EVOLUTION

MAJOR EVENTS IN THE EARTH'S EVOLUTION

S. MOHANA KUMAR

Nothing in this universe is unchanging. Change may be instantaneous, or may involve time-spans of several hundreds to millions of years. In the context of the Earth's history, we use the term 'evolution' to represent the progression of major changes that have shaped the planet; and the gradual development of the planet to the complex form that we know of today.

Our little planet was formed along with all the other planets of the solar system about 4.6 billion years or 4600 million years ago (one billion is equivalent to 10^9). Earth scientists divide this long time span into divisions which provides a chronological reference of the Earth's evolutionary history. The larger and more major divisions in this time scale are called **eons**. Each eon is subdivided into smaller time units called **eras** and even further into **periods** and so on (as shown in Table 1).

Eons	Eras	Duration
Precambrian	Hadean	from 4000 million years to about 4600 million years (600 Myr)
	Archean	from 2500 million years to 4000 million years (1500 Myr)
	Proterozoic	from about 540 million years to 2500 million years (1960 Myr)
Phanerozoic	Palaeozoic	from about 252 million years to about 540 million years (288 Myr)
	Mesozoic	from 66 million years to about 252 million years (186 Myr)
	Cenozoic	from the present day to 66 million years (66 Myr)

Table. 1. The geological time scale (the abbreviation Myr stands for 'million years'). Note that the numerical ages shown above are subject to revision in the future.

The Precambrian eon

This eon is the first major division of geologic time covering about 88% of the Earth's history. It started with the formation of the planet (about 4.6 billion years ago) and lasted till the sudden diversification of multicellular organisms about 540 Myr ago, in what is known as the **Cambrian Explosion** (in the **Cambrian Period** at the commencement of Phanerozoic Eon).

All the planets of the Solar System were formed from a nebula — a spinning interstellar cloud of dust, hydrogen, helium and other ionized gases several light years in diameter surrounding the young Sun after its formation. The small particles of dust in this cloud collected together into larger and larger objects called planetoids. Planetoids were composed of pebbles, rocks and boulders that became massive enough to attract more and more material with the force of gravity. **The Giant Impact Hypothesis** (refer **Fig.1**) suggests that our moon was probably formed somewhere close to about 4500 billion years ago, not long after Earth's formation. An object about the size of Mars (which has been named **Theia**) smashed into the Earth and threw up a huge cloud of debris. The particles in this debris began to clump together, becoming larger and larger, resulting in our Moon.

(a) Hadean Era: This era, the earliest of the Precambrian Eon, lasted for nearly 600 myr. The history of the Hadean time is poorly understood because no rocks from this period have survived for our study. The Hadean Era would have been a terrible time to live in. During this time there were a lot more comets, meteoroids and asteroids in space, which often came crashing into the Earth's surface, creating much heat. The numerous craters found on the Moon

Fig. 1. The Giant Impact Hypothesis to explain the formation of the Moon.

and other planets are evidence for the conditions that existed during the infancy of the Solar System. Scientists also believe that the Earth and other planets would have been molten at this stage of development (refer **Fig. 2**). The atmosphere of the Earth in this era would also have been very different from what we breathe today. Composed of methane, ammonia, and other gases, this reducing atmosphere would be toxic to most life on our planet today. With time, the Earth gradually cooled. The heavier molten iron sank into the centre of the planet to form its core; while lighter materials rose to the surface, cooled, and formed the crust. The Earth and the Moon continued to be bombarded by extra-terrestrial objects throughout the Hadean.

Box 1. Prokaryotes vs. Eukaryotes.

The difference between prokaryotic and eukaryotic organisms is a fundamental one. While the latter have a nucleus and other membrane-bound structures called organelles; cells of prokaryotes are devoid of these. Prokaryotes were the first forms of life on Earth, appearing between 3900 Myr and 2500 Myr ago. These organisms also remained the only forms of life on Earth for several millions of years. It was only much later (about 1850 myr ago) that eukaryotic organisms with their more complicated structures and larger sizes came into being.

