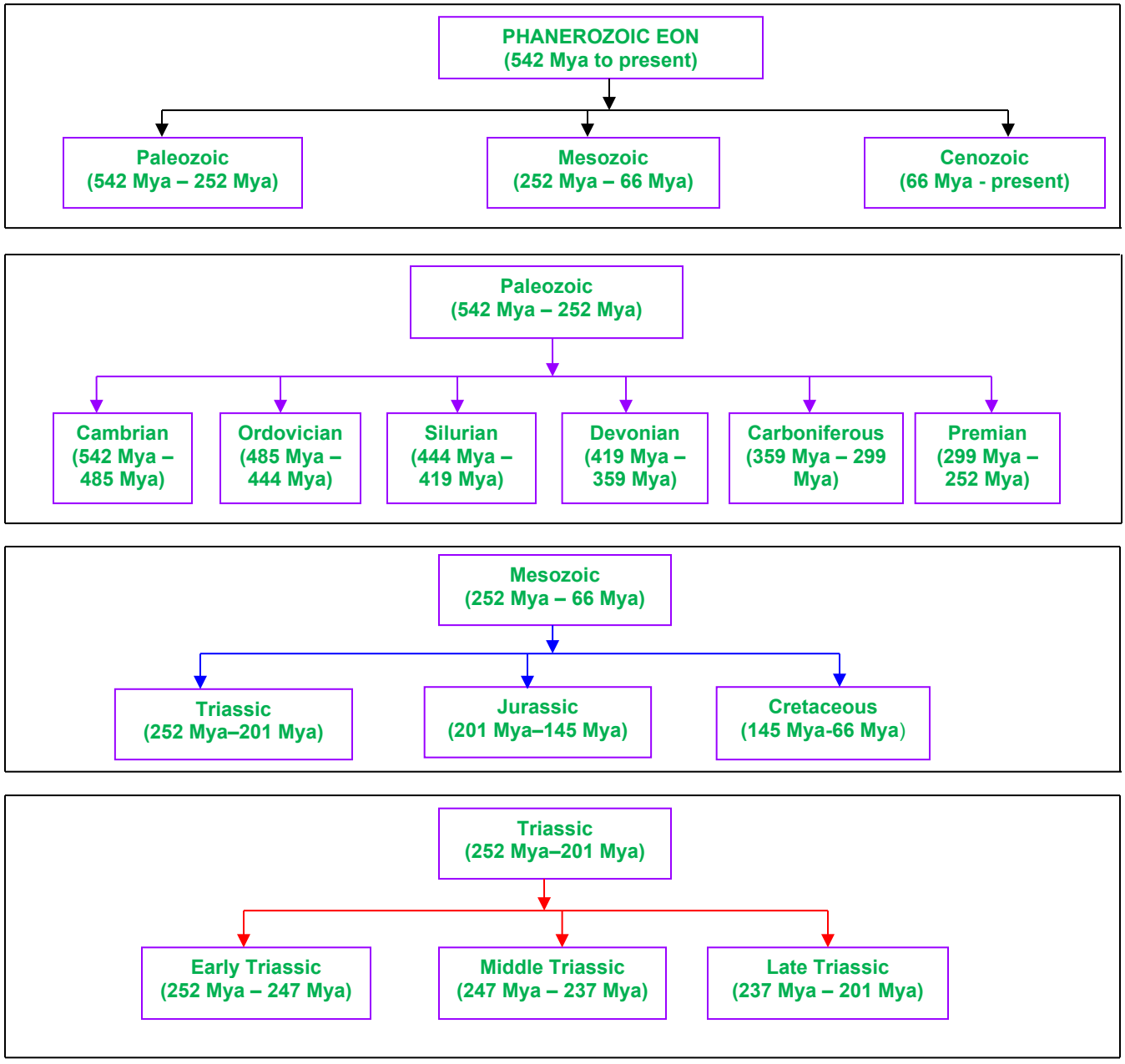
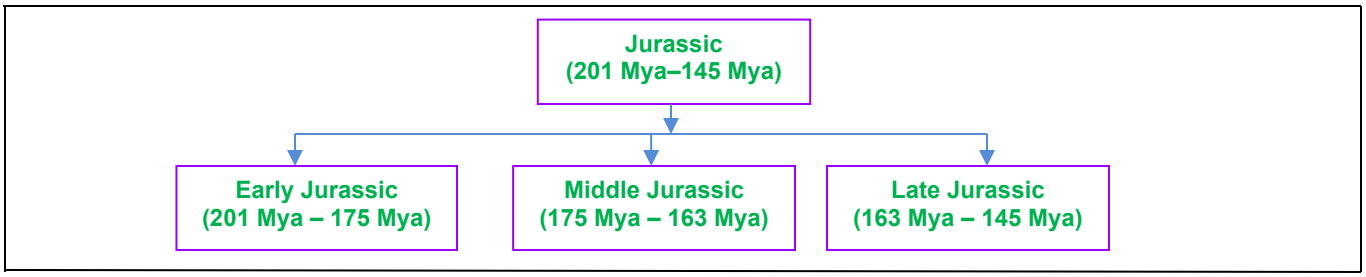
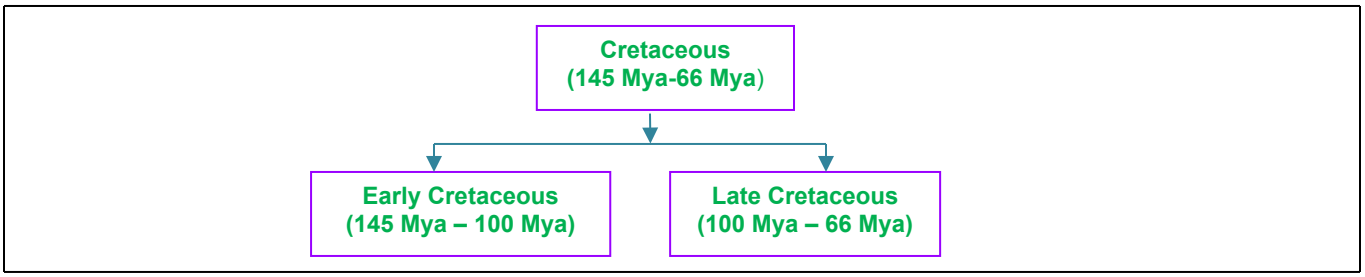
Cambrian Explosion, Evolution of Plant and Animal Phyla and Formation of Supercontinent Pangaea

