THE STORY OF CREATION

Chapter-16
OUR PLANET EARTH

> *There is nothing either good or bad but thinking makes it so.*
> (William Shakespeare)

16.01. OUR PLANET

Our mother planet Earth is unique in the solar system. In this connection, we often refer it by the term 'terra' and 'geo' in combining form.

Its creation was from the same gas and dust cloud about 4,600 myr ago. How that gas-and-dust cloud evolved into its present form? Once created as planetary body, how it created its landmass, oceans and atmosphere before generating its ecology compatible for creation of living world?

The cold celestial body started to compact on its own under gravity and heated up. Heavier materials concentrated near the core and lighter materials towards its surface. At first no atmosphere could be held up. Later increased gravity permitted retention of gases.

Fig:16.1. Earth as seen from space.

Gradually it cooled down and became a condensed body. Complex compounds had been formed into minerals and rocks making its superficial crust and interior body. Liquids filled up depressions. Gases, retained inside, were released partially to form the atmosphere. Chains of organic compounds were made. Inside remained in semi-liquid state. The top layers floating over it, moved,

clashed and buckled to form varieties of land-mass, oceans and mountains.

None created our planet. The planet created itself over long geological time.

With the emergence of hydrosphere and atmosphere, biosphere evolved. Bio-organic molecules came up that evolved into bacteria-algae-fungi-plants-animals. We, the conscious being, live only on this planet. Thus our Earth was the only planet that traversed an altogether different course of evolution unlike other planets of the solar system. We do not know yet if any other extrasolar planet exists with such living biosphere.

Present features of our mother planet Earth with oceans and continents, mountains and plateaux are produced after continuous activities of forces of Nature. Forces are still active. Major forces are (1) tectonic forces and (2) several agents of weathering, erosion and deposition, active through solar heat, wind, water, ice etc.

The planet comprises of (1) interior solid body made of concentric shells of core-mantle-crust, (2) the surface relief forming different landmass-hills-plains-deserts, (3) hydrosphere with oceans-seas-rivers, (4) atmosphere of gaseous layers, and (5) magnetosphere. The present forms had been created after long inter-active evolutionary play. Such geological evolution is a continuation and part of the evolution as a whole. It is active all the while.

Apart from the Planet's physical nature, it has created its living nature within it at some point of geological time. The living and supportive physical nature interplay as Global Ecosystem. Rather the living nature gets all its resources from this biosphere and has evolved enriching itself from simple to higher level of complex living forms.

First let us look at physical nature of our planet.

16.02. PLANETARY NOTES

Astronomical facts about the planet have been already described in chapter-15. Here we take note of some important points.

The Earth circles the Sun in slightly eccentric orbit. The planet comes closest to the Sun at **perihelion** on 3rd January and farthest at **aphelion** on 4th July. The orbital eccentricity of the planet changes by 6% over 100,000 years. The tilting of axis varies from 21.8° to 24.4° over 40,600 years. Present axial tilt is around 23.5°.

The precessional angle changes from 43°18′ to 49°12′. The precession of the axis occurs over 21,000 years. The present precessional angle is 46°52′56″

All these astronomical factors contribute towards changes in solar heating and thermal distribution, resulting into cyclic changes of climate, glaciation, water level, salinity of oceans, ocean currents, in other words, in general evolution of the planet.

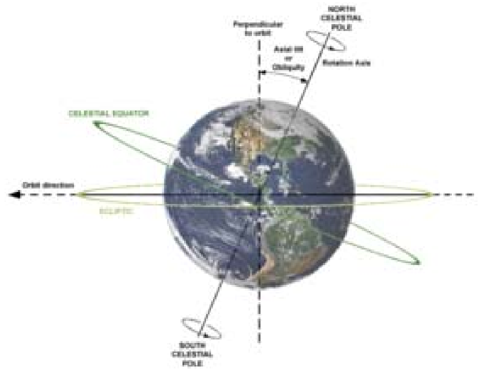

Fig:16.2. Rotational axis of Earth.

Human being, plants and animals, oceans and continents, mountains and gaseous atmosphere all exist on the surface of the Earth and are glued to it by gravity. The surface has been formed by solid landmass exposed to atmosphere or to oceans.

We have no uniform surface level. We have defined one **mean sea level** measured at Newlyn, Cornwall as the standard base. We have also assumed several circles passing through North and South Poles as **longitudes** and in between two Poles as **latitudes** as reference guide. **Equator** is the greatest circle of latitudes (marked as 0° degree), decreasing gradually in diameter towards each Pole. Our Sun passes annually over two latitudes, **Tropic of Cancer** (23.5°N) and **Tropic of Capricon** (23.5°S) on 21st June and 21st December respectively. One longitude passing through Greenwich of Great Britain is the reference zero degree longitude, called Greenwich line. We have also assumed one **International Date Line** (IDL) nearly 180° east or west of Greenwich line. Since the planet is rotating towards east, the sun appears to move towards west. We assume

that the day begins when the Sun rises over the International Date Line and sunrise proceeds towards west. These are all known facts, but often misconceived.