(b) Archean Era: During this era, which lasted between 4000 Myr and 2500 Myr ago, there was little free oxygen in the Earth's atmosphere. As a result of the prevailing high temperatures, all the water in the Earth's atmosphere was in the form of vapour. Towards the later part of this era, some forms of bacteria evolved ways of harnessing sunlight to make sugar from carbon dioxide and water just like green plants today. These bacteria started releasing oxygen, a waste product of this reaction, into the atmosphere. This led to the gradual development of an oxygen-rich atmosphere. As the Earth continued to cool down, water vapour in its atmosphere condensed and fell as torrential rain, filling its depressions to form the earliest oceans. Although highly debated, most scientists consider the origin of life to be a natural event in the evolution of the Earth. The oldest fossils to be discovered, in rocks called stromatolites, are those of 3.8 billion years old colonies of single-celled prokaryotes, called cyanobacteria that obtain their energy through photosynthesis (refer **Fig. 3**) The appearance of these single-celled forms of life, much like modern bacteria, marks the origin and development of the biosphere.

(c) Proterozoic Era: This era extended from about 540 Myr to 2500 Myr. There were two **ice ages** during the period – one between 2400 Myr to 2100 Myr, and another one between 720 Myr and 635 Myr. Around about 2000 Myr ago, the first definite eukaryotes made their appearance (refer **Fig. 4**). By 1800 Myr, the atmosphere became oxidising. Oceanic cyanobacteria, which evolved into multicellular forms more than 2.3 billion years ago, are believed to have become the first microbes to produce oxygen by photosynthesis which was free to escape into the atmosphere. The

Fig. 2. The Hadean Earth was frequently bombarded by comets, meteoroids and asteroids.
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Fig. 3. Modern Stromatolites.

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oxygen in the atmosphere gradually increased from <1% to 21% somewhere around 500 Myr, as a result of continued organic evolution and the consequent increase in biological activity. Available fossil records show that in a period of 100 Myr towards the close of this era, a group of complex, soft-bodied multicellular organisms or metazoans made their first appearance, and progressively became more common towards the end of Precambrian Eon. Because there were no predators, these earliest metazoans lacked any hard parts and have left perfect fossils. This assemblage of organisms is called the **Ediacara fauna** as these were first discovered in the Ediacara Hills of Australia.

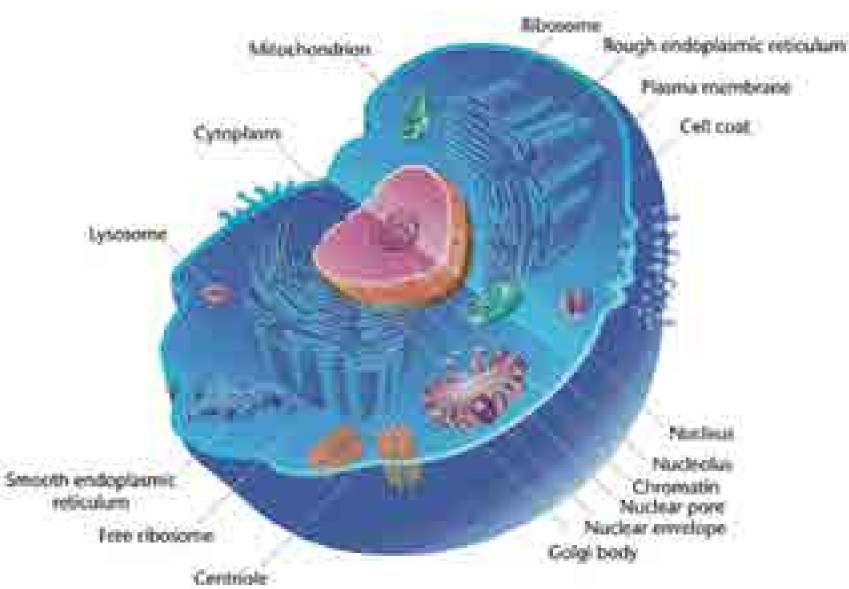

Fig. 4. Modern eukaryotic cells evolved from ancestors that first appeared about 1850 Myr ago.

