a) For geographically widely distributed species, extinction is likely only if the killing stress is one so rare as to be beyond the experience of the species, and thus outside the reach of natural selection. (b) The largest mass extinctions produce major changes in the biosphere wherein some successful groups are eliminated, allowing previously minor groups to expand and diversify. (c) Except for a few cases, there is little evidence that extinction is selective in the positive sense argued by Darwin. It has generally been possible to predict, before the fact, which species will be victims of an extinction event.

Mass Extinction –

For more than 3.5 billion years, living organisms have thrived, multiplied and diversified to occupy every ecosystem on Earth. The flip side to this explosion of new species is that species extinctions have also always been part of the evolutionary life cycle. But these two processes are not always in step. When the loss of species rapidly outpaces the formation of new species, this balance can be tipped enough to elicit what are known as “mass extinction” events.

A mass extinction is usually defined as a loss of about three quarters of all species in existence across the entire Earth over a “short” geological period of time. Given the vast amount of time since life first evolved on the planet, “short” is defined as anything less than 2.8 million years.

More than 99 percent of all organisms that have ever lived on Earth are extinct. As new species evolve to fit ever changing ecological niches, older species fade away. But the rate of extinction is far from constant. At least a handful of times in the last 500 million years, 75 to more than 90 percent of all species on Earth have disappeared in a geological blink of an eye in catastrophes we call mass extinctions.

Though mass extinctions are deadly events, they open up the planet for new forms of life to emerge. The most studied mass extinction, which marked the boundary between the Cretaceous and Paleogene periods about 66 million years ago, killed off the nonavian dinosaurs and made room for mammals and birds to rapidly diversify and evolve.

Though the Cretaceous-Paleogene extinction is famous for being caused mainly by a huge asteroid, it's the exception. The single biggest driver of mass extinctions appears to be major changes in Earth's carbon cycle such as large igneous province eruptions, huge volcanoes that flooded hundreds of thousands of square miles with lava. These eruptions ejected massive amounts of heat-trapping gases such as carbon dioxide into the atmosphere, enabling runaway global warming and related effects such as ocean acidification and anoxia, a loss of dissolved oxygen in water.

Since at least the Cambrian period that began around 540 million years ago when the diversity of life first exploded into a vast array of forms, only five extinction events have definitively met these mass-extinction criteria.

These so-called "Big Five" have become part of the scientific benchmark to determine whether human beings have today created the conditions for a sixth mass extinction.

The Big Five

These five mass extinctions have happened on average every 100 million years or so since the Cambrian, although there is no detectable pattern in their particular timing. Each event itself lasted between 50 thousand and 2.76 million years. The first mass extinction happened at the end of the Ordovician period about 443 million years ago and wiped out over 85% of all species.

The Ordovician event seems to have been the result of two climate phenomena. First, a planetary-scale period of glaciation (a global-scale “ice age”), then a rapid warming period.

The second mass extinction occurred during the Late Devonian period around 374 million years ago. This affected around 75% of all species, most of which were bottom-dwelling invertebrates in tropical seas at that time.

This period in Earth’s past was characterised by high variation in sea levels, and rapidly alternating conditions of global cooling and warming. It was also the time when plants were starting to take over dry land, and there was a drop in global CO₂ concentration; all this was accompanied by soil transformation and periods of low oxygen. The third and most devastating of the Big Five occurred at the end of the Permian period around 250 million years ago. This wiped out more than 95% of all species in existence at the time.

Some of the suggested causes include an asteroid impact that filled the air with pulverised particle, creating unfavourable climate conditions for many species. These could have blocked the sun and generated intense acid rains. Some other possible causes are still debated, such as massive volcanic activity in what is today Siberia, increasing ocean toxicity caused by an increase in atmospheric CO₂, or the spread of oxygen-poor water in the deep ocean.

Fifty million years after the great Permian extinction, about 80% of the world’s species again went extinct during the Triassic event. This was possibly caused by some colossal geological activity in what is today the Atlantic Ocean that would have elevated atmospheric CO₂ concentrations, increased global temperatures, and acidified oceans.

The last and probably most well-known of the mass-extinction events happened during the Cretaceous period, when an estimated 76% of all species went extinct, including the non-avian dinosaurs. The demise of the dinosaur super predators gave mammals a new opportunity to

diversify and occupy new habitats, from which human beings eventually evolved.

The most likely cause of the Cretaceous mass extinction was an extraterrestrial impact in the Yucatán of modern-day Mexico, a massive volcanic eruption in the Deccan Province of modern-day west-central India, or both in combination.