The planet now contains seven continents and numerous isolated landmasses forming islands. It has five large oceans apart from numerous seas, bays, gulf. Out of the total surface area of about 550,000,000 sq km, landed portions cover some 30%. The continents and oceans are unevenly distributed over the surface. Most of the lands now occur in the northern hemisphere while vast water remains mostly in the south.

Why the planet could not evolve uniformly and distribute its rocks and soil, mineral and water more evenly over the planet? As if, our mother Nature has no responsibility to make things evenly spread, ordered and symmetric.

Table.16.01. Major elements of Earth. (source: Emiliani, p-165)

Oxygen	48.86	Iron	18.84	Silicon	13.96
Magnesium	12.42	Sulphur	1.39	Nickel	1.39
Aluminium	1.31	Sodium	0.64	Calcium	0.46
Phosphorus	0.14	Hydrogen	0.12	Cromium	0.11
Carbon	0.10	Potassium	0.05	Manganese	0.05
Cobalt	0.05	Chlorine	0.04	Titanium	0.03
others	0.04				
Elements	**% of atoms**	**Elements**	**% of atoms**	**Elements**	**% of atoms**

16.03. PLANET'S INTERIOR

The solid Earth is made up of rocks, minerals and soil composed from 92 natural elements. Major chemical constituents are silicon, magnesium, iron, nickel, aluminium, chromium (refer Table:16.01). They occur as solid compounds of silicates, sulphates, oxides, etc in varieties of minerals and soils. Minerals combine to form rocks and rocks make mountains.

According to the nature of its origin, rocks are of three types — igneous, sedimentary and metamorphic. The oldest and primary rocks that came into being from solidification of gas clouds are **primordial rocks**. Oldest minerals we have found now, are zircon 4,300 myr old and oldest rocks 3,960 myr old. Primordial rocks had been presumably recycled and are now mostly non-existing.

In geological times, igneous rocks were formed from molten magmas which was a gas-enriched silicate melt occurring at depth inside the planet's interior. These rocks are the first constituents of the planetary body. When such magma solidifies at depth, they produce abyssal or intrusive rocks with coarse crystalline grains. When igneous rocks are exposed to the surface, it cools rapidly and produces fine crystalline structure as in basalt.

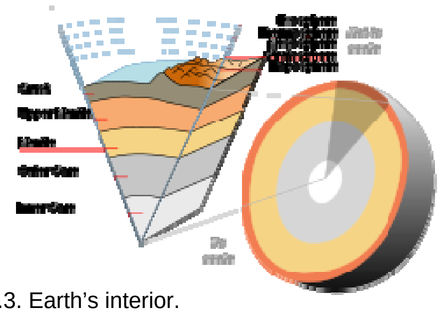

Fig:16.3. Earth's interior.

Sedimentary rocks are formed from sediments of older rocks under pressure and heat. Metamorphic rocks are formed from decomposition of igneous or sedimentary rocks. Some examples of common rocks are (1) granite, basalt - Igneous type; (2) sandstone, limestone - Sedimentary type; and (3) marble, slate - Metamorphic type.

Table:16.2. components of Earth's Interior body.

Depth from MSL (km)	Component layer	Density (g/cu.cm)
0-60	Lithosphere	
0–35	Crust	2.2–2.9
35–60	Upper mantle	3.4–4.4
35–2890	Mantle	3.4–5.6
100–700	Asthenosphere	
2890–5100	Outer core	9.9–12.2
5100–6378	Inner core	12.8–13.1

The planetary body is structured in differentiated layers. In the process of progressive solidification and contraction from the molten mass during accretion of the planet, the lighter rocks moved up. They are named SIAL, as they are rich in silicates of alumina. At core it consists of NIFE.

The Austrian geologist **Edward Suess** (1831-1914) categorised **five shells** composing the planetary mass on the basis of major constituents. They are as follows :

(1) **SIAL** – Silicon + Aluminium;
(2) **SIMA** – Silicon + Magnesium;
(3) **CHROFESIMA** – chromium+ Iron +Silicon + Magnesium;
(4) **NIFESIMA** – Nickel + Iron + Silicon + Magnesium; and
(5) **NIFE** – Nickel + Iron.

As we go inside the planet, its temperature increases at the rate of 2-3 °c per 100 m. Beyond 8 km, temperature gradient cannot be measured directly. At depth of 40 km, it is taken as 1000°c at tectonically active zone and 500°c below stable continents. At core-mantle boundary it is 3700°c while at the centre around 4300°c.

The best way to study planet's interior is by digging which is simply impossible. We could only dig borehole down to 9.583 km in Oklahoma (USA), 12 km in Kola peninsula (USSR) and a shaft of 3.428 km in South Africa. The centre lies beyond 6000 km deep inside. To study our planet's interior, we adopt seismic method and use the instrument called Seismograph. The instrument records Earthquake shocks.

The solid Earth is divided in three concentric major sub-shells of **crust**, **mantle**, and **core**. The core is further divided into **outer core** and **inner core** and the mantle into upper, middle and lower mantle. The crust is either continental and oceanic one.

The **crust** is the outermost surface on which lands, seas and mountains sit. Its depth varies from 7 km below oceans to 35 km under continents. Two type of rocks are mainly found here - (i) oceanic basaltic rocks containing iron and magnesium, having densities 2.8 to 3 g/cm^3 and (ii) continental rocks which are lighter and rich in silicon and aluminium, with average density of 2.7 g/cm^3, over the basaltic layer.