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Plate tectonics, one of the most important discoveries of the 20th century, is a modern theory developed from an earlier concept — that of **continental drift.** This theory is widely accepted today, and has almost entirely replaced the earlier concept of continental drift. According to plate tectonics, the relatively rigid lithosphere of the earth is divided into seven large **plates** and a number of smaller plates which float on and travel independently in different directions, over the underlying partially molten mantle. This movement happens very slowly — as slow as the growth of your finger nails (refer **Fig. 5**). Movements of these lithospheric plates (not continents, as believed earlier) over millions of years result in significant changes in the global geography. Much of the Earth's activity — earthquakes, volcanoes, the rising of mountains etc. — are confined to the boundaries of these plates. Earth scientists believe that

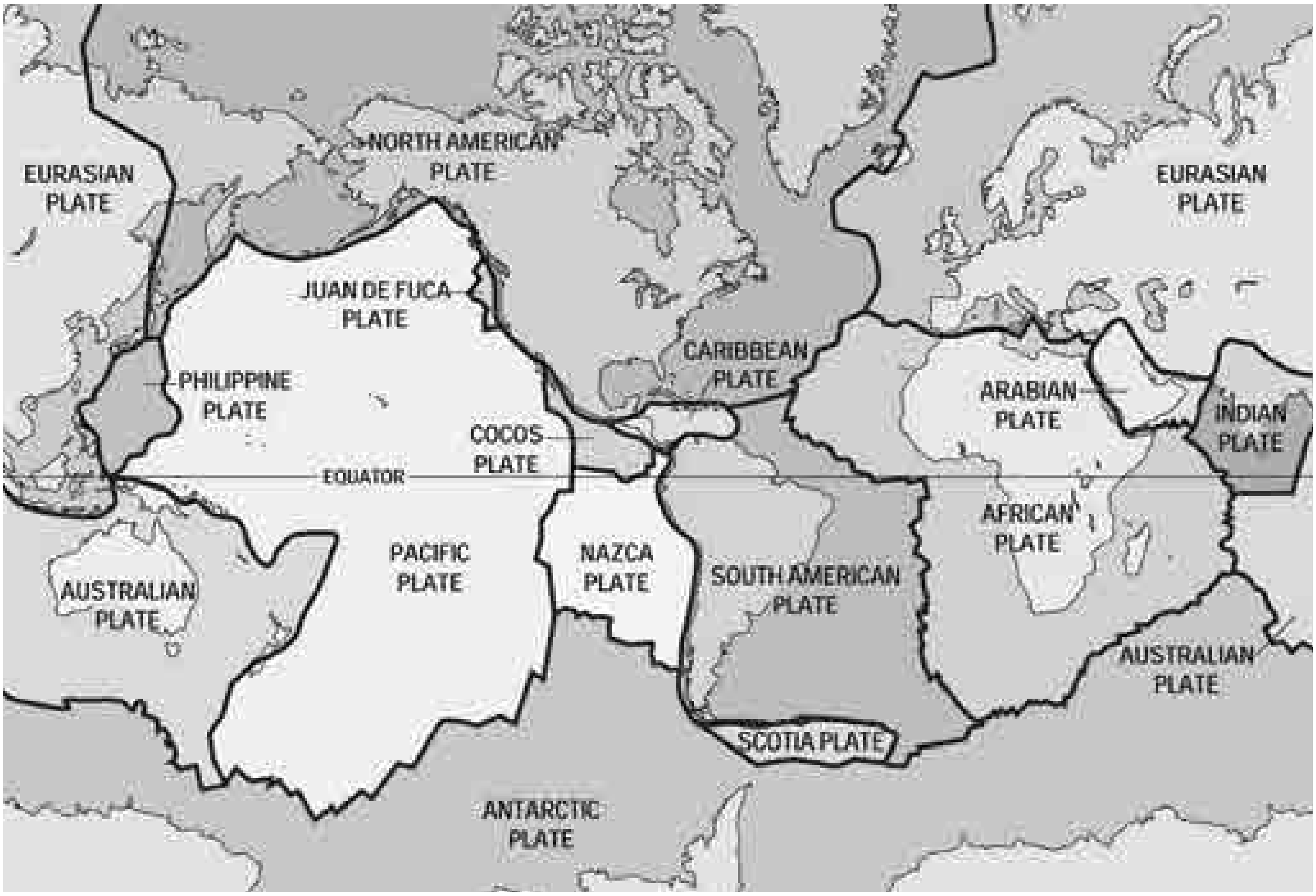

Fig. 5. According to Plate Tectonics, the Lithosphere of the Earth is divided into seven large plates and numerous small plates.

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plate tectonics in the Earth's outer shell commenced earlier than 3000 Myr ago.

The most important development in Earth sciences since the advent of plate tectonics is the discovery that the history of the Earth has been interposed by the development of supercontinents. A **supercontinent** is produced by the gathering or clustering of most or all of Earth's continental blocks, resulting in a single large landmass. During the history of the Earth, these supercontinents subsequently fragmented and the resulting continental blocks drifted apart to produce a new global geography. We know that the spatial disposition of the continents of today is really only a temporary arrangement in a long history of lithospheric plate movement. During the Precambrian Era, **Ur** was a supercontinent that formed somewhere around 3100 Myr ago. **Columbia** was another one formed between 2500 Myr and 1600 Myr ago, and **Rodinia** was yet another supercontinent that existed between about 1000 Myr and 750 Myr ago. **Pannotia** was a supercontinent that existed at the end of the Precambrian somewhere around 650 Myr ago. **Pangaea** – yet another supercontinent that existed about 300 Myr, started to split about 280 Myr to 230 myr (refer **Fig. 6**).