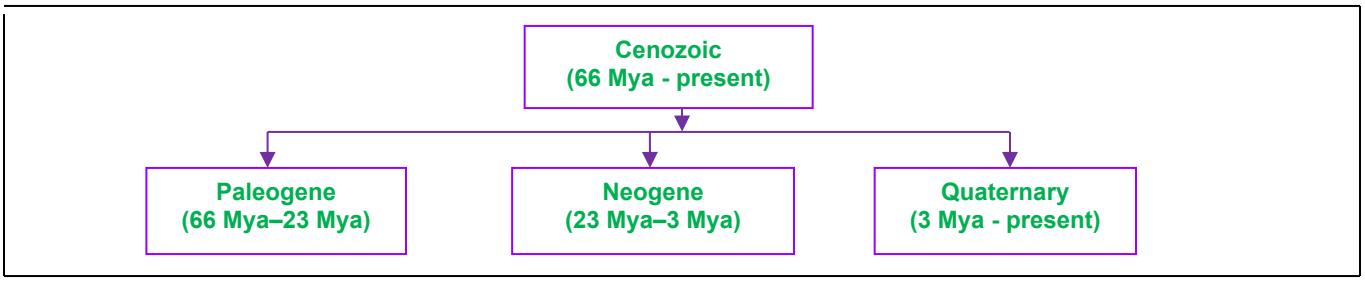
1.0 *Introduction*

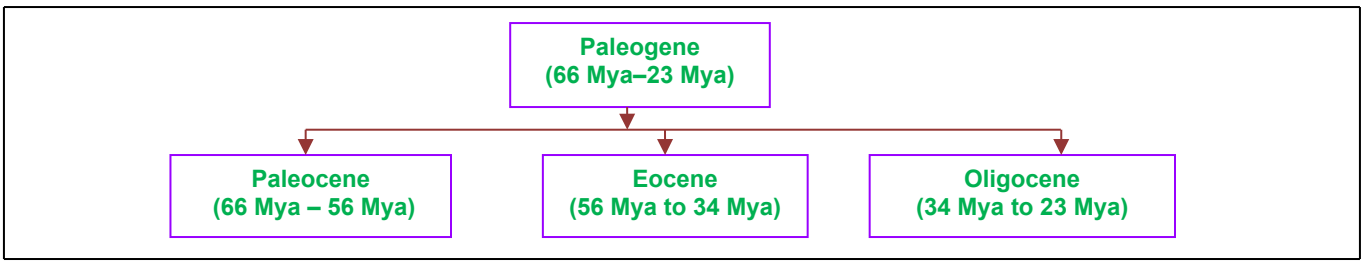
Earlier issues covered the Precambrian Eon. July and August issues would cover Phenerozoic (Cambrian) Eon. This Eon has three Eras and twenty seven periods. Various Eras and periods of this Eon is shown in the diagram given below:

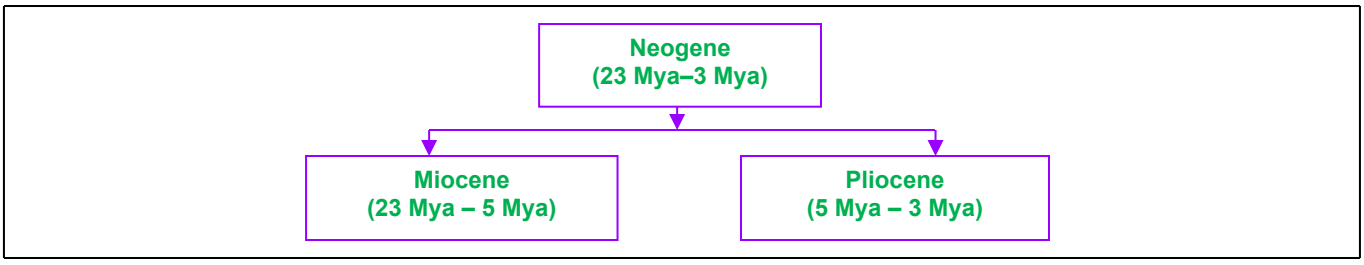


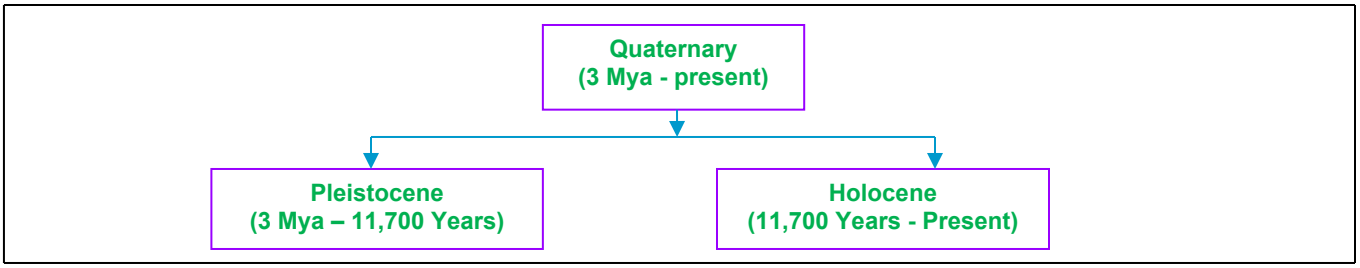












This Eon started about 542 million years ago following Cambrian Explosion. This issue narrates the various events that took place during the Paleozoic Era, the early part of Cambrian Eon covering about 300 million years. The major event of this Eon is Cambrian Explosion during which the largest number of creatures were evolved. There was a rapid emergence of a number of animal phyla in diverse forms, namely, fish, insects, tetrapods, amphibians and reptiles besides development of modern fauna and complex plants. Tectonic forces caused the continents to move and eventually form a single landmass known as ***Pangaea*** which then separated later into current continental landmasses. Like other periods, mass extinction of many species and organisms took place simultaneously with evolution of many other new species.

