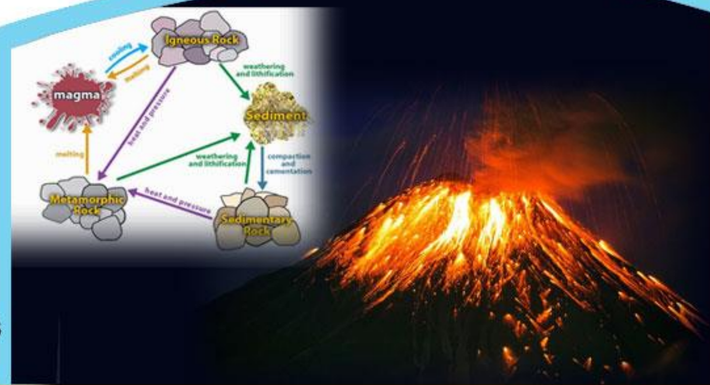
A Gateway to all Post Graduate Courses

MHRD Govt. of India

An MHRD Project under its National Mission on Education thought ICT (NME-ICT)

Subject: Environmental Sciences



Production of Coursework

- Content for Post-Graduate Courses

Paper No: 4 Environmental Geology

Module: 38 NATURAL HAZARDS AND DISASTERS

A Gateway to all Post Graduate Courses

MHRD Govt. of India

Development Team

Principal Investigator & Co- Principal Investigator	Prof. R.K. Kohli Prof. V.K. Garg & Prof. Ashok Dhawan Central University of Punjab, Bathinda
Paper Coordinator	Dr. R. Bhaskar, Guru Jambheshwar Uni. of Sci & Technology, Hisar
Content Writer	Dr. Sushmitha Baskar SOITS, IGNOU, New Delhi
Content Reviewer	Prof Tanu Jindal Amity University, Noida
Anchor Institute	Central University of Punjab

Description of Module	
Subject Name	**Environmental Sciences**
Paper Name	Environmental Geology
Module Name/Title	**NATURAL HAZARDS AND DISASTERS**
Module Id	EVS/EG-IV/38
Pre-requisites	
Objectives	After reading this unit, you should be able to: • define the term natural hazards and disaster; • explain the types of natural hazards and their effects; and • list the measures for hazard mitigation.
Keywords	Hazrad, Disaster, Natural Hazards, Chronic Hazards, Earthquake, Landslide, Forest fires, Floods, Cyclones

UNIT 38: NATURAL HAZARDS AND DISASTER

Structure

1.0 OBJECTIVE

After reading this unit, you should be able to:

- define the term natural hazards and disaster;
- explain the types of natural hazards and their effects; and
- list the measures for hazard mitigation.

1.1 INTRODUCTION

Hazards originate from the interplay of physical, biological and social systems. India is prone to natural disasters such as earthquakes, floods, cyclones and droughts. Environmental degradation is accelerating the vulnerability to natural disasters. Some major natural hazards that India as experienced include: the Kashmir floods in 2014, the Uttarakhand flash floods in 2013, the Indian Ocean Tsunami in 2004, the Bhuj earthquake in Gujarat in 2001, the Odisha Super cyclone in 1999 and the earthquake in Latur, Maharashtra in 1993. These hazards are considered most hazardous and have lead to serious economic loss and loss of lives.

Our planet earth is an ever dynamic, evolving system with complex interactions of internal and external processes. The movement of plates, earthquakes, volcanic activities is due to the internal processes. Floods, hurricanes, tornadoes and droughts are caused as a result of external processes. The source of energy for the internal process is radioactivity, and the source of energy for the external process is the sun. Natural hazards can be extreme event can lead to several other disasters which can be hazardous. For example, earthquakes result in landslides and in the destruction of buildings. This in turn can contaminate water sources resulting in water borne diseases i.e. cholera outbreak after the 2010 Haiti earthquake.

1.2 DEFINITIONS: HAZARD AND DISASTER

Earth processes are natural events that occur within the lithosphere, hydrosphere or atmosphere. They become hazardous only when they affect life or property. These life or property threatening processes is called natural hazards. For example the earthquake that occurred in Kobe, Japan in 1995 witnessed 5000 deaths and 200 billion dollars loss. This was a deadly earthquake and costly in a developed country. Human activities play an important role in how severe a hazard can be.

Hazard: A hazard can be defined as: "*The elements of the physical environment, harmful to man and are caused by forces extraneous to him*" (Burton et al. 1978). A hazard has the potential to cause harm to: people, human activity, property and the environment.

Disaster: A disaster is the realization of the hazard.

Hazard Event: They are physical parameters of the hazards which cause harm to humans and society. Environmental events can become hazards when they cause adverse effects to the society and the environment. Volcanic eruptions mostly do not cause harm to humans. Hence it is termed a natural phenomenon. Such natural phenomenon events that occur in a populated region are referred to as hazardous events.

Natural disaster: A Hazard event that causes a very large number of fatalities and damage to property is known as a natural disaster. In order to understand natural hazards and to predict and prepare ourselves for the same let us now learn in detail about the dimensions of a hazard and hazard classification.

1.3 DIMENSIONS OF HAZARD

In order to understand the impact of a hazard; the magnitude, the frequency and the intensity at the impact point is of importance. Further, some other factors like climate, geology, vegetation, population and land use is equally important. Most hazards have return periods on a human time-scale. For example, there are five-year floods, fifty-year floods etc. This gives an estimate of how often the hazard event of a given magnitude and intensity will reoccur.

1.4 CLASSIFICATION OF NATURAL HAZARDS

Natural hazards can be classified as: geological, hydrological, meteorological and biological hazards.

1.4.1 Natural Hazards

(a) Geological

Geological hazards are caused due to earth processes. Earthquakes, volcanic eruptions, landslides, avalanches, subsidence, and impacts with space objects are some examples of geological hazards. Among all these, earthquakes release maximum energy in a short duration. Earthquakes cause large scale loss of life and property and disrupt most essential services such as water supply, communication, power and transport.

(b) Hydrological

The natural hazards that are triggered exclusively by hydrological extreme-event phenomena of nature are called “hydrological hazards” or simply “water hazard. They include floods, droughts, mudslides and tsunamis. Among these floods are the most frequent and cause damage to life and property.

(c) Meteorological

Meteorological hazards are those hazards caused due to weather/ metereological processes. They include: cyclones, hurricanes, tornadoes, droughts, lightening thunderstorms, heavy rain and flooding, heatwaves and bushfires. A number of other hazards such as hail, flooding or wind can also occur as a result of more than one of these meteorological phenomena.

The above hazards are primary hazards. Natural Hazards can also be termed as catastrophic hazards when they have devastating consequences to large numbers of people.

(d) Biological Hazards

Biological hazards are caused by biological agents. They include disease infestations such as the outbreak of bubonic plague in the 1300s which killed 100 million people, and the 1918 "Spanish" flu pandemic. Epidemic is defined as the occurrence of an illness or other health catastrophes which affect large number of people. Epidemic outbreaks of communicable diseases are potentially high after a disaster. It may be due to poor environmental conditions leading to water contamination and subsequent breeding of the disease vectors. Epidemics cause mass illness and/or death. Epidemics may be the consequence of primary disasters such as cyclones, floods, earthquakes etc. Epidemics can also affect animals leading to economic disasters.

The vulnerability is high among those who are poorly nourished, people living in unhygienic in sanitary conditions, poor quality of water supply, lack of access to health services. Some examples of biological hazards include Dengue, Avian flu, Swine flu, Cholera, Chikungunya and Bubonic plague.

Dengue

This is an example of a biological disaster caused by a virus transmitted through the mosquito *Aedes aegypti*. It is also known as Break bone fever or Dandy fever. It is an acute, infectious, mosquito-borne hemorrhagic fever. It is also characterized by an extreme pain and stiffness of the joints. Dengue fever is rarely fatal but can result in death if left untreated. Presently, no vaccine is available. The Epidemic control measures such as mosquito destruction, elimination of breeding sites and the use of mosquito repellents by exposed persons are some effective measures to prevent the spread of the disease.

1.4.2 Secondary hazards: They occur as a result of other primary hazards. For example a primary hazard is the earthquake. Dam failures, building collapse, ruptured power and water lines, landslides, tsunami etc. are some types of secondary hazards that can result due to an earthquake.