Ordovician-Silurian extinction - 444 million years ago

The Ordovician period, from 485 to 444 million years ago, was a time of dramatic changes for life on Earth. Over a 30-million-year stretch, species diversity blossomed, but as the period ended, the first known mass extinction struck. At that time, massive glaciation locked up huge amounts of water in an ice cap that covered parts of a large south polar landmass. The icy onslaught may have been triggered by the rise of North America's Appalachian Mountains. The large-scale weathering of these freshly uplifted rocks sucked carbon dioxide out of the atmosphere and drastically cooled the planet.

As a result, sea levels plummeted by hundreds of feet. Creatures living in shallow waters would have seen their habitats cool and shrink dramatically, dealing a major blow. Whatever life remained recovered haltingly in chemically hostile waters: Once sea levels started to rise again, marine oxygen levels fell, which in turn caused ocean waters to more readily hold onto dissolved toxic metals.

The second worst mass extinction known to science, this event killed an estimated 85 percent of all species. The event took its hardest toll on marine organisms such as corals, shelled brachiopods, eel-like creatures called conodonts, and the trilobites.

Late Devonian extinction - 383-359 million years ago

Starting 383 million years ago, this extinction event eliminated about 75 percent of all species on Earth over a span of roughly 20 million years.

In several pulses across the Devonian, ocean oxygen levels dropped precipitously, which dealt serious blows to conodonts and ancient shelled relatives of squid and octopuses called goniatites. The worst of these pulses, called the Kellwasser event, came about 372 million years ago. Rocks from the period in what's now Germany show that as oxygen levels plummeted, many reef-building creatures died out, including a major group of sea sponges called the stromatoporoids.

It's been hard to nail down the cause for the late Devonian extinction pulses, but volcanism is a possible trigger: Within a couple million years of the Kellwasser event, a large igneous province called the Viluy Traps erupted 240,000 cubic miles of lava in what is now Siberia. The eruption would have spewed greenhouse gases and sulfur dioxide, which can cause acid rain. Asteroids may also have contributed. Sweden's 32-mile-wide Siljan crater, one of Earth's biggest surviving impact craters, formed about 377 million years ago.

Though it may sound surprising, land plants may have been accessories to the crime. During the Devonian, plants hit on several winning adaptations, including the stem-strengthening compound lignin and a full-fledged vascular structure. These traits allowed plants to get bigger—and for their roots to get deeper—than ever before, which would have increased the rate of rock weathering.

The faster rocks weathered, the more excess nutrients flowed from land into the oceans. The influx would have triggered algae growth, and when these algae died, their decay removed oxygen from the oceans to form what are known as dead zones. In addition, the spread of trees

would have sucked CO₂ out of the atmosphere, potentially ushering in global cooling.

To add to the puzzle, not only did some creatures go extinct during the late Devonian, but species diversification slowed down during this time. The slowdown may have been caused by the global spread of invasive species, as high sea levels let creatures from previously isolated marine habitats mix and mingle, which let ecosystems around the world homogenize.

Permian-Triassic extinction - 252 million years ago

Some 252 million years ago, life on Earth faced the “Great Dying”: the Permian-Triassic extinction. The cataclysm was the single worst event life on Earth has ever experienced. Over about 60,000 years, 96 percent of all marine species and about three of every four species on land died out. The world’s forests were wiped out and didn’t come back in force until about 10 million years later. Of the five mass extinctions, the Permian-Triassic is the only one that wiped out large numbers of insect species. Marine ecosystems took four to eight million years to recover. The extinction’s single biggest cause is the Siberian Traps, an immense volcanic complex that erupted more than 720,000 cubic miles of lava across what is now Siberia. The eruption triggered the release of at least 14.5 trillion tons of carbon, more than 2.5 times what’d be unleashed if every last ounce of fossil fuel on Earth were dug up and burned. Adding insult to injury, magma from the Siberian Traps infiltrated coal basins on its way toward the surface, probably releasing even more greenhouse gases such as methane.

The resulting global warming was downright hellish. In the million years after the event, seawater and soil temperatures rose between 25 to 34 degrees Fahrenheit. By 250.5 million years ago, sea surface temperatures at the Equator got as high as 104 degrees Fahrenheit, a hot tub's standard maximum temperature. At the time, almost no fish lived near the Equator.

As temperatures rose, rocks on land weathered more rapidly, hastened by acid rain that formed from volcanic sulfur. Just as in the late Devonian, increased weathering would have brought on anoxia that suffocated the oceans. Climate models suggest that at the time, the oceans lost an estimated 76 percent of their oxygen inventory. These models also suggest that the warming and oxygen loss account for most of the extinction's species losses.