2.0 *Cambrian Period (542 – 485 Mya)*

Before Cambrian period, majority of the species were small, unicellular and simple. Due to **Cambrian Explosion**, a diverse group of animals appeared during a short period changing the diversity and composition of the Earth's biosphere. Many animals, namely, chordates — animals with a dorsal nerve cord; hard-bodied brachiopods, resembling clams (mollusk), and arthropods — ancestors of spiders, insects and crustaceans evolved. Initially, animals were mostly invertebrates. Over a period of time, process of biomineralization (formation of bones, shells and teeth) evolved gradually in several creatures. Development of a wide variety of bilaterians (animals having bilateral symmetry) led to predation, a new ecological interaction. With increase in the number and variety of organisms, marine environments and habitats changed. Cambrian seas became filled with animals of various sizes, shapes; some lived on the sea floor (***a benthic lifestyle***), while others actively swam in the water column ***(nektonic)***. The species and the animals could move over long distance, forage for food and protect themselves against predators by having hard mineralized skeletons. ***Euthycarcinoids***, amphibious arthropod had legs to walk on land. Animals with shells and exoskeletons including trilobites, brachiopods also appeared during the time. Calcified ***Archaeocyathans*** (extinct group of sponges) diversified rapidly into many species and some of these species contributed to the creation of first reefs. ***Haikouichthys*** was the earliest jawless fish that predominated during this period. Trilobites, surviving for almost 300 million years eventually became one of the most universal groups of invertebrate organisms in the Paleozoic seas. A velvet worm like creature found in the Cambrian seas was

Hallucigenia that stood on seven legs. Its long, tube-shaped body had two rows of tall spikes along its back which provided protection since it had no eyesight to warn it of dangers. Cambrian landscapes were, however, devoid of vegetation as plants were not yet evolved.

2.1 *Causes of Cambrian Explosion*

Outcome of many researches based on fossil record shows that a precise balance between mutation and selection through which evolution occurs was the main factor for evolution of life in a large scale in a short period. In the Mesoproterozoic Eon (1.6 Ga to 1 Ga), symbiotic relationship that occurred between small cells and large cells helped evolve organelles comprising of mitochondria and chroloplasts of eukaryotic cells. Sophisticated development of that symbiosis caused proliferation of multi–celled organism in the Cambrian period through adaptations. There are other theories, namely, (a) Increase in oxygen level allowed evolution of larger and more complex animals with respiratory and circulatory systems, (b) Increase in calcium concentration in the Cambrian sea water helped marine organisms to build skeletons, (c) Development of ***Hox genes*** might have changed the structure and composition of animals and marine organisms.

2.2 *Cambrian Substrate Revolution*

The revolution consisted of first burrowers to burrow deep into the substrate (sea floor), rather than grazing at the surface or just below the microbial mats which dominated the sea floor at that time. As these microbial mats created a barrier between the water and sediment underneath making an anoxic (without oxygen) environment beneath the surface, it was inhabited by sulfate-reducing bacteria which emitted hydrogen sulfide making the substrate toxic to other organisms. These burrowing animals broke down the microbial mats. This allowed water and oxygen to penetrate below the surface. This restricted the sulfate reducing bacteria and their hydrogen sulfide emissions to the deeper layers making the upper layers of the sea floor habitable for various organisms. The upper level of the sea floor thus became wetter and softer as it was constantly churned up by burrowers. The ultimate result was the evolution of wide range of burrowing organisms and opening up of new ecological niches beneath the sea floor.

2.3 *Breakup of Pannotia (about 500 Mya)*

Pannotia which was formed around 600 Mya, started breaking up into smaller continents and a larger landmass. The smaller fragments were **Laurentia**, **Baltica** and **Siberia.** The larger landmass was called **Gondwana.** The Paleozoic ocean between Gondwana, Laurentia and Baltica was called the ***Iapetus Ocean***.