1.4.3 Chronic hazards: These are referred to as chronic because they are a group of hazards that do not originate from one event. They occur due to continuous hazardous conditions such as pollution, toxic contamination that accumulate over time and so on.

Natural hazards can also further be classified into rapid onset hazards and slow onset hazards. Examples of rapid onset hazards include volcanic eruptions, earthquakes, floods, landslides, severe thunderstorms that strike rapidly. Examples of slow onset hazards include drought and disease epidemics that are slow and take years to form. Therefore the speed of onset of a hazard is an important factor. **Spatial dispersion** is the distribution pattern of a hazard over the geographic area where hazard can occur. **Temporal spacing** refers to the sequencing and seasonality of events. **Hazard scape** refers to the landscape of numerous hazards. These hazards affect people and the places they live in with the interaction on nature, society, and technology at a variety of spatial scales. This term is generally used in reference to a specific region. Every hazard has a different space and time characteristic (Table. 1.1; Navalgund, R.R. 2001).

Table 1.1 Hazards: Impact time and special extent

(Source: Navalgund, R.R. 2001)

Type	Impact time	Spatial extent
Earthquake	Seconds to minutes	102 – 104 sq.km
Landslide	Seconds	0.1 – ½ sq.km
Forest fires	Minutes to days	101 – 103 sq.km
Floods	Minutes to hours	105 – 107sq.km
Cyclones	Few hours	103 – 104 sq.km

India has been affected by many natural hazards which resulted in the loss of many lives and property. The decade (1990-99) was the International Decade for Natural Disaster Reduction (1990-99).

1.4.4 Man-made hazards

These hazards are also referred to as technological hazards. They include: exposure to hazardous substances, such as radon, mercury, asbestos fibres, acid rain or contaminated waters. They also include chemical disasters and fires.

(a) Chemical Disasters

Industrial disasters are an example of man-made disasters. There was an increase in the growth of the chemical industry after the Second World War. This led to a number of chemical disasters. In these disasters there are uncontrolled events involving fires, explosions or releases of toxic substances that result in the death/ injury of people and extensive environmental and economic damage. In India, the Bhopal gas tragedy that occurred in Bhopal, 1984 was a major worst chemical disaster.

(b) Slow-Onset Disasters

This type occurs when humans are exposed to environmental toxic substances released due to man-made pollution activities. An example is the “Minamata disease”. A factory discharged its effluent containing inorganic mercury into Minamata Bay, Japan. The bacteria converted this into organic methyl mercury which was consumed by the fishes in the bay. In 1953 it was observed that the fishes in the bay were lethargic and the humans who had consumed these fishes had unusual neurological disorders. The disease was named kibyo, the "mystery illness". The victims complained with polyneuritis, cerebellar ataxia, cortical blindness which was due to mercury poisoning.

(c) Fires

Fires can cause environmental pollution and are a threat to human life, property and wild life. They can spread rapidly and cause extensive damage in a short time. Man-made causes of fires include: trashing burning matchsticks, during cooking from LPG gas or kerosene, short circuits in electrical wirings, forest fires and during transportation of inflammable material or explosive chemicals.

These are some types of man-made disasters.

SAQ1

1. Define hazard and disaster.
2. How are hazards classified?

CASE STUDY OF KASHMIR FLOODS, 2014

The Kashmir valley is prone to floods basically due to geological reasons: the structure, location, hydrographic features and the drainage characteristics of the Jhelum river. Jammu and Kashmir experienced extreme and heavy rains during the first week of September 2014. It was a major flood as the city was submerged under 18 feet water for more than three weeks that crippled the residents of Srinagar. The flood washed away crops, fruit orchards and damaged houses and business establishments. All major hospitals were inundated; electricity and communication links were disrupted. It was the worst disaster recorded in over fifty years that left 280 people dead. The underlying causes of this heavy rain were due to the western disturbances and their interaction with monsoon rains. An analysis by Centre for Science and

Environment (CSE), New Delhi reports that, the floods were a combination of an intense and unprecedented rainfall event combined with mismanagement of drainage and unplanned urbanization and lack of preparedness by the state. Jammu and Kashmir has been exacerbated by unplanned development, especially on the riverbanks. The report also says that, in the last 100 years, more than 50 percent of the lakes and wetlands have been encroached for construction purposes. Similar construction activities on the banks of the Jhelum river have reduced the river's drainage capacity. Jammu and Kashmir does not have a flood forecasting system and its disaster management system is also rudimentary. The past decade has witnessed several extreme rainfall events that have devastated India. The restoration of wetlands, removal of encroachments in the flood spill channels, amendments to the existing land use policy and building codes should be implemented for reducing loss to life and property.

Source: Centre for Science and Environment (CSE), New Delhi

1.5 Effects of Hazards

Natural hazards cause a number of primary, secondary and tertiary effects. The severity of the secondary effects produced varies with the type of event. Tropical cyclones bring strong winds and heavy rains which cause secondary hazards such as flood, storm tide, landslides and water pollution. Flood inundates areas, which in turn may lead to landslide, erosion, water quality deterioration or turbidity, as well as sediment deposition. Earthquakes may also bring fire, flood, water pollution, landslide, tsunami and soil liquefaction, which can be as devastating as the primary hazard.

Primary effects: These occur due to the process itself. Examples include: building collapse as a result of an earthquake or a landslide.

Secondary effects: These occur since a primary event has caused them. Examples include: fires ignited due to volcanic eruptions; power and water service disruptions due to earthquakes.

Tertiary effects: These are long term effects which are normally set off due to primary events. Some examples include: crop failures caused due to volcanic eruptions and loss of habitats due to severe floods.

1.6 Natural Service functions of natural hazards

Natural hazards also have some important natural service functions for the biosphere and people. For example, volcanic activities have been responsible for producing the hydrosphere and the atmosphere. Soil is replenished as a result of floods and landslides. Further, in rivers water flows over the riverbanks and the floodplain. So water and nutrients are stored on the floodplain and the floodplain has nutrient rich soils. Therefore the physical processes linked to the biological environment produce varied landscapes. It is only because of the disturbances from natural processes, such as earthquakes, floods and so on there is water availability and the soils are fertile.

1.7 Vulnerability

Vulnerability refers to not only the possible physical effects of a natural hazard, but the way it can affect the human life and to property. Vulnerability to natural hazards depends on a number of factors. They include the following:

- Proximity to a possible hazardous event
- Population density, construction styles and building codes
- Understanding and awareness of the nature of the hazard
- Early-warning systems, lines of communication and emergency infrastructure

Generally, developing nations are more vulnerable to natural hazards than the developed ones. This is because of lack of understanding, education, infrastructure, and poor building codes.

1.8 Natural hazards and human intervention

Human beings can do nothing about the incidence or intensity of most natural phenomena. They can however help in changing their behavior and action to the environment, so that natural events do not turn into disasters. Human intervention can increase the frequency natural hazards. For example, when the toe of a landslide is removed for a settlement, there can be disasters. This is human-induced.

Volcanic eruptions occur periodically. But when the fertile soils formed on their surface are occupied by humans for farms, they can be hazardous. Therefore, human intervention in such natural processes can increases vulnerability by the following:

1. Development and habitation of lands susceptible to hazards
2. Human interventions reduce the mitigating effect of natural ecosystems. The destruction of coral reefs, (which protects from storm surge and ocean currents) cause disturbances to the natural coastal ecosystem.

1.9 Assessing Hazards

Hazard Assessment is also known as Hazard Evaluation or Hazard Analysis (UNDRO, 1991). It is the process of estimating the probabilities of the occurrence of a disaster of a given magnitude within a specified period of time. The probability of a hazard occurrence differs from each place. The use of mapping to understand natural hazards data improves to network among people in the hazard management process and between planners and decision-makers. Hazard assessment process consists of answering the different hazardous processes that have occurred in the past, the magnitude and frequency of the past hazardous processes and the socio-economic impacts of a hazardous event. It also involves the analyses of locations, buildings and highways that are subject to hazards. The above information is collected and presented to the concerned public officials, scientists and decision makers for making decisions and mitigation steps in event of a disaster.