The last known supercontinent, called **Gondwana**, was comprised of what are now Africa, India, Madagascar, Australia and Antarctica (refer **Fig. 7**). Numerous studies have indicated that the formation and disruption of supercontinents during different portions of Earth's history, known as the **supercontinent cycle**, has profoundly influenced the evolutionary course of the lithosphere, hydrosphere, atmosphere and biosphere.

Phanerozoic eon

The name Phanerozoic was derived from the ancient Greek words phanerós and zoe, meaning **visible life.** This is based on the once-held understanding that life began in the Cambrian period of this eon. This eon is characterised by the appearance of organisms with hard parts (that are capable of preservation as fossils in contrast with the traces and chemical fossils left from organisms in earlier times). The Phanerozoic Eon is divided into three eras.

(a) Paleozoic Era: This is the earliest and the longest era of the Phanerozoic eon, covering a period of about 288 Myr. This era is further subdivided into six geologic periods – known as the

Fig. 6. Pangea – one of the many supercontinents formed during the Earth's changing geography.

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Cambrian, Ordovician, Silurian, Devonian, Carboniferous and **Permian** periods in decreasing order of age.

The beginning of the Palaeozoic Era is defined by the appearance of the first skeletal or shelly fauna — the first animals with hard parts. The atmospheric CO_2 levels were ten times higher in the early Paleozoic. The sea level was much higher than today, and was reduced to modern levels by the end of the era. Between 450 Myr and 420 Myr, the Earth was swept by the third ice age — evident through the glacial deposits of different periods now preserved in rock records. Following this, shallow seas flooded continental interiors. Earlier forests were dominated with the **lycopsid** group of plants; woody plants evolved somewhere around 420 Myr ago. The accumulations of these plants and their later transformation is what gave rise to the coal deposits that are now found in many parts of the world (refer **Fig. 8**).