3.0 *Ordovician Period (485 – 444 Mya)*

3.1 A period of continental glaciations occurred in the beginning of Ordovician period causing the Earth to cool down. As a result of this cooling, ocean water was frozen into ice. This lowered the sea levels causing withdrawal of shallow seas and depletion of oxygen. Thus, the organisms were left dry without any habitat. The loss of habitat and increased competition among other organisms led to the mass extinction of most of the species which evolved during Cambrian period including brachiopods, chordates and trilobites. This event is known as ***Cambrian Mass Extinction (around 488 Mya).***

3.2 ***The Great Ordovician Biodiversification*** (about 485 Mya) not only increased the biodiversity of marine life but also tripled the number of marine species with different shape, size and function. Trilobites and other organisms which were dominant in the Cambrian period were replaced by marine invertebrates such as cephalopods, hard shelled brachiopods or clams, sea lilies or crinoids (echinoderms) and many others such as sponges, corals and crabs. These marine organisms developed strategies for protection and to catch their prey. The first great coral reefs appeared during this time and gave shelter to crustaceans of all kinds. The first true vertebrates (***jawless fish — Ostracoderms***) appeared in the beginning of Ordovician period and ***gnathostome (jawed fish)*** appeared in the Late Ordovician period. A kind of hunter fish, like eel, large eyed conodonts also evolved during this period.

3.3 Land plants with ability to reproduce with spores were evolved for the first time during this period (around 470 Mya). These plants had no veins for moving water around inside their bodies, but had chlorophyll to make their own food. The first land fungi which evolved this time was ***arbuscular mycorrhiza fungi (Glomerales)***. They played a crucial role in facilitating the colonization of land by plants through mycorrhizal symbiosis by which mineral nutrients were made available to plant cells. Fungi and algae left on bare land

worked together to form lichen which broke down the rock they lived upon producing soil which ultimately helped the land plants and fungi change the Earth's landscape paving the way for evolution of land animals.

3.4 During the Middle of Ordovician period, there was a large increase in the intensity and diversity of bioeroding organisms like 'boring fauna' that caused bioerosion of hard carbonate substrates produced by organisms such as corals and carbonate sponges (stromatoporoids). Corals accumulate calcium carbonate or limestone to form their skeleton framework structure which provided food and shelter to many coral reef organisms. Bioeroders naturally broke down accumulated calcium carbonate to make rubble and sand. This is known as ***Ordovician Bioerosion Revolution***.

3.5 ***Ordovician Ice Age*** and ***Second Mass Extinction*** (about 440 – 460 Mya) occurred at the final stage of Ordovician period due to decrease in carbon dioxide level. Tropical ocean temperatures dropped to 5^0 C which was a major factor leading to ice age and responsible for mass extinction of a majority of marine communities, namely, brachiopod, bryozoans, trilobites, conodonts and graptolites.

4.0 *Silurian Period (444 – 420 Mya)*

4.1 During this period, the Earth's general climate changed and entered a long warm greenhouse phase with high levels of carbon dioxide with a resultant rise in temperature. Coral reefs such as ***stromatoporoids*** with outer skeleton appeared and survived by eating microscopic animals trapped by their stinging tentacles. In the early Silurian, a primitive jawless fish known as ***Agnatha*** appeared having a notochord as the main support to its body. In the mid-Silurian, the primitive armored jawed fish ***Romundina, a placoderm*** evolved. ***Erypterids,*** commonly known as sea scorpions were the largest known arthropods in the oceans. They had a semi-circular exoskeleton, followed by four pairs of jointed legs and a long tapering tail at the end that had spikes which were used to inject venom into the prey. A warm stable climate facilitated arrival of first land plant **-** .***Cooksonia*** with no true leaves. The oldest vascular plant that had needle shaped true leaves was ***Baragwanathia***, a lycopod. This plant marked the first emergence of club mosses and was very important in the evolution of land plants. Insects such as millipedes, centipedes, ancestors of spiders and leeches appeared in

this period. The earliest known terrestrial millipede to have lived on land was ***Pneumodesmus***.

4.2 *Formation of supercontinent Euramerica (about 433 Mya)*

Much of the northern half of the planet was ocean with two smaller continents: Laurentia and Baltica near the equator. A microcontinent known as Avalonia drifted northward. These three northern continents that is Laurentia, Baltica and Avalonia collided forming the new supercontinent ***Euramerica.*** This collision was accompanied with a major mountain building event known as ***Caledonian Orogeny*** which caused closure of **Iapetus Ocean**. Euramerica was also known as the ***'Old Red continent'*** because of its reddish, erosion-produced sediments deposited on it.