1.10 National and International Attention: Hazard Mitigation

The year 1990's was designated as the International Decade for Natural Disaster Reduction (IDNDR) by the United Nations with primary goal to reduce the loss of life, property, socio-economic disruption caused by natural disasters. Within this context the IDNDR advised the UN-member states to establish National Platforms which would facilitate the adjustment of general disaster risk reduction objectives to national/local conditions implement the agreed policies and expand the understanding and perception of the importance of disaster risk reduction on national levels. The (international strategy for disaster reduction) ISDR aims to push the initiatives and cooperation agreed on during the IDNDR, and developing new mechanisms as well as ensuring for further commitments from policy-makers.

The ultimate goal is to reduce human, social, economic and environmental losses due to natural hazards.

The Yokohama conference, 1994 underlined the need for shift in the strategy for disaster mitigation. In this conference, it was stressed that disaster prevention, mitigation, preparedness and relief are fundamental to sustainable development policies. Hence all nations should incorporate disaster management in their development plans and ensure follow up measures at the national and international levels. The Yokohama conference also discussed that disaster prevention, mitigation and preparedness are essential to integrated disaster management. The Government of India has adopted mitigation and prevention as essential components of their development strategy. The Tenth Five Year Plan has a detailed chapter on Disaster Management. This plan emphasizes that development cannot be sustainable without mitigation institutionalized into developmental process.

Hazards are an integral part of life and no one can live in an environment totally free of hazards and disasters. Each hazard varies in dimensions and assessing hazards is the first important step for adopting the strategies. Policies play an important role in influencing the impact of natural disasters, in emergency management, land use planning and construction standards.

SAQ 2

1. Explain the effects of hazards.
2. Describe vulnerability and human intervention.

1.11 Summary

In this unit we have studied about natural hazards and disasters, their types, effects, impacts, vulnerability, human intervention and an overview of assessing hazards. By understanding the consequences of hazards and disasters we increase our awareness and help protect communities, infrastructure and our economy. Natural hazards will continue, but with scientific understanding and effective preparedness, the devastation can be reduced to a great extent. Further, past events are learning strategies and with innovative research and technology we can build more resilient and safer communities on our planet.

1.12 Key words

Hazard: It can be defined as a potential threat to humans and their welfare and risk as the probability of hazard occurrence.

Disaster: It can be defined as the realization of the hazard.

1.13 References and Suggested further readings

Baskar, S and Baskar, R. 2009. Natural Disasters. Unicorn books, Pustak Mahal, India. 159p.

Bryant, E. 2005. Natural Hazards. 2nd Edition, Cambridge university press, 330p.

Burton, I. And Kates, R.W. (1964). The perception of natural hazards in resource management, Natural Resources Journal 3, 412-41.

Burton, I., Kates, R.W., and White, G.F. (1978) The Environment as Hazard New York: Oxford University Press.

Hewitt, K. and Burton, I. (1971). The Hazardousness of a Place: A Regional Ecology of Damage Events, University of Toronto.

Keller, E.A. 2010. Environmental Geology, 9th Edition, Pearson publication, 624 p.

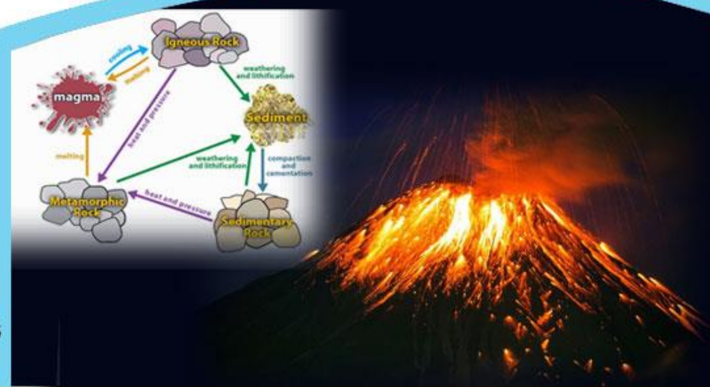
United Nations Disaster Relief Organization. (1991). Mitigating Natural Disasters: Phenomena, Effects and Options: A Manual for Policy makers and Planners. New York: United Nations.

e-Pathshala पाठशाला
A Gateway to all Post Graduate Courses
MHRD Govt. of India
An MHRD Project under its National Mission on Education thought ICT (NME-ICT)

Subject: Environmental Sciences

Production of Coursework

- Content for Post-Graduate Courses



Paper No: 4 Environmental Geology

Module: 01 Geological Time scale and Geological Processes

e-Pathshala पाठशाला
A Gateway to all Post Graduate Courses
MHRD Govt. of India

Development Team

Principal Investigator & Co- Principal Investigator	**Prof. R.K. Kohli** **Prof. V.K. Garg & Prof. Ashok Dhawan** **Central University of Punjab, Bathinda**
Paper Coordinator	**Dr. R. Baskar,** **Guru Jambheshwar Uni. of Sci & Technology, Hisar**
Content Writer	**Dr Gurmeet Kaur and Dr Shashi Kad , Panjab University, Chandigarh**
Content Reviewer	**Prof. Manoj Pandit, Rajasthan University, Jaipur**
Anchor Institute	**Central University of Punjab**

Description of Module	
Subject Name	**Environmental Sciences**
Paper Name	Environmental Geology
Module Name/Title	Geological time scale and geological processes
Module Id	EVS/EG-IV/01
Pre-requisites	Knowledge of basic geological fundamentals, terms like formation, igneous, metamorphic and sedimentary rocks, stratigraphy, palaeontology
Objectives	Understand the chronological story of Earth and how the processes shaped it.
Keywords	Eon, Era, Period, Internal heat, External process, plate tectonics

Module 1: Geological time scale and geologic processes

Objectives:

1. **Geological Time Scale**

   1.1 Why do we need a geological time scale and how the geological time scale evolved?

   1.2 Understanding the modern geological time scale and the basis of its divisions.

2. **Geological Processes**

   2.1. Geological processes and their role in understanding Earth

   2.2. Concept of Geological processes *vis-a-vis* Geological Time Scale

   2.3. Internal and External Geological Processes

Who knows for certain
Who shall here declare it
Whence was it born, whence came creation
The Gods are later than this world's formation
Who then can know the origins of the world
(The Rig Veda, X.129).

1. Geological Time Scale

1.1 **Why do we need a Geological time scale and how the Geological Time Scale evolved.**

Introduction: Our planet Earth, the only known habitable planet in the known Universe, continues to be a dynamic system. Just as we write and the reader reads, the internal and external physical, biological and chemical processes are continuously reshaping the Earth. Geological processes in general are very slow that we can hardly notice during our life span while some are abrupt and catastrophic. What we observe today on the surface of the Earth is a snapshot resulting from complex interplay of many internal processes, and by understanding these processes; the Geologists have extrapolated the information to reveal the story of the Earth from its inception.

Earth as a Jigsaw: How do we understand the story of the Earth? How do we fit these small pieces of this complex jigsaw puzzle to spatially and temporally validate our understanding of the processes today? The reader may appreciate that even to tell the story of the world for the last one hundred years; historians would often refer to the global events such as Pre-World War I, or post World War II or first oil crisis or second oil crisis. Some others may be familiar with the Facebook timeline where a person is choosing to tell his/her story in a reverse chronological way. Similarly, to tell the story of the Earth, geologists look for global events that can have significant relevance and presence across the planet.

Early work on Geological Time Scale: The initial studies that contributed to the understanding of the geological processes were limited in scope to a region or a field; to correlate and construct the story of the Earth has been a very formidable and complex task. It may be important to mention that from the time when interest in this subject appeared the age of the Earth was not known and information on natural processes was limited to unverified hypotheses. The early efforts to construct this story started in 1600's.

One of the earliest attempts to calculate the age of the Earth was 6000 years by Archbishop James Ussher mentioned in Genesis (Annals of the World, A.D. 1658)

Nicolaus Steno, a 17th century Danish scientist, pioneered the field of stratigraphy (study of strata). Contemporary geoscientists to date rely on the timeless principles viz., ***The principle of original horizontality*** and ***the principle of superposition,*** proposed by Steno to comprehend sedimentary rocks. **William Smith**, British surveyor, developed the concept of faunal succession. Smith's ***Principle of faunal succession*** on the basis of characteristic fossils in different strata helps in identifying strata of the same age in different outcrops at different locations.