Triassic-Jurassic extinction - 201 million years ago

Life took a long time to recover from the Great Dying, but once it did, it diversified rapidly. Different reef-building creatures began to take hold, and lush vegetation covered the land, setting the stage for a group of reptiles called the archosaurs: the forerunners of birds, crocodilians, pterosaurs, and the nonavian dinosaurs. But about 201 million years ago, life endured another major blow: the sudden loss of up to 80 percent of all land and marine species.

At the end of the Triassic, Earth warmed an average of between 5 and 11 degrees Fahrenheit, driven by a quadrupling of atmospheric CO₂ levels. This was probably triggered by huge amounts of greenhouse gases from the Central Atlantic Magmatic Province, a large igneous province in central Pangaea, the supercontinent at the time. Remnants of those ancient lava flows are now split across eastern South America, eastern North America, and West Africa. The Central Atlantic Magmatic Province was enormous. Its lava volume could cover the continental U.S. in a quarter-mile of rock.

The uptick in CO₂ acidified the Triassic oceans, making it more difficult for marine creatures to build their shells from calcium carbonate. On land, the dominant vertebrates had been the crocodilians, which were bigger and far more diverse than they are today. Many of them died out. In their wake, the earliest dinosaurs—small, nimble creatures on the ecological periphery—rapidly diversified.

Cretaceous-Paleogene extinction - 66 million years ago

The Cretaceous-Paleogene extinction event is the most recent mass extinction and the only one definitively connected to a major asteroid impact. Some 76 percent of all species on the planet, including all nonavian dinosaurs, went extinct.

One day about 66 million years ago, an asteroid roughly 7.5 miles across slammed into the waters off of what is now Mexico's Yucatán Peninsula at 45,000 miles an hour. The massive impact—which left a crater more than 120 miles wide—flung huge volumes of dust, debris, and sulfur into the atmosphere, bringing on severe global cooling. Wildfires ignited any land within 900 miles of the impact, and a huge tsunami rippled outward from the impact. Overnight, the ecosystems that supported nonavian dinosaurs began to collapse.

Global warming fueled by volcanic eruptions at the Deccan Flats in India may have aggravated the event. Some scientists even argue that some of the Deccan Flats eruptions could have been triggered by the impact.

Extinction today

Earth is currently experiencing a biodiversity crisis. Recent estimates suggest that extinction threatens up to a million species of plants and animals, in large part because of human activities such as deforestation, hunting, and overfishing. Other serious threats include the spread of invasive species and diseases from human trade, as well as pollution and human-caused climate change. Today, extinctions are occurring hundreds of times faster than they would naturally. If all species currently designated as critically endangered, endangered, or vulnerable go extinct in the next century, and if that rate of extinction continues without slowing down, we could approach the level of a mass extinction in as soon as 240 to 540 years.

Climate change presents a long-term threat. Human's burning of fossil fuels has let us chemically imitate large igneous provinces, through the injection of billions of tons of carbon dioxide and other gases into Earth's atmosphere each year. By total volume, these past volcanoes emitted far more than humans do today; the Siberian Traps released more than 1,400 times the CO₂ than humans did in 2018 from burning fossil fuels for energy. However, humans are emitting greenhouse gases as fast as—or even faster than—the Siberian Traps, and Earth's climate is rapidly changing as a result.

As mass extinctions show us, sudden climate change can be profoundly disruptive. And while we haven't yet crossed the 75-percent threshold of a mass extinction, that doesn't mean things are fine. Well before hitting that grim marker, the damage would throw the ecosystems we call home into chaos, jeopardizing species around the world—including us.

Detecting mass extinctions in the fossil record

Such dramatic changes in adjacent rock layers make it clear that mass extinctions were geologically rapid and suggest that they were caused by catastrophic events (e.g., a period of intense volcanic activity). Exactly what do we mean by "geologically rapid?" Even in cases where a mass extinction seems to have been triggered by a near instantaneous event (e.g., a massive asteroid colliding with Earth), the impact of this event on Earth's systems and biota may have taken much longer to play out. Figuring out exactly how much real time passed during a mass extinction is difficult and requires the use of state-of-the-art radioisotopic dating techniques. Using such techniques, geologists estimate that some of these massive extinctions took place in 200,000 years or less. Current techniques for dating such ancient rocks cannot pinpoint dates more specifically than this — so we can't be sure if some mass extinctions took place in 150 years or 150,000 years. Either way, this represents a sudden event when compared to life's 3.5 billion year

history. For example, if you compressed the entire history of life into a human lifespan of 80 years, a mass extinction would zip by in less than a day.