5.0 *Devonian Period (420 – 360 Mya)*

5.1 During the early period of this period, climate was warm and arid, average sea surface temperatures hovering around 30^0C. This period was characterized by fluctuating climate condition; initial period was warm followed by cool weather in the mid and finally very warm weather at the end. This erratic climate change contributed to the extinction of the stromatoporoids evolved during Silurian period. Jawless armored fish ***(Ostracoderms)*** became extinct and was replaced by jawed fish ***(Gnathostomes),*** cartilaginous ***(Chondrichthyes)*** and bony fishes ***(Osteichthyes)*** in both sea and freshwater. By the mid-Devonian, two groups of fish, namely, ***Ray-finned fish*** *and* ***lobe-finned fish,*** ancestors of modern fish, ancestors of tetrapods that had bones, teeth, swim bladder and gills evolved. ***Devonian Explosion*** by way of rapid growth of plants took place in this period. Plants started to develop roots and seeds and built huge forests on lands for the first time on the Earth. By the end of the Devonian period, ***Archaeopteris***, a progymnosperm which had tree like plants with fern like leaves were the first tree that had true wood. Other plants were ***Prototaxites***, a giant fungus with a tree-trunk like structure and ***Wattieza,*** resembling the modern tree fern appeared. By the end of Devonian, rapid growth of plants increased oxygen level in the atmosphere. Soils which began to form from prehistoric rocks during the Precambrian times began to develop further. The organic matter produced from lichens, bacteria and algae joined the action of erosion wearing away the rocks to create first true soils. This paved the way for the joint legged invertebrate animals (arthropods) to move onto the land. ***Rhyniella praecusor***, a flightless hexapod with antennae and segmented body was

the earliest known larval insect in the early Devonian times. Four limbed vertebrates (tetrapods) evolved from lobe finned fishes. The first amphibians breathed through simple lungs and their skin. The earliest known tetrapod having fish like pelvis and crocodile like head was ***Tiktaalik rosae*** who ventured out onto the land. While there was evolution of plants and animals, there was mass extinction also mainly due to change in climate and high frequency sea level. Brachiopods, ammonoids, conodonts, trilobites, placoderms and reef building organisms mainly stromatoporoids and corals completely disappeared. Jawless vertebrates (agnathans) declined. With development of soil, release of ions became normal. These ions acted as nutrients to plants and algae that used up all the available oxygen by decaying the organic matter contained in them. This caused anoxic conditions in which bottom dwelling fish became extinct due to suffocation for want of oxygen. At the end of this period, there was reduction in carbon dioxide levels due to greening of the land. This caused global cooling resulting in glaciations. Continuous weathering of rocks drew down carbon dioxide from the atmosphere which transformed the Earth from its Greenhouse state into Icehouse state.

6.0 *Carboniferous Period (360 – 300 Mya)*

6.1 In this period, active mountain building event took place. The southern continents comprising of present Australia, Africa, Southern Europe, Antarctica and South America which remained joined together in the supercontinent Gondwana collided with Euramerica supercontinent resulting in the ***Hercynian orogeny*** near the present Europe, and the ***Alleghenian orogeny*** near the present North America. The collision of supercontinent Gondwana with southern part of Euramerica resulted in an 'O' shaped new continent which was the first step of formation of great supercontinent ***Pangaea***. There were two major oceans inside the 'O' shaped Pangaea – ***Panthalassa*** and ***Paleo-Tethys.***

Sea levels greatly varied during this period causing extensive formation of low lying swamp forests that was later transformed into coal deposits. The growth of forests took away huge amounts of carbon dioxide from the atmosphere leading to an increase in oxygen levels. This oxygen level presumably promoted abnormal largeness of insects and amphibians.