Nicolaus Steno in 1667 found shark tooth while studying the sedimentary strata in Tuscany, what were then called “tongue stones” (Figure 1.1). The concept promoted by Nicolaus that these were remains of sharks left in the rock was not accepted at that time. William Smith, worked on understanding the distinct rock types with distinct fossils, that helped him create a sequence that he was able to validate in other parts of England as well. This stratigraphic sequencing was one of the earliest attempts at creating a geological order for assigning relative ages to the rock formations.

Figure1.1 Shark tooth drawings made by Nicolaus Steno (Source: Wikipedia)

Charles Darwin’s assumptions on age of the Earth was 6000 years, a common belief during that time, however based on some geology and his own work on natural selection he thought that the age of Earth could be several hundred million years, which was not what Lord Kelvin believed. Lord Kelvin’s work based on thermodynamics and Earth’s thermal gradient predicted a much younger age.

There were multiple geological evidence pouring in to support a backward revision in the age of the Earth.

At this stage a better understanding on deposition of sedimentary rocks was developed. While observing the then rate of deposition, estimates on time it may have taken to deposit a thick rock succession was made. As an example, the age of thickest sedimentary sequence such as Grand Canyon was placed at 100 Ma, which supported the theory that Earth is much older than the other estimates that were being made.

To simplify our understanding of the story of the Earth, geologists made attempts at the widest divisions of rock strata into eons, periods and epochs. One of the big events that kept shifting the boundary of these divisions was the presence and absence of life, and of simple and complex life.

Relative ages: Smith's and Steno's principles were applied to outcrops across the globe in the nineteenth century. Similar fossils from formations in different parts of the world were found. Fossil assemblages also matched up for these formations along with other cross cutting relationships. At the end of the century, the geologists could put a time scale together which was the first geologic time scale based on relative ages.

Absolute age: The story of absolute ages started when the radiometric dating began. Rutherford in 1905 deduced that radioactivity could be used to give an accurate and absolute age for a rock. This started the trend of isotopic dating that could provide absolute ages. However, till about 1953, the age of the Earth was nowhere close to what we know now.

Claire Patterson, American geochemist, calculated age of the Earth to be 4.55 billion years in the year 1956 and this age of earth calculated on the basis of geochronology has remained largely unchanged since then.

1.2. Understanding the Modern Geological Time Scale and the basis of its subdivisions:

Modern Geological Time Scale is a result of many centuries of work put together by geologists that includes understanding stratigraphic successions in the field and studying correlations to comprehend relative ages, and determining absolute ages using radiometric dating.

Intervals of Geologic Time

What is fundamental to the primary divisions of the Geological Time Scale is the presence or absence of fossils and/or distinct set of fossils. The end of a division and start of another demarcates a distinct presence or absence of a particular set of fossils. **Eon** is the longest subdivision of the Geologic time and two or more **Era'**s form an **Eon**. **Period** is the basic unit of Geologic time in which a typical set of rock unit is made, and is usually named after a locality or the distinguishing characteristics of the rocks reported. **Devonian,** as an example, is named after a locality in England and **Carboniferous** period for coal bearing sedimentary rocks. However, **Palaeogene** and **Neogene** are an exception and mean old and new respectively.

International Commission on Stratigraphy v 2016/04 (Figure 1.2) is an agreed upon and elaborate description of the Modern Geological Time Scale, which offers numerical age for each Eon, Era, Period, Epoch and Stage. This represents no finality as numerical ages are subject to further refinement etc.

Primary Divisions of the Geological Time Scale: To understand the Geological Time Scale, one can start with its broadest divisions called eons. There are four eons: Hadean, Archean, Proterozoic and Phanerozoic. The Geological Time Scale in its tabular form is presented in a reverse chronological scheme, with the most recent at the top. Hadean (4600 to 4000 Ma) is the oldest eon and is at the base while Phanerozoic the youngest at the top. **Hadean:** The term 'Hadean' comes from the Greek God of the underworld. This represents a time with absolutely no record of rocks present. One can say that Hadean eon represents those 600 million years of young earth about which we have no records available.

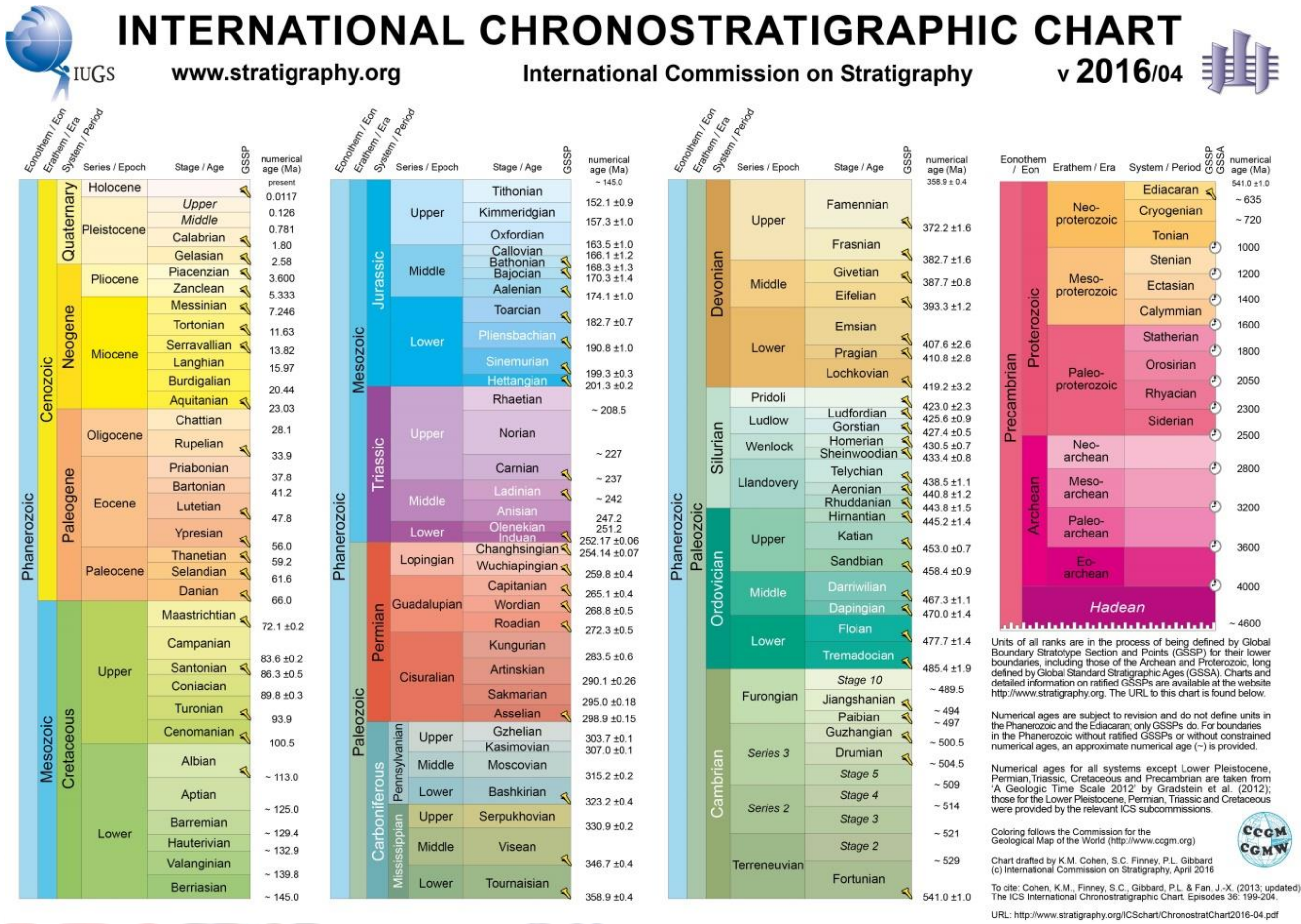


Figure 1.2 International Chronostratigraphic Chart (Source: International Commission on Stratigraphy)

Archean: Archean eon (4000 to 2500 Ma) was like a new chapter in Earth's history as the Earth is thought to have cooled off sufficiently to allow formation of continents during this eon. Readers may note during the earlier versions of Geological Time Scale that Archean was considered as the oldest (Greek meaning 'beginning). To envision the conditions during Archean is to see the planet as a time of high volcanic activity and so the surviving rocks of the eon are metamorphic and igneous. The readers must also note that owing to the long-time gap between the beginning and end of the period, there must have been considerable variation in the conditions of the Earth at the beginning of the eon and at its end. Archean is now divided into four era's, Eo-Archean, Palaeo-Archean, Meso-Archean and Neo-Archean.