Fossil records indicate that with the beginning of this era, organisms with mineralized hard parts, which were capable of preservation in rocks during fossilization, first appeared in the oceans. These, then, suddenly became very numerous. The earliest fossils of this era consist mostly of trilobites, brachiopods, reef-forming archaeocyathids, and small little marine shells (refer **Fig. 9**). As discussed earlier, the rapid radiation and diversification of life-forms, probably from a common ancestor, during the 540–520 Myr interval in the Cambrian Period is known as the Cambrian Explosion. All known phyla had appeared by then. This produced the first representatives of almost all modern marine invertebrate animal groups. Because there was no vegetation, most of the land surface of the continents, which were clustered in the Southern Hemisphere at this time, was probably dry, rocky or blanketed with a microbial soil crust. The period about 440 Myr ago was marked by an extinction in which nearly 86% of all species of some groups of organisms disappeared from the Earth. This is known as **Ordovician-Silurian Extinction Event**.

It was during this era that the Appalachian, Ural, and mountains of Mongolia were formed by the collision of lithospheric plates. Towards the end of this era, the first modern plants (conifers) appeared on Earth, and molluscs and arthropods dominated the oceans. The appearance of vertebrate animals is one of the notable events of this era.

TRIASSIC-200 million years ago

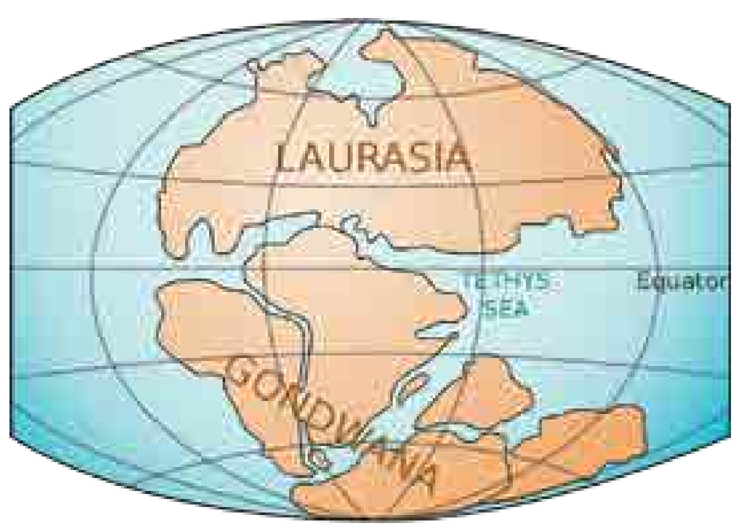

Fig. 7. Gondwana – the last known supercontinent in the Earth's history.

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Fig. 8. **Lycopods (like club mosses) are some of the oldest living vascular plants.**

In the period between 415 Myr and 355 Myr ago, fishes of many different types appeared in the oceans. Lobe-finned fishes – ancestors to the amphibians and the early sharks – made their appearance in this period. This period of the history of the Earth is therefore called the **Age of Fishes.** The appearance of fishes led to extinction of about 75% of the species of some primitive groups of marine organisms, including trilobites.

The Earth witnessed a fourth ice age between 360 Myr and 260 Myr ago. A major mass extinction that occurred at about 250 Myr seriously affected nearly 95% of the species living at that time, including tabulate corals, and most extant trees. Described as the **Great Dying**, this resulted in the disappearance of many earlier forms of animals and plants from the Earth.