Causes of Mass Extinctions -

Mass extinctions are associated in time with major environmental changes. The problem, of course, is that other times of no mass extinction also mark the times of environmental change, and it is fair to say that we could not easily predict all mass extinctions with non-fossil data alone. If environmental forcing, which transcends the abilities of species to survive or adapt, is a major cause of mass extinction, what are the factors? We can list them but finding smoking guns is often another matter.

1. Impact or a series of impacts of extraterrestrially derived objects.
2. Volcanism.
3. Climate change.
4. Lowering of sea level, which reduces available habitats for marine species.
5. Anoxia, especially transgressive spread of deep-anoxic waters onto the continental shelves.
6. Methane hydrate release, resulting in extreme global warming.

These causes, stem more from associations in time between inferred geological events and extinctions, and not from a solid model linking environmental change to extinction. The best example of the latter is the Permian mass extinction. The vast marine regression may have been the driving force behind a variety of environmental changes, including a rise in carbon dioxide, which led to increased temperature and oceanic anoxia. At the end of the Permian, sea level dropped, perhaps about 200 m, which was followed by a transgressive rise of sea level in the Lower Triassic of similar magnitude in just 2 Mya. Seasonality and reduction of habitat complexity during the regression may also have

begotten environmental instability, beyond the adaptive ranges of a number of specialized groups. Robert Berner produced a solid model that demonstrated a remarkable drop in atmospheric oxygen from the end of the Permian to the beginning of the Triassic. The drop may have been stimulated by a period of extensive volcanism, which in turn caused dry climates and the wide-spread drying of the planet, which reduced burial of carbon in swamps and released carbon dioxide to the atmosphere. This might have caused extensive warming and temperature stress. The reduction of oxygen might have been the trigger for extinction both on land and sea. If oxygen in the ocean declined, hydrogen sulfide might have appeared, which would be poisonous to most marine life. Volcanism might be a minor contribution to climate change at the end of the Permian, because calculations preclude much of a change in the large ^{13}C deviations at this time, due to outgassing. However, the extensive volcanism in Siberia might have risen to the surface and heated up carbonates and coal deposits, liberating lethal methane, which might have triggered extinctions and caused larger ^{13}C deviations. The Siberian traps cover an enormous area of about two million square kilometers. Paleontologists Norman Newell and Anthony Hallam have implicated sea-level change in a number of extinctions throughout the Mesozoic, but they are also often combined with other events, such as bolide impacts, anoxia, and temperature change.

Around 65 million years ago, something unusual happened on our planet—we can see it in the fossil record.

Fossils that are abundant in earlier rock layers are simply not present in later rock layers. A wide range of animals and plants suddenly died out, from tiny marine organisms to large dinosaurs.

Species go extinct all the time. Scientists estimate that at least 99.9 percent of all species of plants and animals that ever lived are now extinct. So the demise of dinosaurs like *T. rex* and *Triceratops* some 65 million years ago wouldn't be especially noteworthy—except for the fact

that around 50 percent of all plants and animals alive at the same time also died out in what scientists call a mass extinction.

A Brief History of Earth

Early life forms began to flourish during the Cambrian Explosion, 540 million years ago.

Mass extinctions—when at least half of all species die out in a relatively short time—have occurred only a handful of times over the course of our planet's history. The largest mass extinction event happened around 250 million years ago, when perhaps 95 percent of all species went extinct.

Top Five Extinctions

Ordovician-silurian Extinction: 440 million years ago

Small marine organisms died out.

Devonian Extinction: 365 million years ago

Many tropical marine species went extinct.

Permian-triassic Extinction: 250 million years ago

The largest mass extinction event in Earth's history affected a range of species, including many vertebrates.

Triassic-jurassic Extinction: 210 million years ago

The extinction of other vertebrate species on land allowed dinosaurs to flourish.

Cretaceous-tertiary Extinction: 65 Million Years Ago

What to Call It?

Scientists refer to the major extinction that wiped out nonavian dinosaurs as the K-T extinction, because it happened at the end of the Cretaceous period and the beginning of the Tertiary period. Why not C-T? Geologists use "K" as a shorthand for Cretaceous. "C" is shorthand for an earlier period, the Cambrian.

Dawn of a New Age

The extinction that occurred 65 million years ago wiped out some 50 percent of plants and animals. The event is so striking that it signals a major turning point in Earth's history, marking the end of the geologic period known as the Cretaceous and the beginning of the Tertiary period.

