

Schematic global oceanic thermohaline circulation. Blue lines are deep coldwater flow; red lines are warmer surface flow. Source: IPCC

with high-latitude processes that altered the temperature/salinity of deep water mass. Woodard et al. (2013) found that before the intensification of northern hemisphere glaciers, the North Pacific deep waters were substantially colder (4°C) and probably fresher than the North Atlantic Deep Water. Based on analysis of reconstructed bottom water temperature they suggested that at ~2.73 million years ago the Atlantic-Pacific temperature gradient was reduced to <1°C, suggesting the initiation of stronger heat transfer from the North Atlantic to the deep Pacific. The authors have attributed the enhanced interhemispheric heat and salt transport to increased glaciation of Antarctica and, which caused global climate change at that time by contributing to the intensification of northern hemisphere glaciers. Thus ocean can play critical role in climate change.

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## A Brief History of Earth

### History

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According to the current scientific consensus, universe formed 15 bya (billion years ago), which is 1500 Crore years ago, in the so-called “big bang hypothesis.” Sun and the solar system including Earth formed 4.567 bya, which is 456 Crore years ago. According to Vedas, age of earth is 1.97 billion years (precisely 197,29,49,116 years, in year 2015), which is much closer to the current understanding rather than 6019 years, as calculated by 17th Century Vice Chancellor of University of Cambridge, John Lightfoot [1]. Soon after the earth formed, a giant Mars-sized body “Theia” collided with our planet in so-called “giant impact hypothesis” (4 bya) ejecting a huge mass of earth to the space, that resulted in a giant crater on

this planet, which would soon turn out to be the Pacific Ocean, and ejected mass became moon [2].

Evolutionary history of Earth is gauged by evolutionary or geologic time scale (Fig. 1). The scale is divided into four major eons (each eon is 1 billion years or more); Hadean, Archean, Proterozoic and Phanerozoic. Earliest eon is Hadean, which begun with the formation of the earth and lasted till about 3.8 bya. Early molten earth was cooled down, and precipitation resulted in the formation of oceans. It is thought that during this period the first RNA (Ribonucleic Acid) molecules formed, that later turned out to be self-replicating (able to make copies of itself) to form the so-called “RNA World.” About 3.9 bya earth and moon was pounded with heavy bombardment by meteorites (lunar cataclysm) -that resulted in craters in moon as we can see today on the lunar surface and numerous craters (almost 20,000 of them!) on our planet.

Archean eon began 3.8 bya and lasted till 2.5 bya. Life originated (abiogenesis) around 3.8 -3.4 bya, with first organisms believed to be chemoautotrophic bacteria- that fix carbon dioxide with energy derived from oxidization of inorganic chemicals. During this eon, the earth was a bacterial world- when the first cells evolved to prokaryotes, and first cyanobacteria formed through endosymbiosis of one bacteria with another. Cyanobacteria started the photosynthesis, resulting in enrichment of oxygen in the atmosphere, evolution of aerobic bacteria, and the formation of the Ozone layer. Cyanobacterial biofilms formed in rocky intertidal habitats, and these turned out to be “stromatolites”- some of the oldest fossils.

Proterozoic eon began 2.5 bya with a major global glaciation event called Huronian. As the temperature rose, glaciers melted and first eukaryotes (green algae) appeared around 1.8 bya, colonial eukaryotes appeared 1.2 bya, dinoflagellates (1.1 bya) and protozoa 750 mya (million years ago). Second global glaciation (snowball earth) happened around 630 mya that would soon melt, when some of the complex multicellular eukaryotes of “Ediacaran” evolved around 580 mya. Soon, the most magnificent event in the history of life on planet would begin, the so-called “Cambrian explosion”, when most of the diversity of life on oceans formed, that included fungi, ctenophora (comb jellies), porifera (sponges), crustaceans (marine arthropods), and mollusks. This event was so profound that evolutionary biologists group entire history of the earth till this time as “pre-Cambrian” [3].

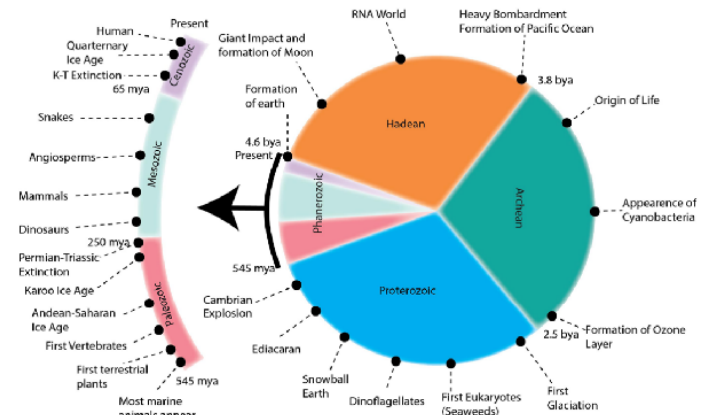


Fig. 1. Evolutionary time scale. Source: Felix Bast © 2014 Creative Commons Attribution-ShareAlike 2.5 India License.