(b) Mesozoic Era: This era included three periods – **Triassic, Jurassic** and **Cretaceous** – in deceasing order of their age. The Mesozoic era began 252.2 Myr ago, and lasted for another 186.2 Myr. The continents of today began to move into their present locations during the later stages of this era. The ancestors of major plant and animal groups that exist today evolved during this portion of Earth's history. Called the **age of reptiles**, it is in this era that dinosaurs began to appear, roughly 20 Myr after the major extinction event that wiped out almost all life on Earth 250 Myr ago. Terrestrial life diversified rapidly, and giant reptiles, dinosaurs and other monstrous beasts roamed the Earth till the end of this era. Another major mass extinction occurred at about 200 Myr ago, when about 20% of marine families and many terrestrial vertebrates vanished from the Earth. It is believed that an asteroid with a diameter of about 10km hit the Earth and caused another major mass extinction at the end of this era. This resulted in the extinction of the dinosaurs and several other terrestrial animal groups (refer **Fig. 10**). In the marine world, all the ammonites, reef-building bivalves, and marine reptile species also died off.

(c) Cenozoic Era: the era of new life: This era covers the last 66 Myr period. In this era, a drying and cooling trend culminated in the last known ice age –

Fig. 9. **Fossils of Trilobites (a), Brachiopods (b) and Archaeocyathids (c) from the Palaeozoic era.**

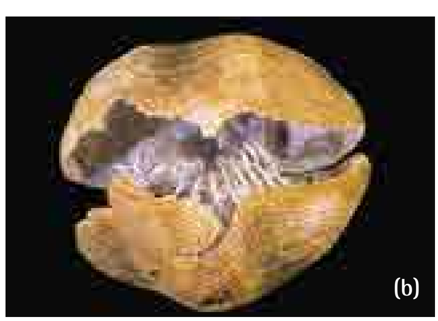

Fig. 10. Dinosaurs appeared in the Mesozoic Era.

known as the **Quaternary Glaciation**, which began 2.58 Myr ago. The polar ice caps and continental ice sheets of the northern hemisphere began to expand as far as 40 degrees latitude, and thickened repeatedly in North and South America, Europe, Asia, and Antarctica. At the peak of this ice age, nearly 30% of the Earth's surface was covered by glacial ice. The major consequence of glaciation was a world-wide drop in the mean sea level. The extinction of the dinosaurs towards the close of Mesozoic Era allowed mammals to diversify, with many becoming larger in size during the Cenozoic. As large mammals (such as mammoths, mastodons and several others), birds (including large flightless ones) and flowering plants formed the major groups of organisms in regions not covered by ice, this era is described both as **Age of Mammals** and the **Age of Birds** (refer **Fig. 11**).

Most of these animals became extinct during the Quaternary extinction event, at the end of the glacial period, about 11,700 years ago. Most scientists believe that all the modern humans alive today have descended from a small population which lived in Africa 150,000 to 200,000 years ago. Later, about around 100,000 years ago, modern humans migrated to Europe and Asia. The Indian subcontinent collided with Eurasia to form the Himalayas. The collision of Africa and Europe resulted in the Alps.

Early humans first appeared in Africa and migrated into Asia, probably between 2 million and 1.8 Myr. Species of modern humans populated many parts of the world much later. The beginnings of agriculture and the rise of the first civilizations occurred within the past 12,000 years. The term **Anthropocene** is often used as an informal term to describe the current geological period in which we are living. The significance of this term is that for the first time in the history of the planet, human activity is influencing planetary conditions — experienced in the form of climate change, sea-level rise, mounting environmental degradation, and air and water pollution.

From this very brief summary of the Earth we know that the lithosphere, atmosphere, hydrosphere and the biosphere of our planet are constantly changing. And the effects of these changes are likely to manifest themselves over long periods of time, involving millions of years. These processes will definitely continue to influence our future and the future of all other life on Earth.

Fig. 11. The Cenozoic Era was characterized by mammals (like the woolly mammoths, equids, woolly rhinoceros, European cave lions and the reindeer carcass shown in this image) that diversified and became larger in size.

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S. Mohana Kumar is a native of Thiruvananthapuram, Kerala. After obtaining an M.Sc in Geology in 1965, he worked as an educator from 1969-2001 in colleges under the Directorate of Collegiate Education, Kerala, and retired as Principal, Government College, Nedumangad. He can be contacted at one234ten@gmail.com.