Eo-Archean (4000 to 3600 Ma) is characterised by earliest crust and greenstone belts in certain shield areas. Palaeo-Archean is younger than Eo-Archean (3600 Ma to 3200 Ma), where the first evidence of fossils ever, dated at 3500 Ma and called stromatolites, were found in Western Australia.

The readers may note that newer scientific discoveries would continue to refine and alter our current understanding of the Geological Time Scale. One such recent discovery of stromatolites from Greenland has taken the stromatolite appearance to 3700 Ma (2016), in the Eo-Archean. Meso-Archean (3600 to 2800 Ma) is characterised by Banded Iron Formations, when oxygen levels on the planet were still low. Some of the earliest super continents formed during this time. Stromatolites diversified during Meso-Archean. Neo-Archean (2800 Ma to 2500 Ma) is when continents started to shape up and continued to fragment and assemble through various supercontinent cycles to acquire present day configuration.

Proterozoic, in Greek means "early life" and the Eon extends from 2500 Ma to 541 Ma; subdivided into three eras, namely Palaeo-Proterozoic (2500 to 1600), Meso-Proterozoic (1600-1000 Ma) and Neo-Proterozoic (1000-541).

Earth's atmosphere changed substantially in the Proterozoic, with increased oxygen levels, referred to as the Great Oxidation Event Although oxygen did show up in the atmosphere in Archean eon, it is only now for the first time that oxygen build up happened to a certain degree that was conducive for many life processes to follow.

Oxygen was a by-product of photosynthesis by cyanobacteria. In its initial stages, whatever oxygen was produced was taken by dissolved iron or organic matter. At one point these sinks became saturated when no more oxygen could be taken up, at which point it started getting released into the atmosphere. It is also argued that free oxygen in the atmosphere may have been detrimental to the anaerobic bacteria of that time, so in that sense, while it paved way for oxygen that is so required for life, it may have caused the first mass extinction. The other thing that this oxygen did was convert methane into carbon dioxide (less potent greenhouse gas and water) which started the Huronian Glaciation, one of the earliest glaciations events in the history of the Earth that led to snowball earth.

In this way, Banded Iron Formations and later red beds coloured by haematite, imply an increase in oxygen levels. The other most significant events in Proterozoic are the formation of the supercontinents and further evolution of life, while stromatolites proliferated, eukaryotes or complex organisms showed up for the first time on the Earth.

Precambrian- this term was used for everything before Cambrian, and if everyone is wondering what is the most often used name Precambrian refers to, it can be called a super eon that represents 'stuff before Cambrian" and combines Hadean, Archean and Proterozoic.

Phanerozoic is the current geologic eon. Phanerozoic in Greek means visible life, and it represents the last 541 Ma on the Earth, from the start of the hard-shelled organisms to the dominance of humans. The 541 Ma years have the most records in terms of life on the Earth and other expressions of geological processes.

Phanerozoic eon is divided into Palaeozoic, Mesozoic and Cenozoic eras. **Palaeozoic** started with the appearance of first complex organisms and it is divided into Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian. **Cambrian (541 to 485 Ma)** which symbolizes the 'explosion of life' is known for proliferation of trilobites. **Ordovician (485 t0 440 Ma)** was the time of primitive fishes. Tectonically, Gondwana the large southern amalgam of continental blocks was at the south pole in the Ordovician period. Glaciation in this period led to mass extinctions. **Silurian (440 to 415 Ma)** is the age when vascular plants as well as arthropods, fish, both jawed and jawless, became widespread. **Devonian** (415 Ma to 360 Ma) can be called the 'the age of fishes' first tetrapods, trees, seeds and amphibian evolution. At the end of Devonian another mass extinction happened. **Carboniferous (**360 and 300 Ma) started with high temperature conditions, trees created carbon that got buried as coal deposits. On the other hand amphibians were dominant. Later carboniferous underwent a period of glaciation. **Permian** (300 to 250 Ma) is the time when all continents came together and formed Pangaea supercontinent and the ocean surrounded it is called Panthalassa. Conifers also evolved during this period and this period ended with mass extinctions.

Mesozoic Era (252 Ma to 66 Ma): This is called the age of the dinosaurs and further subdivided into Triassic, Jurassic and Cretaceous periods. Pangaea fragmented during Triassic (250 million to 200 Ma) and Tethys Sea opened up, modern corals and dinosaurs, such as Coleophysis appeared. There was extinction at the start and end of this period.

In the Jurassic (200 Ma to145 Ma) period, primary vertebrates in sea were fish and marine reptiles and ichthyosaurs, plesiosaurs, pliosaurs, crocodiles and turtles proliferated. In Cretaceous (145 to 66 Ma) period, first flowering plants evolved and sauropods became extinct along with the ichthyosaurs. Deccan volcanism in India and a large meteorite impact in Chicxulub marked the end of Cretaceous period (Cretaceous – Paleogene boundary, previously known as the K-T boundary)

Cenozoic Era is the age of mammals, and divided into Palaeogene, Neogene and Quaternary. Palaeogene (66 Ma to 23 Ma) comprises Palaeocene, Eocene and Oligocene epochs. India and Asia were in the position of collision, all continents started to drift towards their present position. Australian plate separated from Antarctica during this time. One of the significant events in this time was initiation of Antarctic Circumpolar current which cooled the Earth. There is an exceptionally high temperature period in between, called Palaeo-eocene thermal maxima. This period saw the spread of cetaceans, primates and birds.

Neogene (23 Ma to 2.58 Ma) comprises Miocene and Pliocene epochs and during this period, mammals and birds continued to evolve. The movement of plates resulted in North and South America getting connected at the Isthmus of Panama in the Pliocene epoch. The impact of this was that warm pacific waters were transferred to Pacific only through the Gulf Stream. This led to global cooling and to several subsequent glaciation episodes. This was also the time when grasses spread which was significant for the evolution of many grazing herbivores that we see today. This is also the time when first hominids evolved in Africa and moved to Eurasia.

Table 1.1 Five most significant boundary events in the history of Earth and life.

Boundary Events	Age	Characteristics	Life forms appeared/disappeared
Cretaceous Tertiary Mass Extinction	65 Ma	Also called the Cretaceous – Paleogene (KT) boundary event- Multiple events are held responsible for this drive towards extinction, that includes volcanic activity, also sea level change, rise of mountains and impact of a huge asteroid at Chicxulub in Mexico.	Most charismatic animals of the past, the dinosaurs disappeared along with ammonites, flowering plants and pterosaurs.
Triassic Jurassic Mass Extinction	200 Ma	Almost half of all species wiped out. Although called as a boundary event at 200 Ma, the extinctions started 18 million years before as a result of asteroid impacts and volcanic eruptions.	Marine reptiles, large amphibians, corals and cephalopod molluscs were largely wiped out. Did not impact plants so much.
Permian Triassic Mass Extinction	258 Ma	The biggest extinction event when 96% of the species died out. Asteroid impact, volcanic eruptions and drop in oxygen levels are some of the possible causes for these extinctions.	Marine animals and insects (their only extinction episode) wiped out.
Late Devonian Mass Extinction	359 Ma	It impacted three quarters of all the life on Earth. Sea level changes and asteroid impacts, along with change in type of plants may have contributed to these extinctions.	It impacted coral reefs and life in shallow seas.
Ordovician Silurian Mass Extinction	443 Ma	Third largest extinction event spread over two episodes, 85% of marine life disappeared owing to cooling that impacted the chemistry of oceans.	Trilobites, graptolites and brachiopods reduced.

Quaternary (2.58 Ma to the present) is the time when there is no major change, glaciation episodes were periodic in this time period. Many animals such as saber toothed, wooly mammoths and mastodons became extinct. Quaternary subdivisions are based on biostratigraphy and the two epochs are Pleistocene (2.58 Ma to 0.0117 Ma) and Holocene that begun at 0.0117 Ma to Recent (11700 years ago or 9700 B.C.).