K-T Extinction –

KT extinction stands for Cretaceous-Tertiary Extinction. This is a global extinction event that witnessed the elimination of about 70% of the species living on the earth within a very short time 65 million years ago. This mass extinction is known as KT extinction. It occurred at the end of the Cretaceous period and the beginning of the Tertiary period. It ranks third in severity among the five major mass extinctions. The theory about the KT mass extinction proposed by Louis Alvarez and his son is the widely accepted theory. They stated that an asteroid about 15 km in diameter hit the earth forming a crater at the tip of the Yucatan Peninsula in Mexico. This crater is known as Chicxulub crater. The impact of the crater is believed to have penetrated the earth's crust which released a large amount of dust and debris in the atmosphere and led to the tsunami, fires, wind storms, acid rains, and volcanic activities. The dust must have blocked the sunlight coming to the earth which would have

lowered the earth's temperature. 90% marine species, 50% marine genera, 85% land species, and 56% of genera got extinct as a result of KT extinction. This catastrophic event marked the advent of the mammalian age. Dinosaurs form the major group of animals that got extinct during this period. However, it is not proved that the asteroid attack killed the dinosaurs. Many species of dinosaurs have diminished millions of years after the KT extinction.

The group of reptiles comprising birds, dinosaurs, crocodilians survived the extinction and evolved into modern birds and crocodiles. Among the marine flora and fauna, only 13% of the planktons remained alive. Sometimes the remains of the dead organisms are preserved as fossils. The evidence for the KT extinction can be obtained by comparing the fossils found at the end of the Cretaceous period to that at the beginning of the Tertiary period.

Almost all the large vertebrates on Earth, on land, at sea, and in the air (all dinosaurs, plesiosaurs, mosasaurs, and pterosaurs) suddenly became extinct about 65 Mya, at the end of the Cretaceous Period. At the same time, most plankton and many tropical invertebrates, especially reef-dwellers, became extinct, and many land plants were severely affected. This extinction event marks a major boundary in Earth's history, the K-T or Cretaceous-Tertiary boundary, and the end of the Mesozoic Era. The K-T extinctions were worldwide, affecting all the major continents and oceans. There are still arguments about just how short the event was. It was certainly sudden in geological terms and may have been catastrophic by anyone's standards. Despite the scale of the extinctions, however, we must not be trapped into thinking that the K-T boundary marked a disaster for all living things. Most groups of organisms survived. Insects, mammals, birds, and flowering plants on land, and fishes, corals, and molluscs in the ocean went on to diversify tremendously soon after the end of the Cretaceous. The K-T casualties included most of the large creatures of the time, but also some of the smallest, in particular the plankton that generate most of the primary production in the oceans.

There have been many bad theories to explain dinosaur extinctions. More bad science is described in this chapter than in all the rest of the book. For example, even in the 1980s a new book on dinosaur extinctions suggested that they spent too much time in the sun, got cataracts, and because they couldn't see very well, fell over cliffs to their doom. But no matter how convincing or how silly they are, any of the theories that try to explain only the extinction of the dinosaurs ignore the fact that extinctions took place in land, sea, and aerial faunas, and were truly worldwide. The K-T extinctions were a global event, so we should examine globally effective agents: geographic change, oceanographic change, climatic change, or an extraterrestrial event. The most recent work on the K-T extinction has centered on two hypotheses that suggest a violent end to the Cretaceous: a large asteroid impact and a giant volcanic eruption.

KT Boundary

The point between the Cretaceous (K) and the Tertiary (T) period is known as the KT boundary. This period has been dated to be 65.5 million years ago by the geologists. The geologists have discovered that the KT boundary has a very high concentration of iridium than normal. The iridium concentration found in the KT boundary is similar to that in the meteorites.

It was estimated that the asteroid that hit the earth would have been 10 km in diameter releasing immense energy. It not only destroyed a region up to thousands of kilometres but also formed a cloud of dust that interrupted the sunlight reaching the earth's surface for years. The plants, the main basis of the food chain could not survive and eventually, the dinosaurs died.

The Cretaceous-Tertiary boundary transition is marked by one of the most dramatic environmental changes in the Earth's history, with both cause and effect still vigorously disputed. Presently the most popular theory of the cause of this global change is a large extraterrestrial bolide

impact. Supporters of this theory cite anomalously high concentrations of noble elements and shocked mineral grains in a thin boundary clay layer in the marine and terrestrial realm as sufficient evidence of a bolide impact.