The **continental crust** is made up of sedimentary rocks about 1 km thick (with density 2.5 g/cm^3). Below lies granite layer of 1 - 30 km thick on average (density 2.6 - 2.8 g/cm^3). The layer contains most of the radioactive elements. Under this, there is a gabbro / basalt layer 30 - 35 km thick (density 2.9 - 3.3 g/cm^3).

Oceanic crust is made up of loose sediments of 0.5 km average thickness over predominantly gabbro-basaltic layer 7 km thick. It has seismic velocity of 6.7 km/sec. Interestingly, the continental crust is found sometimes as old as 3800 myr while oceanic crust little more than 150 myr. Further while depth of continental crust averages 25 to 80 km, oceanic crust is quite thin.

Why these two crusts differ in age and depth?

Andrija Mohorovicic (1857-1936), of Sagreb, Yugoslavia found in 1909 one peculiar discontinuity where sound velocity makes a jump from low to very high value. The layer where this occurs, is named as **Moho discontinuity**. It lies just below the crust.

Recent studies rename crust and parts of mantle into lithosphere and asthenosphere. Below the crustal layer, denser rocks in the shell extends to a depth upto 250 km. Upper part of the crustal layer is solid and form relatively rigid body known as the **lithosphere**. Lower part, called **asthenosphere** from 120 km below continents and 65 km below oceans, is partially molten and capable of mild flow. Since it is plastic in nature, overlying solid mass or plates of the crust can slide over it. Below this layer, seismic velocity changes abruptly.

The **Upper mantle** consists of asthenosphere and part of lithosphere for a depth upto 670 km. It is composed of periodite-pyrolite rocks. The **lower mantle** extends to a depth of 2885/2920 km and is made of pyrolites. Part of this mantle between depth 200-2885 km is often called **mesosphere**. It lies below the asthenosphere as a rigid layer.

The **Core** of Earth is expected to have density fluctuation from 9 g/cm^3 to 11.5 g/cm^3. Its pressure fluctuation should be in the range of 10,000 t/sqin to 25,000 t/sqin and temperature as high as 5,000°c. One element can only exist in such conditions - iron. At surface, its density is 7.86 g/cm^3 but under pressure inside the core it should be in the range of 9 - 12 g/cm^3. It should also remain in liquid state there.

Meteorite study indicates that its core may be composed of iron-nickel since iron meteorites are composed like that. Iron amounts to 90%, nickel 9% and sulphur-phosphorus-carbon 1%.

At a depth of 2,885-2920 km, the seismologic wave (S waves) are stopped but another kind of waves, called P waves, emerge late with altered direction. In 1906, **Richard Dixon Oldham** (1858-1936) of Britain explained this by assuming that the Earth has a core at this range of depth.

The German-American geologist, **Beno Gutenberg** (1889-1960) showed (in 1913) that the core would be in liquid state and extend down to 3,485 km from the centre. The boundary of the core-mantle is called **Gutenberg discontinuity**. Density at this

boundary takes a jump from 6 g/cm^3 to 9 g/cm^3 and increases to 11.5 g/cm^3 at the centre.

Table:16.3. Earth's interior

Lithosphere	ocean	0-65 km	crust	oceanic	0- 7 km
	continent	0-120 km		continent	0-35 km
asthenosphere		65 / 120 km ~ 200 km			(av) maxm 80 km
			mantle		7/35 - 670 km
mesosphere		200 - 2885 km			670-2885 km
outer core	(liquid)	2885 - 4720 km	core	(Fe=90% Ni=9 5%)	2885-6371 km
transition zone	(mashy)	4720 - 5170 km			
inner core	(solid)	5170 - 6371 km			

In 1936, the Danish geologist **Inge Lehmann** (1888-1993), observed that some thousand kilometre from the centre of the planet, there is another discontinuity. Accordingly, the core has been further divided into two. The **outer core** goes upto a depth of 4720 km and constitutes a volume of 15.16% and a mass of 29.8% of Earth. It allows easy transmission of P-waves but no S-waves. The layer is believed to be fluid and made up of iron-nickel composition. The **inner core** is of radius 1100 km and have 0.7% volume and 1.2% mass of the Earth. P-wave velocity here is 11.1 to 11.4 km/sec. Interestingly, S-waves propagate through this layer, thus indicating its solid state near the stage of melting. Its chemical composition must be different from the outer core.

The layered structure of planetary body evolved from astronomical era to pre-geological times when the Earth solidified with stratification. Radioactive decay, gravitational differentiation and several phase transitions were active to provide requisite energy. Dense materials sank down while lighter materials emerged to the surface. Shells arose due to stratification. Iron and nickel went down into the core and silicates into the mantle. Feldspar (silicates of aluminium, potassium, sodium, and calcium) have low melting point and low density and arose upward during differentiation of iron and silicates. The mantle contained less-easily-melted and denser silicates of magnesium and iron like pyroxenes and olivines.

Thus created our solid planet on its own natural system.