It has been scientifically established that the Earth was born between **4.6-4.5 billion years** ago. The current estimated age of the Earth is based on rocks brought back from the Moon (4.4 Ga) and meteorites (4.6 Ga) that are thought to be good representatives of the primary and undifferentiated chemical systems, unlike the Earth where rocks have been recycled several times. This data suggests that the present chemical composition of the crust must have evolved for more than 4.5 Ga.

Oldest dated terrestrial minerals and rocks on the Earth: To date, the detrital zircons from a conglomerate horizon in Jack Hills, Western Australia are the oldest dated terrestrial minerals (4,363 ± 20 Ma).

The 4.03–3.94 Ga granitoids and diorites from the Acasta Gneiss Complex, Slave Craton, Canada is the so far, oldest rock.

2. Geological Processes

Geological processes form mountains in place of oceans and vice versa and how earth scientists unearth the Earth's story!

"They look at mud and see mountains, in mountains oceans, in oceans mountains to be. They go up to some rock and figure out a story, another rock, another story, and as the stories compile through time they connect-and long case histories are constructed and written from interpreted patterns of data and clues. This is detective work on a scale unimaginable to most detectives, with the notable exception of Sherlock Holmes"

John McPhee, Annals of the Former World

2.1 Geological processes and their role in understanding Earth

Geological features that adorn the Earth's surface, both on continents and oceans, in the present form are result of dynamic geological processes that have been operative inside the Earth since the birth of this unique and the only life sustaining planet of the Solar System, almost since last 4.56 billion years. Geological features and events on the Earth are the outcome of a complex interplay of **internal** and **external processes;** the former is driven by the internal heat and the latter by the solar heat and atmosphere.

James Hutton, Scottish geologist, gave the concept of **'Principle of uniformitarianism'.**

Principle of uniformitarianism: The geological processes we see in action on Earth today have analogy to the geological processes which operated throughout the geologic past. This important concept is known as the 'principle of uniformitarianism'.

Charles Lyell, British geologist, in his book '***Principles of Geology, being an attempt to explain the former changes of the Earth's surface, by reference to causes now in operation'*** gave the famous punch-line **"The present is the key to the past."**

2.2. Concept of Geological processes *vis-à-vis* Geological Time Scale

The concept of geological time as discussed in detail in the above section is the greatest geologic discovery that has revolutionized the way earth scientists look at the dynamic Earth in the contemporary times. Pioneering geological field and laboratory observations of scientists such as James Hutton, Charles Lyell, Nicolas Steno, William Smith, Alexander von Humboldt, Alfred Wegner, Claire Patterson to name a few, logically convinced us that the present Erath is an outcome of the past geological processes which operated on multiple time scales since 4.56 billion years. The temporal variation is on a large-to- small scale i.e. million of years to few years to a fraction of seconds! These geological processes are still operative and will continue to operate in future as well. Thus the face of Earth is ever changing and evolving *vis-à-vis* the geological time scale. Geoscientists have built up an understanding of the present Earth and how it has shaped up and evolved through geologic time.

Lithosphere: Rigid outermost part of the Earth comprising the crust and upper mantle, resting on the weak and ductile asthenosphere.

Plate tectonics: Theory which got acclaim during 1960's on the basis of sea floor spreading**.** The Earth's surface has been divided into large and small lithospheric plates (**Figure 2.1**). The plates are in motion and their relative motion with respect to each other determines the type of boundary: convergent, divergent or transform.

Continental drift: Alfred Wegener, a German meteorologist and explorer, formally proposed the breakup and drifting of continents. His theory was based on his observations of rock types, coastline fit, geological structures and fossils on both the sides of the Atlantic Ocean. In his book entitled **'*The Origin of Continents and Oceans'*** he proposed that the landmasses of the Earth almost fit together like a jigsaw puzzle (**Figure 2.2**).

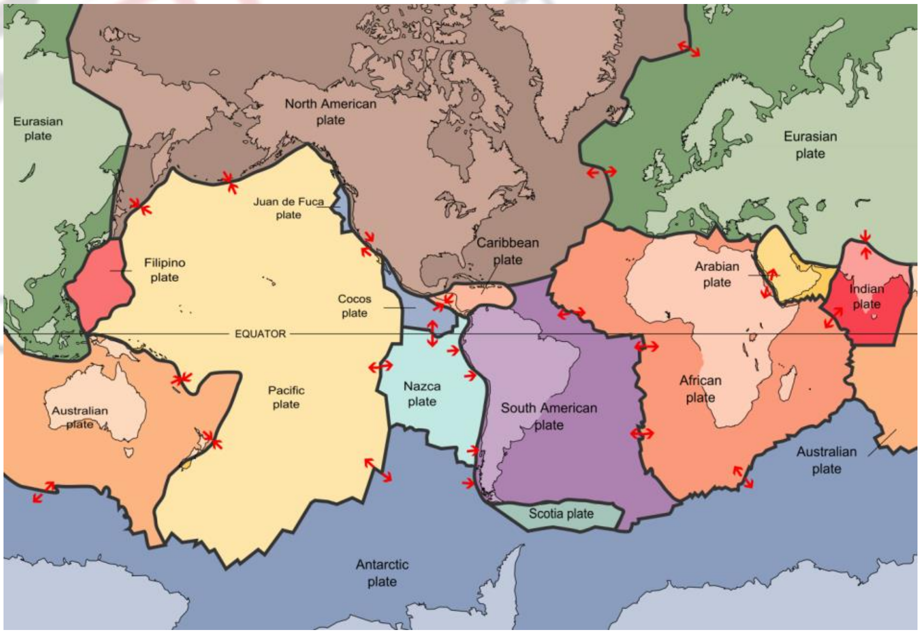


Figure 2.1. The lithospheric plates of the Earth. (Source USGS -http://pubs.usgs.gov/publications/text/slabs.html)

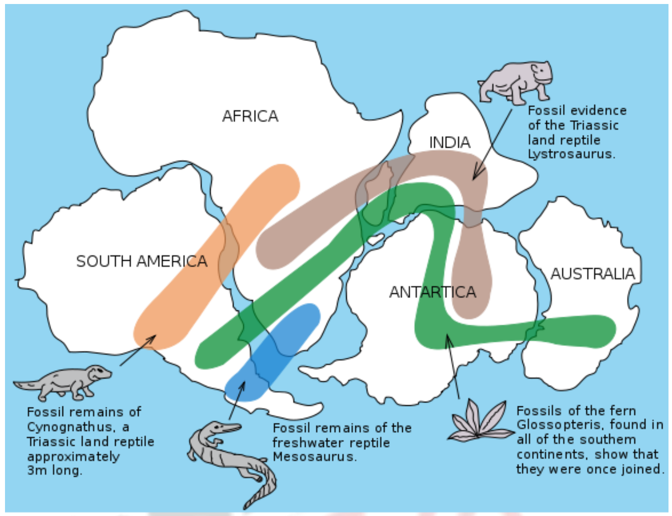


Figure 2.2. Concept of continental drift.
(Source: USGS)

The principle of uniformitarianism does not imply that all geologic phenomena proceed at the same gradual pace but it gives us clues to understand the basic idea how the Earth has evolved since its inception. Geologic processes can occur in a matter of seconds (volcanic eruptions e.g. Colima volcano, earthquakes e.g. Ring of fire), time span of human life i.e. few years (movement of plates e.g. Rising of Himalaya up to 5 mm every year, migration of sand dunes etc.) or take millions of years (Plate tectonics: Assembly and breaking up of supercontinents e.g. formation of the Himalaya; formation of sedimentary rocks; **Figure 2.3 and 2.4**) to shape the Earth's exterior. Let us consider examples of two geological processes operative on short and long time scales. The example of a short time scale is of drop in altitude of a segment of the Himalaya post-Nepal earthquake, which occurred on 25th April, 2015. "The primary stretch that had its height dropped is a 80-100 km stretch of the Langtang Himal (to the northwest of the capital, Kathmandu)," said (Richard Briggs, a research geologist with the United States Geological Survey (USGS) quoted in 'Himalayan drop after Nepal quake' published by BBC world service on 8th May, 2015 in the Science and Environment section).