The effects of the Cretaceous-Tertiary (K/T) boundary global change on calcareous nanoplankton and planktic foraminifera are most severe in low latitudes and negligible in high latitudes. In low latitudes, species extinctions are complex and prolonged beginning during the final 100,000 to 300,000 yr of the Cretaceous, accelerating across the K/T boundary, and reaching maximum negative conditions between 10,000 and 40,000 yr into the Tertiary accompanied by low primary productivity. In high latitudes, no significant species extinctions occurred at or near the K/T boundary, and all dominant species thrived well into the early Tertiary. Return to a more stable ecosystem and to increased marine productivity in low latitudes does not occur until about 250,000 to 350,000 yr after the K/T boundary, coincident with the extinction of Cretaceous survivors in high latitudes. Within this transition interval, habitats of deep- and intermediate-dwelling tropical planktic foraminiferal species are gradually and selectively eliminated in low latitudes, and by K/T boundary time only cosmopolitan surface dwellers survive. This implies the disruption of the water-mass structure, change in the thermocline, and a drop in surface productivity. Although no single cause is likely to account for these different prolonged and dramatic faunal and environmental changes between low and high latitudes, long-term oceanic instability associated with sea-level, temperature, salinity, and productivity fluctuations may account for most of the faunal changes observed in planktic foraminifera. However, other environmental changes (e.g., volcanism, bolide impact) may have accelerated the demise of the low latitude Cretaceous fauna already on the decline.

An Asteroid or Cometary Impact?

A meteorite big enough to be called a small asteroid hit Earth precisely at the time of the K-T extinction. The evidence for the impact was first discovered by Walter Alvarez and colleagues. They found that rocks laid down precisely at the K-T boundary contain extraordinary amounts of the metal iridium. It doesn't seem to matter whether the boundary rocks were laid down on land or under the sea. In the Pacific Ocean and the Caribbean the iridium-bearing clay forms a layer in ocean floor sediments; it is found in continental shelf deposits in Europe; and in North America, from Canada to New Mexico, it occurs in coal-bearing rock sequences laid down on floodplains and deltas. The dating is precise, and the iridium layer has been identified in more than 100 places around the Earth. Where the boundary is in marine sediments, the iridium occurs in a layer just above the last Cretaceous microfossils, and the sediments above it contain Paleocene microfossils from the earliest part of the Cenozoic. The iridium is present only in the boundary rocks and therefore was deposited in a single large spike: a very short event. Iridium occurs in normal seafloor sediments in microscopic quantities, but the iridium spike at the K-T boundary is very large. Iridium is rare on Earth, and although it can be concentrated by chemical processes in a sediment, an iridium spike of this magnitude must have arisen in some unusual way. Iridium is much rarer than gold on Earth, yet in the K-T boundary clay iridium is usually twice as abundant as gold, sometimes more than that. The same high ratio is found in meteorites. The Alvarez group therefore suggested that iridium was scattered worldwide from a cloud of debris that formed as an asteroid struck somewhere on Earth. An asteroid big enough to scatter the estimated amount of iridium in the worldwide spike at the K-T boundary may have been about 10 km (6 miles) across. Computer models suggest that if such an asteroid collided with Earth, it would pass through the atmosphere and ocean almost as if

they were not there and blast a crater in the crust about 100 km across. The iridium and the smallest pieces of debris would be spread worldwide by the impact blast as the asteroid vaporized into a fireball. If indeed the spike was formed by a large impact, what other evidence should we hope to find in the rock record? Well-known meteorite impact structures often have fragments of shocked quartz and spherules (tiny glass spheres) associated with them. The glass is formed as the target rock is melted in the impact, blasted into the air as a spray of droplets, and almost immediately frozen. Over geological time, the glass spherules may decay to clay. Shocked quartz is formed when quartz crystals undergo a sudden pulse of great pressure. If they are not heated enough to melt, they may carry peculiar and unmistakable microstructures.

All over North America, the K-T boundary clay contains glass spherules, and just above the clay is a thinner layer that contains iridium along with fragments of shocked quartz. It is only a few millimeters thick, but in total it contains more than a cubic kilometer of shocked quartz in North America alone. The zone of shocked quartz extends west onto the Pacific Ocean floor, but shocked quartz is rare in K-T boundary rocks elsewhere: some very tiny fragments occur in European sites. All this evidence implies that the K-T impact occurred on or near North America, with the iridium coming from the vaporized asteroid and the shocked quartz coming from the continental rocks it hit. The K-T impact crater has now been found. It is a roughly egg-shaped geological structure called Chicxulub, deeply buried under the sediments of the Yucatán peninsula of Mexico. The structure is about 180 km across, one of the largest impact structures so far identified with confidence on Earth. A borehole drilled into the Chicxulub structure hit 380 meters (more than 1000 feet) of igneous rock with a strange