16.04. SURFACE FEATURES

Landmass occurring over crust show innumerable varieties of surface relief that narrate beauties of our Grand Nature on Earth.

Features are endless – mountain ranges and hills with peaks and valleys, springs and glaciers, table lands and uplands; rivers and lakes with gorges and canyons, waterfalls and deltas, horse-shoe lakes and estuaries; river plains, coastal plains and flood plains; plateaux and valleys; deserts, grassland, forest land, barren land; hot, cold and temperate areas; high and low rainfall areas; and so many other features.

All these emerged eventually after a long history of deformations, depositions and erosion by several agents. Tectonic movements caused folding-faulting-volcanism-earthquake. Agents of weathering and depositional forces are rain, river, wind, heat, snow, ocean currents etc. Matters recycle through these forces which are continually active. The pace of changes is generally slow, but often turns out rapid and catastrophic. Nothing remains eternal and final. Evolution and changes are everywhere.

16.05. HYDROSPHERE

Hydrogen and oxygen combine into water, once considered as one of the five prime elements of nature. Water may not be the prime element but must be a prime compound for Creation of Living Nature.

Water accumulated in oceans, seas, bays, gulfs, lakes, rivers etc. together with ice in the cold polar regions and high mountains. Apart from surface water, the planet reserves some water as underground water and some in the atmosphere. All these form planet's **hydrosphere**.

Oceans contain about 97% of water. Less than 3% of all water on Earth is fresh and 75% of this is contained in icecaps. Snows occur in high mountains and in cold polar regions.

Oceans contain saline water (salinity level 34.72 per $\%_0$) while fresh water's salinity level shall be within 0.2$\%_0$ - 4$\%_0$.

Surface temperature in oceans vary from 25 - 28°c in tropics to 0°c in polar regions. Bottom temperature of oceans go down to 1 - 2°c.

Ocean depths are divided into several zones for different ecosystems – (i) littoral zone, (ii) sub-littoral zones, (iii) continental shelf (iv) epibathyal zones, (v) bathyal zone, (vi) abyssal zone, (vii) ultra-abyssal zone.

Oceanic water are not still but in motion. There occur four types of motions in water – (1) surface ocean currents, (2) deep sea circulation, and (3) tides in regular course, and (4) tsunamis as catastrophic event.

The planet has a vast storage of underground water that often come up as springs.

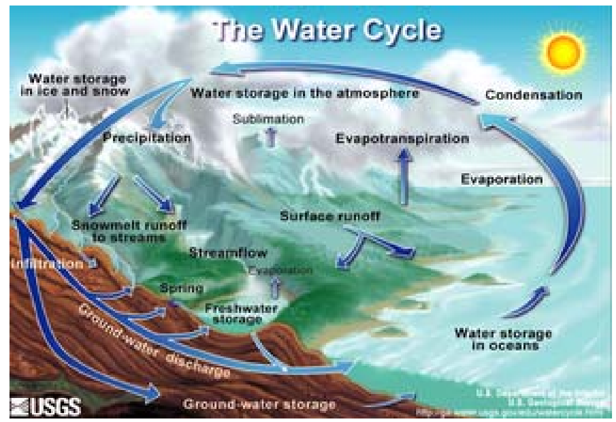

Fig:16.4. Water Cycle.

Water rises up from oceans-lakes-rivers by evaporation to form clouds. It again drops down as rain-snow-hail through condensation upon the planetary surface. This cycle goes on continuously. Part of this falling water recharges underground stock and remainder flow down through the surface drainage of rivers to larger water bodies. They are again exposed to solar radiation for evaporation. Water thus moves in a cycle, called **water cycle** or **hydrological cycle**. This cycle is a very important feature of the planet, not only to support its biosphere but also towards creation of life. Vegetation consumes part of surface and underground water and also contributes to the air some amount water vapour through transpiration.

16.06. ATMOSPHERE

The gaseous envelope surrounding our Earth comprise its **atmosphere**. We name this gas-mixture 'air', also thought as one prime elements of all creations.

The composition of air varies very slightly in different areas and in different altitudes. Air consists of a mixture of nitrogen and oxygen, in the main. Volume composition of dry air at sea-level (average values) are shown in the Table:16.04 below.

Table:16. 4. composition of air in % volume

elements	%	elements	%	elements	%
nitrogen	78.08	oxygen	20.95	carbon dioxide	0.03
argon	0.93	neon	0.0018	krypton	0.0001
helium	0.0005	xenon	0.00001		
other compounds	H_2O, CH_4,	N_2O, CO O_3, H_2O	NH_3, CH_3Cl,	CCl_4, CF_2Cl_2	H_2S, $CFCl_3$

Air contains, in addition, water vapour, hydrocarbons, hydrogen peroxide, sulphur compound, and dust particles in small and very variable amounts. Conspicuously, noble gases (He, Ne, Ar, Kr, & Xe) are too low in Earth's atmosphere which imply that gaseous component of solar nebula had been dispersed before accretion of the Earth, possibly, due to solar wind at Sun's T Tauri stage. Further early degassing is indicated by the radio-active Argon-data. Primitive volatile gases escaped from the mantle in the first billion years after accretion. Xenon data indicate that upto 80% of the degassing occurred within 50 myr or so.