6.2 Average global temperature in the Early Carboniferous period was about 20^0 C. During the middle, temperature cooled down to about 12^0 C. Gradually, temperature further dropped

causing intense glaciations and drop in sea levels. Sudden cooling and drying of the climate led to extinction of most of the species of fish evolved during Devonian period. On the other hand, there was rise of more advanced species of tetrapods and amphibians. Besides, many marine invertebrates grew in large numbers. Of them, ***Foraminifera***, a single celled protists/eukaryotes with shells and ***Fusulina***, a spindle shaped foraminifera appeared at that time. ***Gigantoproductus*** were the largest of the Carboniferous brachiopods. ***Serpulites, segmented worms, gastropods (snails), crustaceans, sea lilies (crinoids), sea buds (blastoids)*** appeared in this period. ***Hibbertopterus,*** the giant sea scorpions (eurypterids), ***Hylonomus,*** the earliest known reptile looking like modern lizards and ***Ophiacodon,*** an omnivorous giant alligator (synapsid) having a large skull and jaws lined with numerous small teeth, appeared in the late Carboniferous period.

6.3 Arthropods such as air-breathing insects, myriapods (***millipedes, centipedes and others***), joint legged invertebrate animals (***arachnids***), dragonflies having size of seagulls, marine worms (***Priapulida***), ***Arthropleura***, the largest land dwelling millipede having thirty jointed segments covered by two side plates and one center plate, ***Meganeura,*** the largest known flying insect, beaked insects (***Palaeodictyopteroidea***), ***Protorthoptera*** a kind of winged insects and ancestors of cockroaches appeared during the end of this period. High oxygen levels allowed these arthropods to attain larger size. Their wings were developed from structures used to regulate temperature or perhaps to attract mates and protect from rivals.

6.4 Sharks underwent a major evolutionary diversification during the Carboniferous period and evolved in a wide variety of unusual shapes. One such shark was ***Stethacanthus*** having an unusual dorsal fin shaped like an anvil. Other sharks had piercing teeth. The largest known freshwater fish was lobe- finned ***Rhizodus***.

6.5 During this period, the amphibians dominated the waterlogged forest world. Over a period of time, they evolved into **the earliest reptiles** by reducing their dependence on wetland habitat through an evolutionary adaption known as amniote egg, which allowed the laying of eggs in dry environment. The largest were over two meters long. ***Eogyrinus,*** a large predator having a long tail and an eel like body and ***Proterogyrinus,*** the largest reptiles which were the top predator that hunted both on land and in the water evolved during this time. They

were good swimmers and could move fast through the rivers, lakes, and bogs surrounding the lowland forests. They could also walk on land like some amphibians today.

6.6 Spore bearing vascular plants such as horsetails (***Equisetales***), scrambling or climbing plants (***Sphenophyllales***), club mosses (***Lycopodiales***), scale tree like plants (***Lepidodendrales***), and ***ferns***, appeared. Seed producing plants like seed ferns (***Medullosales***) and primitive conifers (***Cordaitales***) continued to dominate throughout the early Carboniferous period in swamps and mangroves. Late Carboniferous plant groups included seed plants having a woody trunk with a crown of large evergreen leaves known as cycads (***Cycadophyta***), seed ferns or climbing plants were found in coal swamps. The ***Cladoxylopsids*** were huge trees, closely related to ferns and horsetails first appeared in this period.

6.7 An extinction event occurred on land before the end of the Carboniferous period due to a sudden change in climate known as ***Carboniferous Rainforest Collapse*** at about 305 Mya. Vast tropical rainforests collapsed as climate changed from hot and humid to cool and arid. Sea levels dropped and ice covered much of the Earth's landmasses. The new climate conditions were not favorable to the growth of rainforest and animals residing within them. As a result, rainforests shrank into isolated islands, surrounded by seasonally dry habitats finally wiping them out. Several vascular plants (***lycophtes***) were replaced by less diverse tree-fern dominated flora.

7.0 *Permian Period (298 – 252 Mya)*

7.1 The climate in this period varied erratically. At the beginning of this period, the Earth was still in an Ice Age, which began in the Carboniferous period. Glaciers receded around the mid-Permian period as the climate gradually became warm making the continent's interiors dry. Such dry climate caused a major transition in vegetation in the middle of this period. The swamp loving lycopod trees were replaced by more advanced seed ferns and early conifers. Modern trees such as ginkgos and cycads also appeared during this period. The spore bearing moss plants were replaced by first seed bearing vascular plants (gymnosperms) having a proper water transport system.