The current eon Phanerozoic began 545 mya (5.4 Crore years ago). Because of the excellent fossil evidence, this eon is divided into three era (each era is around 150 million years or more); Paleozoic, Mesozoic and Cenozoic. Each era is in turn divided into periods, each period into epochs, and each epoch into ages; for the sake of brevity only up to the era is introduced in this manuscript. Paleozoic era began 545 mya and lasted till 250 mya. It was during Paleozoic era that oceanic biodiversity vastly expanded to have first chordates, echinoderms (that include starfish), forams and radiolarians (protists) around 535 mya. Terrestrial plants formed from intertidal seaweeds around 530 mya. First vertebrate animals (jawless fishes) appeared 485 mya. A minor ice age called Andean-Saharan occurred around 450 mya. In ocean, great diversification of animal phyla continued resulting in ray-finned fishes and crabs. In land, ferns, gymnosperms, beetles, crabs, scorpions, amphibians, reptiles, scorpions, etc. appear. However, a glaciation event (Karoo Ice Age), that would soon transcend to a major extinction event that happened around 250 mya, Permian-Triassic extinction, wipes out around 90% of marine life, marking the end of Paleozoic era.

Mesozoic era began 250 mya and lasted till 68 mya. It was during this era that the first dinosaurs (225 mya), mammals (215 mya), angiosperms (130 mya), snakes and ants (80 mya) appeared. The supercontinent Pangaea was later split into Laurasia and Gondwana (200 mya). The name Gondwana is derived from Sanskrit "Gondavana"-Forest of Gonds, which is located in Central-Northern India. Laurasia split to Laurentia (present day North America) and Eurasia, forming Northern Atlantic Ocean (100 mya). South Atlantic Ocean and Indian Ocean formed when supercontinent Gondwana split into present day continents of Antarctica and Africa (100 mya). Indian subcontinent began north-eastward drift after breaking away from Africa (75 mya) and collided with Eurasia plate (50 mya) resulting in the formation of Alpine Orogeny (mountain ranges including Alps and Himalayas). Australia broke away from East Antarctica around 80 mya.

The current era Cenozoic began 65 mya with a mass extinction event called K-T (cretaceous-tertiary) that wiped out all of the dinosaurs. Modern birds, whales, rodents, and rabbits appeared around 55 mya. Soon bats (52 mya), butterflies (40 mya), pigs and cats (30 mya), deers (25 mya), giraffes (20 mya), mammoths (15 mya) and wolves (10 mya) would appear. South America broke away from West Antarctica (30 mya). Laccadives formed around 36 mya and Andaman & Nicobar Islands formed around 26 mya. Japan broke away from Eurasian plate and started moving eastward (15 mya), that opened up Sea of Japan. First hominin (common ancestor for humans and chimpanzees) appeared around 6.5 mya. Isthmus of Panama formed around 3 mya that separated Atlantic and Pacific Oceans. Last ice age (Quaternary glaciation) occurred around 2.5 mya. Our genus Homo appeared around 2 mya, and modern humans (Homo sapiens) around 200,000 years ago in Africa. Humans would soon start expanding, first from Africa to Eurasia (60,000 years ago), subsequently to Australia through South-East Asian Land Bridges (45,000 years ago) and later to Americas through Bering Land Bridge (12,000 years ago) –that is now Bering Strait between Eastern Russia and Western Alaska [4]. As per a number of reports, the Earth is currently moving towards the sixth major extinction event caused exclusively by the human impact on environment, abbreviated as

HIPPO (Habitat destruction, Invasive species, Pollution, Human Over-Population and Overharvesting). The scientific consensus is that the climate change is in large part caused by human activities and is largely irreversible. Solar luminosity will be augmented by 10% in about 1 billion years, that will result in evaporation of oceans to cause "moist greenhouse" effect, increasing the surface temperature by several fold. By then the entire life on earth will either become extinct, or we will colonize another suitable planet. The earth's ultimate fate would be absorption into the red giant sun- in about 7 billion years.

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## Plate tectonic reconstruction of India and Madagascar closing through the Mascarene Basin

### Student Article

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The Indian Ocean (Fig. 1) was created by fragmentation and dispersal of a continental assemblage, Gondwanaland. In this context, the western continental margin of India and the adjacent ocean basins were evolved by rifting and subsequent drifting of India first from Madagascar, creating the Mascarene Basin, and then from Seychelles, creating the conjugate Arabian and Eastern Somali basins. Since the hydrocarbon occurrence in passive continental margins is closely associated with its spatio-temporal evolution, plate tectonic reconstructions of these margins and adjacent oceanic basins are found to be very useful to provide important constraints on conceptual evolution of hydrocarbons.

The plate tectonic reconstruction of western continental margin of India with its conjugate region of Madagascar has been directly addressed or indirectly depicted in a number of earlier studies. However the proposed relative configurations of India with Madagascar in their pre-drift tectonic scenario vary in different models. The formation of Indian Ocean is associated with Indian Plate (IND), African Plate (AFR) and Antarctic Plate (ANT) to cite the major plates (Fig. 1). Therefore, the India-Madagascar (IND-MAD) reconstruction can be achieved by considering different plate circuits - either by considering movement of IND directly to AFR (closing the Arabian, Eastern Somali and Mascarene basins) or by a combination of movements of IND to ANT (closing Central Indian and Crozet basins) and then IND-ANT