The atmosphere is not homogeneous whole but layered, differing in composition and characteristics. Immediate to the surface, we get lower atmosphere while the upper atmosphere stays from 30 km upwards. The atmosphere has no boundary at the top but simply fades into the near emptiness of the outer inter-planetary space. Up to about 100 km, the composition of the upper atmosphere is similar to that of the ground level. Above that level, the dissociation of oxygen into atoms is almost complete and, at above 150 km, nitrogen separates out owing to its greater mass so that mono-atomic oxygen predominates. Considerable ionisation occurs in the

upper atmosphere as a result of solar ultraviolet radiation and X-rays.

Average surface temperature of the planet is +14.3°c and average pressure at mean sea level is expressed by 760 mm of Mercury (1013.2 mb) or simply 1 atmosphere. Density of air is 1.2 kg/cu.m. at sea level, $8x10^{-7}$ kg/cu.m. at 100 km above and $1x10^{-10}$ kg/cu.m. at 200 km above.

Leon Phillippe Teisserence de Bort (1855-1913), of France was the chief meteorologist of Central Meteorological Bureau in Paris and had his own observatory at Versailles. He suggested in 1902 from unmanned instrumented balloon flights that the atmosphere consists of two layers, troposphere and stratosphere.

We now divide the atmosphere into five spheres –

(1) **exosphere** from 690/800-1600 km and above,
(2) **thermosphere** upto 690-800 km,
(3) **mesosphere** upto 80-85 km,
(4) **stratosphere** upto 50/55km and
(5) **troposphere** upto 9/17 km from ground level.

The **troposphere** extends from Earth's surface to a height of 8-12 km beyond tropics and 16-17 km in equatorial zones and tropics. It is taken on average as 9 km and 17 km. The air is heated by the Earth's surface and becomes cooler with height @ 6-6.5°c per km altitude on average.

Atmospheric whirls like cyclones and anticyclones originate and develop in this layer. Nearly entire steam concentrates in the troposphere to form clouds. Temperature stops decreasing at a layer called **tropopause** where it comes down to -60°c.

The **stratosphere** extends beyond tropopause upto a height of 50-55km. Major atmospheric whirls originate here. Temperature rises by 1-2°c/km. At its upper boundary, the temperature turns out to be 0°c, often less, in the **stratopause** layer. The ozone layer appears densest between 18-24 km within this stratosphere.

At lower level, we get molecular oxygen. But in the ozone-sphere, oxygen atom combines with molecular oxygen to form three atomic molecule of ozone. The layer, called **ozonosphere**, was first detected by **Maurice Paul Auguste Charles Fabry** (1867-1945) of France in 1913. Ozone's concentration is quite thin (1 in 4 million) still the layer can effectively absorb solar ultraviolet radiation. Ozonosphere is rich in ozone near poles and thin at equators. The molecule gets easily split up by sunlight, by nitrous oxide of the air and other chemicals. The balance between formation of ozone and its breakdown is still positive, acting as protection shield that prevents harmful rays from coming down to surface and thus protects life on Earth. We need to protect this ozone shield from thinning out by alternative ozone-friendly technology and other measures. This is necessary to preserve our ecology in our favour.

The term **mesosphere** is coined by **Sydney Chapman** (1888-1970) of Britain in 1950. The sphere is marked by fall of temperature. It lies above the stratosphere to a height of 80-85 km. Temperature drops here at the rate of 2-3 °c/km to a range of -80°c to -120°c at its upper boundary. This upper boundary is called often **mesopause**.

Ionosphere is the layer of charged ions in the atmosphere that occur between 60-400 km height and comprise of mesosphere and lower thermosphere. The Ions are charged atoms. That ions are present in the atmosphere, was first thought by **Oliver Heaviside** (1850-1925) of Britain and **Arthur Edwin Kenelly** (1861-1939) of USA. In 1922, they identified a layer, called **Kenelly-Heaviside layer**, about 70 km above, wherefrom radio signals were reflected back to Earth. In 1925, **Edward Victor Appleton** (1892-1965) of Britain experimentally proved the layer. He located another layer, known as **Appleton layer** or **F layer**, at a height of 225 km wherefrom radio signals are reflected at dawn when Kenelly-Heaviside layer is better operative in the dark.

The whole layer of ions was given the name **Ionosphere** by the physicist and radar pioneer, **Robert Alexander Watson-Watt** (1892-1973), of Scotland in 1930. Later it was found that the ionosphere consists of several sub-layers.

In high latitude zones, the **auroras** are found to blaze in the sky. This is due to recapture of free electrons by ionised gases in the ionosphere. The ionisation is done by energetic electrons of the solar wind that interact with the magnetic field of the Earth.

Thermosphere (extending upto 690-800 km) lies above the mesosphere where temperature increases in the following manner ─ 0°c at 100 km, 500°c between 150-200 km and 2000°c at 800 km. The atmosphere here intensely absorbs u-v radiation and therefore is heated up. Matter as a result exists in ionised state in this strata forming the ionosphere.

Above 690-800 km, we encounter **exosphere** extending as far as 1600 km or beyond and gradually fading into the interplanetary space. The sphere was named by the American physicist-astronomer **Lyman Strong Spitzer** (1914-1997) in the year 1949.