The example of a geological process on longer time scale is the formation of the Himalaya (**Figure 2.4**). John McPhee has beautifully summarised the formation of Himalaya in place of the Tethys ocean by movement of plates (a geological process on a large time scale) and how once the marine fossilferrous limestone which formed in the Tethys ocean now constitutes the summit of Mount Everest (Box below)!

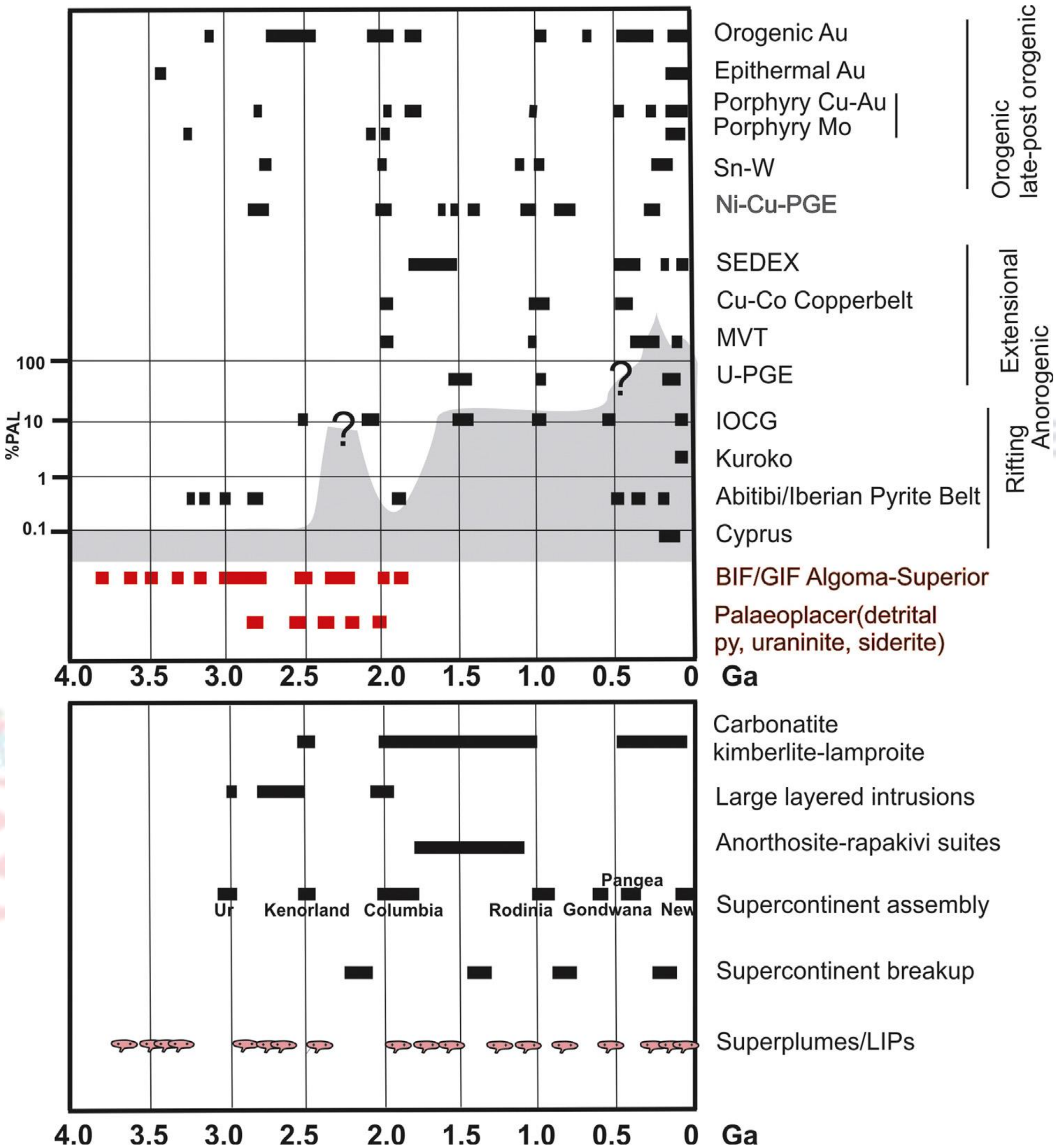


Figure 2.3. Formation and breakup of supercontinents during the Geological time scale.

(Source: Precambrian research journal)

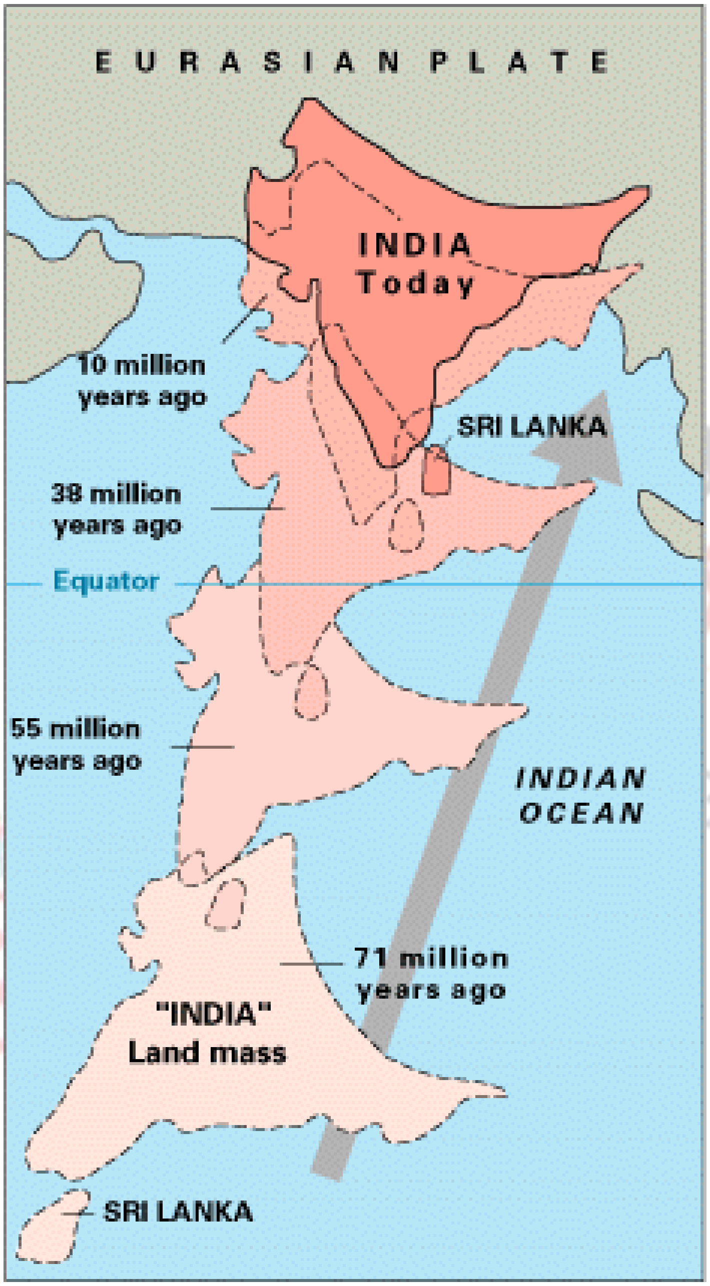


Figure 2.4. Formation of Himalaya.
(Source USGS)

"The Himalayas are the crowning achievement of the Indo-Australian plate. India in the Oligocene crashed head on into Tibet, hit so hard that it not only folded and buckled the plate boundaries but also ploughed into the newly created Tibetan plateau and drove the Himalayas five and a half miles into the sky. The mountains are in some trouble. India has not stopped pushing them, and they are still going up. Their height and volume are already so great they are beginning to melt in their own self-generated radioactive heat. When the climbers in 1953 planted their flags on the highest mountain, they set them in snow over the skeletons of creatures that had lived in a warm clear ocean that India, moving north, blanked out. Possibly as much as 20,000 feet below the sea floor, the skeletal remains had turned into rock. This one fact is a treatise in itself on the movements of the surface of the earth. If by some fiat, I had to restrict all this writing to one sentence; this is the one I would choose: the summit of Mount Everest is marine limestone."