chemistry. That chemistry could have been generated by melting together a mixture of the sedimentary rocks in the region. The igneous rock under Chicxulub contains high levels of iridium, and its age is 65 Mya, exactly coinciding with the K-T boundary. On top of the igneous rock lies a mass of broken rock, probably the largest surviving debris particles that fell back on to the crater without melting, and on top of that are normal sediments that formed slowly to fill the crater in the shallow tropical seas that covered the impact area. Well-known impact craters often have tektites associated with them as well as shocked quartz and tiny glass spherules. Tektites are larger glass beads with unusual shapes and surface textures. They are formed when rocks are instantaneously melted and splashed out of impact sites in the form of big gobbets of molten glass, then cooled while spinning through the air. Haiti was about 800 km from Chicxulub at the end of the Cretaceous. At Beloc and other localities in Haiti, the K-T boundary is marked by a normal but thick (30 cm) clay boundary layer that consists mainly of glass spherules. The clay is overlain by a layer of turbidite, submarine landslide material that contains large rock fragments. Some of the fragments look like shattered ocean crust, but there are also spherical pieces of yellow and black glass up to 8 mm across that are unmistakably tektites. The Beloc tektites apparently formed at about 1300°C from two different kinds of rock; and they are dated precisely at 65 Mya. The black tektites formed from continental volcanic rocks and the yellow ones from evaporite sediments with a high content of sulfate and carbonate. The rocks of the Yucatán around Chicxulub are formed dominantly of exactly this mixture of rocks, and the igneous rocks under Chicxulub have a chemistry of a once-molten mixture of the two. Above the turbidite comes a thin red clay layer only about 5-10 mm thick that contains iridium and shocked quartz. One can explain much of this evidence as follows: an asteroid struck at Chicxulub, hitting a pile of

thick sediments in a shallow sea. The impact melted much of the local crust and blasted molten material outward from as deep as 14 km under the surface. Small spherules of molten glass were blasted into the air at a shallow angle, and fell out over a giant area that extended northeast as far as Haiti, several hundred kilometers away, and to the northwest as far as Colorado. Next followed the finer material that had been blasted higher into the atmosphere or out into space and fell more slowly on top of the coarser fragments. The egg-shape of the Chicxulub crater shows that the asteroid hit at a shallow angle, about 20°-30°, splattering more debris to the northwest than in other directions. This accounts in particular for the tremendous damage to the North American continent, and the skewed distribution of shocked quartz far out into the Pacific. Other sites in the western Caribbean suggest that normally quiet, deep-water sediments were drastically disturbed right at the end of the Cretaceous, and the disturbed sediments have the iridium-bearing layer right on top of them. At many sites from northern Mexico and Texas, and at two sites drilled on the floor of the Gulf of Mexico, there are signs of a great disturbance in the ocean at the K-T boundary. In some places, the disturbed seafloor sediments contain fossils of fresh leaves and wood from land plants, along with tektites dated at 65 Mya. Around the Caribbean and at sites up the Eastern Atlantic coast of the United States, existing Cretaceous sediments were torn up and settled out again in a messy pile that also contains glass spherules of different chemistries, shocked quartz fragments, and an iridium spike. All this implies that a great tsunami or tidal wave affected the ocean margin of the time, washing fresh land plants well out to sea and tearing up seafloor sediments that had lain undisturbed for millions of years. The resulting bizarre mixture of rocks has been called "the Cretaceous-Tertiary cocktail." Once Chicxulub was identified, it became possible to calculate that shocked quartz had been launched into a high-angle spray

from the impact. This first hot fireball blew vaporized and molten debris (including glass spherules and iridium) high above the atmosphere to be deposited last and globally as it slowly drifted downward. The larger fragments, solid and molten, were blasted outward at lower angles, but not very far, and were deposited first and locally. At the same time, smaller fragments, including shocked quartz, were blown upward between the hot fireball and the larger fragments, and were deposited second and regionally. The impact energy, for comparison with hydrogen bomb blasts, was around 100 million megatons.

A Giant Volcanic Eruption?