7.2 Foraminifera (Fusulina), ammonoids, echinoderms and brachiopods continued to exist during this period. Coral reefs were large and diverse. The lobe-finned and spiny fishes that

gave rise to the amphibians of the Carboniferous period got replaced by true bony fish. Growth of sharks and rays continued in large scale.

7.3 There was evolution of diversified groups of insects during this period. True bugs, with mouthparts modified for piercing and sucking plant materials, ***cicadas and beetles*** evolved in this period. About ninety percent of insects at the beginning of this period were cockroach-like insects. They had six fast legs, four well-developed folding wings, fairly good eyes, long, well-developed antennae, an omnivorous digestive system, a receptacle for storing sperm, a chitin-based exoskeleton that could support and protect, as well as efficient mouth parts. Primitive forms of dragonflies were the dominant predators during this time.

7.4 During this period, Siberia continent which was located near the present North Pole, began to move towards South Pole and it collided with the northern part of Euramerica. This completed the formation of the large supercontinent Pangaea at about 270 Mya which was surrounded by an ocean known as Panthalassa.

7.5 Two important groups of animals (amphibians) evolved and dominated the Permian period. They were ***Synapsids,*** ancestors of mammals and ***Sauropsids,*** ancestors of birds and reptiles. These two groups evolved from egg laying amniotes which appeared in the Carboniferous period. The earliest primitive synapsid was ***Dimetrodon*** having a lizard-like body and a large bony sail fin on its back used for thermoregulation. Early Permian was dominated by **pelycosaurs** (mammal like reptiles) and **diadectes** (reptile like amphibians). Middle Permian was dominated by another mammal like reptiles, **therapsids** which evolved from pelycosaurs. ***Dinocephalia*** and ***therocephalians*** were two such large-bodied therapsids that gave rise to mammals later. Late Permian was dominated by more advanced therapsids such as ***gorgonopsians and dicynodonts***. ***Gorgonopsians***, having size of a large bear were the largest carnivores in the late Permian. ***Dicynodonts*** were herbivorous animals with two tusks. Towards the end of the period, the first ***archosaurs***, a reptile of a large group which includes the dinosaurs and flying reptiles (Pterosaur) appeared. ***Cynodonts***, ancestors of modern mammals, were the therapsids that first appeared in the late Permian.

7.6 During the end of this period (252 Mya), ***Great Permian Extinction event*** killed ninety six percent of all marine invertebrate species and seventy percent of terrestrial vertebrates. The

extinction mainly affected organisms with calcium carbonate skeletons. More heavily calcified organisms with simpler breathing mechanisms suffered the most with loss of diversified species. Insects with piercing and sucking mouthparts suffered a major mass extinction at the end of the period. Land plants such as Cordaites (gymnosperms) and Glossopteris (seed ferns) began to decline. Dominant gymnosperms were replaced by smaller herbaceous plants. Later, other groups of gymnosperms became dominant but again suffered major extinction. These cyclical flora fluctuations between gymnosperms and herbaceous plants occurred a few times causing loss of the most plant species.

8.0 *Conclusion*

During Cambrian Eon, catastrophes which swept over the Earth generated vast alteration both in land forms and in life. The late Permian was the most extreme. Almost ninety five percent of all the species that existed on Earth became extinct. Almost all the amphibians and reptiles that had settled on the land faced extinction. On the other hand, mass extinctions permitted the survivors to evolve quickly occupying improved ecological niches. New species also appeared and they persisted for million of years. The process of evolution and extinction is probably concomitant. Some people believe that this is due to the modus operandi of an omnipotent and omniscient 'creator' and today's problems on account of climate change is in accord with the Supreme Lord's wishes. These religious precepts have practical consequences in the human assault on the environment. Science, however, helps us awaken to the true circumstances. Science and religion are different ways of understanding the world. Needlessly placing them in opposition reduces the potential of both to contribute to a better future. Unforgiving principle of nature teaches us to protect the Earth. But, unfortunately, we forget this principle of nature and ignore the Earth and do all deeds which hasten the catastrophes to happen.