John McPhee, Annals of the Former World

The best way to exemplify John McPhee's quote is to look at the summit of Mt. Everest the highest peak of the world, which is made up of The Qomolangma Formation (Ordovician-limestone, 488-443 million years old) in which many marine fossils such as trilobites, crinoids, and ostracods are entombed (Figure 2.5).

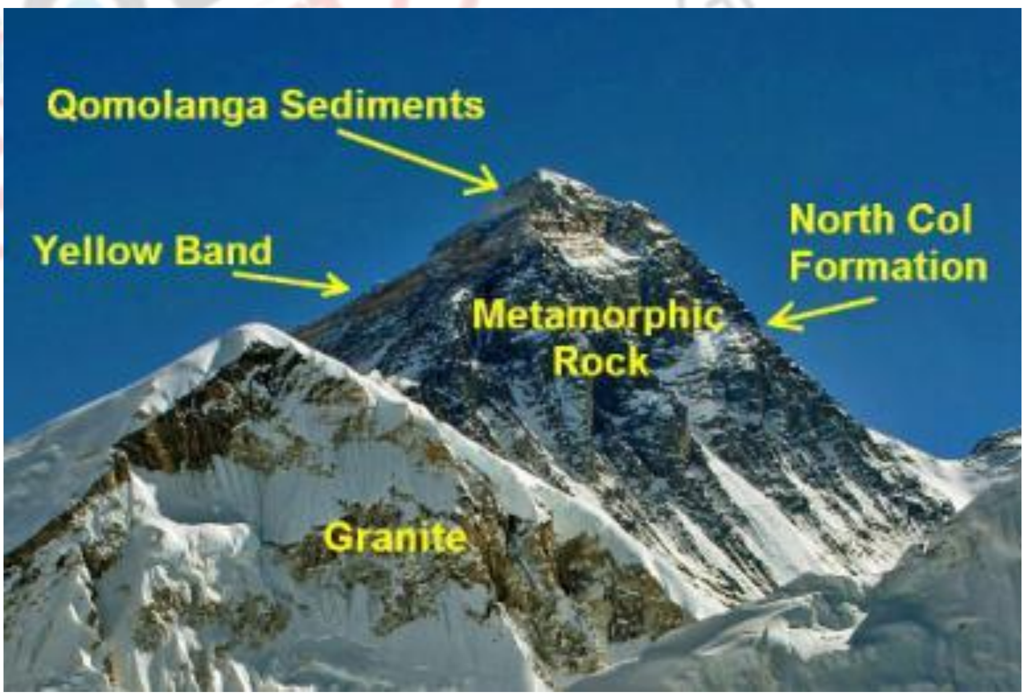


Figure 2. 5. Rock exposures on the Mt. Everest.
(Source: Wikipedia)

2.3. Internal and External Geological Processes

The internal and external geological processes are instrumental in keeping the Earth dynamic and geologically vibrant. These geological processes manifest on the surface in the form of volcanoes, earthquakes, drifting, movement of lithospheric plates, formation of supercontinents and their dispersal, sedimentary rocks, ore deposits, etc. (**Figure 2.3**). To understand these geological processes geologists track the information concealed in various rocks. There are limitations to the accumulation of this data because of the dynamic nature of the Earth. It is not possible to retrieve all the records preserved in the rocks in the past, and records are obliterated due to weathering and erosion of rocks and subduction of earlier rocks both in oceanic and continental environments. Almost all oceanic crust older than 180 million years has been subducted back into the mantle. To understand the geological story of Earth it is important to have an understanding of the pace of these processes and their driving mechanisms.

Sources of heat for Internal processes

There are two principal sources of heat responsible for the internal geological processes: 1. Primordial heat - this heat has been escaping the Earth since its inception, resulting from the collision of the planetesimals and the later accretion and gravitational differentiation which led to three distinct layers of Earth viz. crust, mantle and core. 2. Radioactive elements - the heat generated by decay of radioactive elements contribute significantly to the Earth's internal heat engine. The internal heat is responsible for generation of melts and convection currents in the mantle which are important in terms of large scale magmatism and plate motions **(Figure 2.6).**

Geothermal gradient is the variation in temperature with depth, an indicator of the Earth's internal heat. The average geothermal gradient on the continents is 30º C/km. The geothermal gradient is enhanced in active volcanic areas, mid oceanic ridges and lower in old cratons and subduction zones.

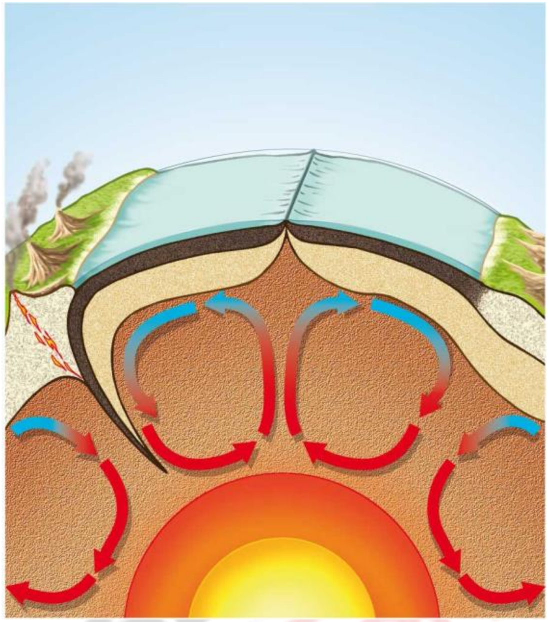


Figure 2.6. Internal heat engine.

(Source: Wikipedia)

Geological features as a result of internal geological process

Internal geological processes like plate convergence, plate divergence and volcanic eruptions tend to lift and modify Earth's relief. The plate convergence/collision has resulted in mountain chains; the mighty Himalaya was created when the Indian and the Eurasian continental plates collided some 40 million years ago **(Figure 2.4).** All along the western coast of South America the plate convergence in the form of collision of oceanic and continental plates resulted in the formation of Andes Mountains. Volcanic eruptions have led to the formation of Deccan Plateau during the Cretaceous period when Indian plate passed over Reunion Plume during its northward journey. The divergence of lithospheric plates in the oceanic environment results in the formation of mammoth network of mid ocean ridges (Example: The Mid Atlantic Ridge, East Pacific Rise, 90 East Ridge, etc.). East Pacific Rise and Mid Atlantic Ridge are examples of relief on the ocean floors. Large scale magmatism in form of extensive and regional igneous provinces could be explained by intraplate magmatism in the rift environments and mantle plume activities (Example: the East African Rift system). The convergence of plates/subduction is responsible for opening of back arc basins giving rise to opening of seas (Example: The Japan sea). The internal geological processes significantly build the Earth's relief.

Sources of heat for external processes

Solar energy is the most important source of heat for all external geological processes operating on the Earth's surface. It creates variations in temperature and pressure in the atmosphere that generates wind, including the monsoon. These processes also complete the hydrologic cycle wherein the water changes its domain and forms; from the oceans, rivers lakes and even glaciers it gets evaporated and is reintroduced into the Earth system through various forms of precipitation such as rain and snow. The activity by rain, wind, snow, glaciers, rivers and oceans promote geological processes on the Earth's surface.

Geological features as a result of external geological processes

External geological processes, primarily driven by the solar energy constantly shape the Earth's surface at variable rates. External agents such as water, ice, wind and also the human beings are responsible for the changing face of the Earth and modify the existing relief. Highlands are eroded by various external geological agents and the eroded materials are transferred/transported to lowlands and thus result in infilling of the basins and depressions on Earth's surface leading to the formation of sedimentary rocks. These activities over millions of years led to the formation of landforms such as deep valleys, deltas, sand bars, river terraces, beaches etc. Different places on the Earth experience disparate rates of external geological processes. The factors which control the formation of landforms are the climate, location (latitude and longitude), rate of weathering, erosion, transportation, deposition, prevalent lithology and relief of a given place. The processes may operate for millions of years before changing landforms. Sedimentary rocks, particularly those enclosing fossils are important in deciphering relative ages of rocks. These sedimentary rocks also preserve the earliest life records and are very crucial in understanding the Earth's palaeo-environments and evolution of diverse life forms.