Exactly at the K-T boundary, a new plume was burning its way through the crust close to the plate boundary between India and Africa. Enormous quantities of basalt flooded out over what is now the Deccan Plateau of western India to form huge lava beds called the Deccan Traps. A huge extension of that lava flow on the other side of the plate boundary now lies underwater in the Indian Ocean. The Deccan Traps cover 500,000 km² now (about 200,000 square miles), but they may have covered four times as much before erosion removed them from some areas. They have a surviving volume of 1 million km³ (240,000 cubic miles) and are over 2 km thick in places. The entire volcanic volume that erupted, including the underwater lavas, was much larger than this. Furthermore, the Deccan eruptions began suddenly just before the K-T boundary. The peak eruptions may have lasted only about one million years ($\pm 50\%$), but that short time straddled the K-T boundary. The rate of eruption was at least 30 times the rate of Hawaiian eruptions today, even assuming it was continuous over as much as a million years; if the eruption was shorter or spasmodic, eruption rates would have been much higher. The Deccan Traps probably erupted as lava flows and fountains like those of Kilauea, rather than in giant explosive eruptions like that of Krakatau. But estimates of the fire fountains generated by eruptions on the scale of the Deccan Traps suggest that aerosols and ash would easily have been carried into the stratosphere. The Deccan plume

is still active; its hot spot now lies under the volcanic island of Réunion in the Indian Ocean. Thus there is strong evidence for short-lived but gigantic volcanic eruptions at the K-T boundary. Some people have tried to explain all the features of the K-T boundary rocks as the result of these eruptions. But the evidence for an extraterrestrial impact is so strong that it's a waste of time to try to explain away that evidence as volcanic effects. We should concentrate instead on the fact that the K-T boundary coincided with two very dramatic events. The Deccan Traps lie across the K-T boundary and were formed in what was obviously a major event in Earth history. The asteroid impact was exactly at the K-T boundary. Certainly something dramatic happened to life on Earth, because geologists have defined the K-T boundary and the end of the Mesozoic Era on the basis of a large extinction of creatures on land and in the sea. An asteroid impact, or a series of gigantic eruptions, or both, would have had major global effects on atmosphere and weather. There is a feeling, particularly among physical scientists, that if we can show that a physical catastrophe occurred at the K-T boundary, we have an automatic explanation for the K-T extinctions. But this connection has to be demonstrated, not just assumed. We still have to ask which catastrophe, if either, caused the K-T extinctions, and if so, how?

Faunal Turnover across the K-T Boundary

The close of the Cretaceous period was marked by the disappearance of marine reptiles, flying reptiles, dinosaurs, ammonites, scleractinian corals, bivalves, gastropods and echinoderms. Besides, coccolithophorids, planktonic foraminifera and belemnites almost completely disappeared, though not instantaneously. Extinction was particularly severe among calcareous planktonic organisms, tropical reef invertebrates and large-sized plankton became extinct over a very short time of 10,000 years, while other extinctions were prolonged. The ammonites, for instance, had been in decline from the Campanian through the end Maastrichtian. The most significant extinction was within the Maastrichtian, a few million years before the end of the Cretaceous period. A striking feature of the K-T faunal turnover is that the faunal changes were not instantaneous. High resolution studies at EI

Kef clearly show that all species did not become extinct simultaneously, but the extinction is spread over 32 cm of sediment with major extinctions beginning 25 cm below the boundary. The planktonic foraminiferal diversity declined by 78% across the K-T at EI Kef while the benthic species declined by only 37%. Further, most faunal changes were sequential, the large and more specialised forms disappearing earlier than primitive and generalised species. The selective nature of species extinction was long known in theory and was first demonstrated across the K-T boundary at EI Kef by Gerta Keller in 1988, confirming that even in a paroxysmally changing environment the theory of selectivity in species extinction holds good.

The K-T boundary separates the age of reptiles and the age of mammals, which was first recognized over one hundred years ago by geologists who realized that there was a dramatic change in the types of fossils deposited on either side of this boundary. This boundary also separates two of the three eras of the Phanerozoic (see time scale at left), which is the time in Earth history that began with the origin of complex life and extends to the present. These two eras are called the Mesozoic and Cenozoic. Dinosaurs were prevalent during the Mesozoic Era and extinct during the Cenozoic Era. The last segment of the Mesozoic Era, from 135 to 65 millions of years ago, is called the Cretaceous Period. The first segment of the Cenozoic Era, from 65 million years ago until the present, has historically been called the Tertiary Period. The abbreviation for the boundary between the Cretaceous and Tertiary periods is the K-T boundary, where K is the abbreviation for the German form of the word Cretaceous.

This boundary corresponds to one of the greatest mass extinctions in Earth's history. At least 75 percent of the species on our planet, both in the seas and on the continents, were extinguished forever. The most famous of the vanquished are the dinosaurs. However, these giants were only a small fraction of the plants and animals that disappeared. In the oceans, more than 90 percent of the plankton was extinguished, which inevitably led to the collapse of the oceanic food chain.