Heat, clouds, rains, fogs, wind etc play in the atmosphere and affect both life and non-life. Combined effect of all these constitute weather and climate. The **weather** of a place is described by temperature, atmospheric pressure, humidity, cloudiness, wind speed and directions for short time-period in dynamic interactions of atmosphere, hydrosphere, lithosphere and biosphere. **Climate** is the same on average for as long as 30 years or more.

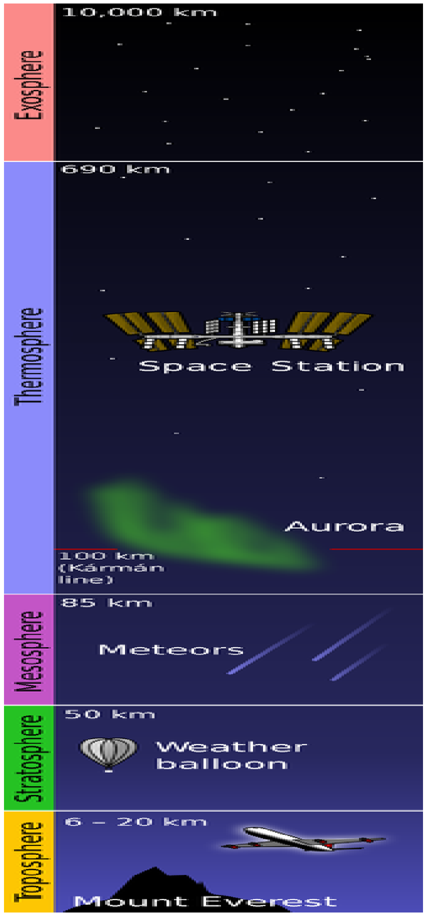

Fig:16.5. Five Spheres of Atmosphere

The Earth gets constant energy from the Sun, measured in langleys (1 langley = 1 gm.calorie/sq.cm. = 4.184 joules / sq.cm.min). It receives about 720 langley daily and maintains its temperature within some constant range. Amount of energy it receives from the Sun, is distributed through radiation, conduction and convection.

There is a mechanism by which **atmospheric energy budget** is kept under control. About 18% of solar radiation are absorbed by ozone, water vapour clouds etc. in the stratosphere and troposphere and radiated back to Earth. About 31% are scattered through clouds into the space. The surface receives 47% directly. About 4% of energy escapes to space through radiation windows. These account 100% incoming radiation. Outgoing radiation also amount to 100%. We have general global heat belts consisting of (1) equatorial torrid zone, (2) tropical temperate zones and (3) polar frigid zones.

The air contains water vapour. The amount of moisture in air changes either added from evaporation and lessened by precipitation. Maximum amount of moisture the air can hold, is called its saturation limit. Amount of moisture in the air is expressed by **relative humidity** or **humidity**. Condensation of water vapour may occur by over-saturation and generally by cooling. Condensation by cooling, depends on radiation-cooling of the air, contact-cooling of the air in contact over a colder surface, mixing of warm and moist air with colder air and adiabatic expansion.

Water vapour in air goes up to form **clouds** in the sky. **Fogs** are clouds of the ground. Water vapour that goes up by evaporation, comes down by precipitation. When clouds precipitate, rain, snow, drizzle, sleet or hail come down.

How clouds condense and form into rain? The Swedish meteorologist, **Tor Harold Percival Bergeron** (1891-1977), suggested in 1933 that production of rain drops depend on the coexistence of water and ice crystals in clouds at temperature quite below freezing.

The **popular theory of rainfall** is based on the difference of saturated vapour-pressure over ice and water surface below 0°c. Ice crystals forming round the nuclei of insoluble soil particles, are vital for rain. Cloud may contain cooled droplets at a range of, say -40°c. At low temperature, more water vapour is required to saturate the air in respect of water surface than icy surface. If the air is saturated with respect to water droplets, it happens to be oversaturated with

respect to ice crystals. As a result, condensation works on ice to reduce vapour pressure and evaporation starts from water droplets to restore it. Ice crystals grow larger to become sizeable enough to overcome atmospheric friction and cloud up-droughts. It then falls, forming snowflakes or melting into water drops. The mechanism is applicable to extra-tropical regions. There are other mechanisms of precipitation.

The basic reason of precipitation is condensation on large hygroscopic nuclei, coalescence by sweeping by falling water droplets or by some electrical attraction between droplets.

Thunderstorm is a natural event of rapid cloud build-up and heavy rain in unstable air conditions extending to great heights. Powerful up-draughts develop within lowering cumulonimbus clouds. Typical storm comprise of several convective cells building a series of vigorous chimneys of rising air.

Lightning occurs to relieve the electrical tensions between opposite charges i.e. between the cloud and the ground or within the cloud. Usually the ground is negatively charged to balance the positively charged ionosphere, without occurrence of sparks due to low electrostatic gradient and high air resistivity. During thunderstorm, the potential difference would increase and a huge electric spark would take place. As lightning heats the adjacent air to high temperature, it causes rapid expansion and vibration of the of the air column. This is known to us as thunder. There is nothing supernatural in thunder or lightning.

Tornadoes are extremely violent storms. They form a cylindrical or conical funnel reaching down from the base of the cumulomnibus clouds. The funnel is usually within 1 km across at the surface, moving at 50-60 km/hr. Pressure inside drops to 60-80% of the normal and the surrounding wind moves at 350 km/hr. **Hurricanes** are tornadoes in a bigger scale. In western Pacific and Indian ocean region, it is known as typhoon.

Wind is the horizontal movement of the air. The basic cause for such motion is the unequal energy pattern of the atmosphere and planetary surface. Globally some permanent features of pressure conditions exist. Winds flow over the surface and also at upper atmosphere. Globally it forms **planetary wind systems** following latitudes.

Table:16.5. Global Climatic Zones.

1 Equatorial rain zone	(5° S-10° N)
dominated by eq trough, weak variable wind mostly from west.	
2 Tropical summer rain zone	(10°-20°N & 5°-20°S)
fine dry trade wind, summer cloudy with rain from ITCZ.	
3 Subtropical dry	(20°-30°N & 20°-30°S)
hot , weak & dry trade-winds, absent from eastern sides of continents.	
4 Subtropical winter rain	(30°-40°N & 30°-35°S)
fine dry summer, subtropical high pressure, westerly in winters.	
5 Temperate	(40°-60°N & 35°-55° S)
prevailing wind from west, moderate rain all year, varying continental effects.	
6 Subpolar zone	(60°-80° N & 55°-70° S)
both westerlies and polar easterlies, heavy rain near oceans.	
7 High polar zone	(80° - 90° N & 70° - 90° S)
ice-caps, variable winds, primarily east, little rain.	

Climate of a region is not simply the average weather condition but rather an association of weather variations. Globally climatic condition is divided in several zones with due consideration to climatic elements like temperature, precipitation and wind conditions. Climates also operate on smaller scale, in accordance with the local features. Local climatic conditions take into account more specific nature of land, insolation, wind circulation, vegetation etc. What we experience in our life mostly, is the local climate or weather.

16.07. MAGNETOSPHERE

The planet assumed to be a huge magnet in its core, possess a magnetic field. The magnetic North pole is near Greenland (73°N, 100°W) and magnetic South pole at 68°S, 134°E.

The German-US physicist, **Walter Maurice Elsasser** (1904-1991), proposed that the rotation of Earth sets up slow eddies in the molten iron core, circling west to east. Eddies have the effect of producing electric currents. It creates something like a magnet extending north and south and cause Earth's general magnetic field.

In 1906, **Bernard Brunhes** (1869-1930), of France noted that some rocks are seen magnetised in the direction opposite to the present. Now we know that Earth's magnetic direction changed several times. Relatively stable period was last 700 thousand to 1.5 myr. Probably it reversed nine times in last four billion years at

irregular intervals. In addition to long term changes, there were small changes, some of which may be related to sunspot activity. Earth experiences often magnetic storm.

The whole planet with its hydrosphere and atmosphere is submerged within this invisible **magnetosphere**. It is believed that iron-nickel core inside is the cause of magnetism. Magnetic axis does not pass through the centre. The axis is 1200 km away from the centre resulting variation in distribution of normal magnetic field. Magnetic anomaly was observed daily, annually, centennially and geologically. It must also be connected with magnetic storm of the Sun. Further its core is not expected to be of single iron core but by a whole aggregate of complex matter and phenomena of terrestrial and cosmic origin. In recent times, space explorations (Explorer-1 in 1958 & others) further revealed that there are two doughnut-shaped main bands of radiation surrounding the Earth. They are called **Van Allen radiation belts** after **James Alfred Van Allen** (1914-2006), of USA who proposed existence of high altitude magnetic field. It is now renamed Magnetosphere. Subsequent studies further revealed that the magnetosphere has sharp boundary called **magnetopause**. It exists some 64,000 km away from the Earth towards the Sun but more then a million km away opposite to it. Charged particles (electron-proton) from the Sun are entrapped along the geo-magnetic lines of force. It is called **Christofilos effect**.

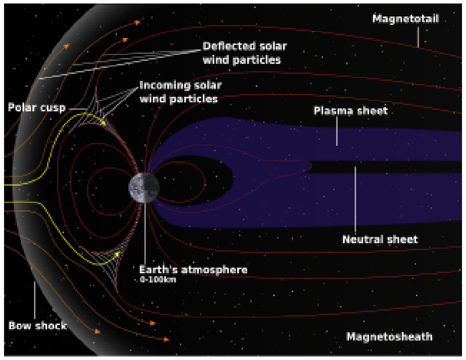

Fig:16.06. Schematic of Earth's magnetosphere. The solar wind flows from left to right. (source: Wikipedia)

16.08. GEOLOGICAL TIMETABLE

To study our past, we have prepared one standard time table, **Gological Tme-Table** (GTT) right from geological origin of our planet (say, 4,600 myr ago) to present. Out of this, earliest 640 myr, was the formative stage of the planetary body itself. No life emerged then and the eon is called **azoic** ('zoa' means life and 'azoic' means no life).

Next 3,960 myr is divided broadly into eon, era and period.

There occurs two eons, **cryptozoic** (3,960-570 myrbp) and **Phanerozoic** (570 myrbp to present).

In the cryptozoic eon spanning for some 3,390 myr, life appeared concealed while in phanerozoic eon of 570 myr span, it was profoundly evident.

The cryptozoic eon is subdivided into **archaean** (3,960-2,500 myrbp = 1460 myr long) and **proterozoic** era (2,500-570 myrbp = 1,930 myr long).

In 1841, the English geologist **John Fillips** (1800-1874) distinguished three eras of the Phanerozoic eon into palaeozoic, mesozoic and cenozoic era.

In the palaeozoic era, ancient life, like marine invertebrates, fish, amphibia and sporophytes, governed. In the mesozoic era, middle life like reptiles and gymnosperms were dominant. In the cenozoic era, new life like mammals and angiosperms were found. Each era is again subdivided into several periods.

Recently whole geological time has been divided into four eons — Hadean, Archaean, Proterozoic and Phanerozoic eon. For more details please see in the chapter-23.

16.09. PLATE TECTONICS

We have not seen mountains moving away? It comes as a shock to learn that our vast continents with mountains and deserts and vast oceans are not fixed in position but move. Our studies reveal that landmasses and oceans are subjected to very slow motion over thousands of years. Australia was not there where it is now. America was elsewhere just like Africa. Atlantic ocean was not there but formed much later.

The present disposition of continents and oceans came after many changes. However unbelievable it may appear, the fact is, all these continents and oceans move and are still moving. From 17th century onwards, Francis Bacon, Count du Buffon, Francois Paget

(1666) feebly voiced such possibilities. **Antonio Snider-Pellegrini** (1802-1885) in 1858 and **Frank B. Taylor** (1860-1939) in 1908, postulated the same. Their thoughts made no impact for want of sufficient proof.

The idea of **continental drift** first emerged from German geophysicist, **Alfred Lothar Wegener** (1880-1930) around 1912. Born in Berlin, he was a doctorate in astronomy but fascinated in meteorology. Eventually he became the Director of Meteorological Research Department of Marine Observatory of Hamburg and later associated with Graz University in meteorology and geophysics. Somehow around 1910, he was struck by the remarkable jigsaw fitting of the coastlines of continents on both sides of Atlantic. Particularly African west fitted so well with South American east. He checked palaeontological and other evidences and started to believe on drifting of continents. He wrote on the subject in 1915 in his book '*Die Entstehung der Kontinente und Ozeane* ' (The Origin of Continents and Oceans).

So long our prevalent ideas was that the cooling Earth contracted to produce wrinkles on its surface. These wrinkles formed continents and mountains with oceans in between. In that case, wrinkles should have been uniform. But that uniformity was found missing. Further there was enough scope of radioactive heat generation to prevent such cooling sequence.

The top layer of our planetary body presents continental surface and abyssal ocean floor. The upper layer of crust consists of lighter rocks like granite while the substratum are made of basalt, gabbro or periodite as in ocean floors. The substratum is expected to act like fluid to accommodate folds. The question arose - if the continental mass could move over this layer in upward direction to form folds, why they could not move laterally?

From geological evidence, the east coastline of South America matched the western coastal shape of west Africa. Striking correspondence between rock formations, mountain structures, sedimentary sequence and fossil distribution between two continents came as a surprise.

During Permian-Carboniferous periods, large low-lying areas of South America, South Africa, India and Australia were glaciated. There was no such corresponding ice-caps in the northern hemisphere. It indicated that all these glaciated areas were grouped together somewhere near the south Pole. Again there exists tropical coal forests across the present temperate zone from North America and northern Europe to Russia. From all these facts taken together, the most likely explanation emerged, was the hypothesis of continental drift.

Nearly 250-225 myr ago when dinosaurs reigned, or even much earlier in late Palaeozoic era, all continents were combined into single giant super-continent, **Pangea** (meaning 'all land'). In the Carboniferous period, South America and Africa began to separate. North America and Europe also started their separation but maintained some contact in the north till the Quaternary period. The Indian ocean began to come up from Jurassic era. The major movement occurred in the Cretaceous and Tertiary period when Indian subcontinent moved northward and collided with Eurasia to raise Himalayan mountains. Australia-New Guinea separated from Antarctica in the Eocene period and moved northward.

Even in our present age, the continents are still drifting. Wegener said - Greenland moving away from Europe at the rate of 1 meter/year. (Later the claim was found not true).

Other evidence in support of the drifting was observed around 1967-68. One 2.5" fossil-bone of an extinct amphibian (labyrinthodont) was found in Antarctica. This fixed Antarctica in a warmer climate. Later fossil Lystosaurus reptile of Triassic period was found in the Central Trans-Antarctic Mountain about 640 km away from South Pole.

The idea of drifting continents appeared impossible to many scientists and Wegener's theory had to face stiff opposition. They argued - continental drifting would be impossible because of continental granite formations floating in the basalt layer below. These basalt layer below the oceans and continents were quite stiff to allow such horizontal movement.

One geologist who supported Wegener, was **Alex du Toit** (1878- 1948) of South Africa. He said that once there were two vast super-continents, northern **Laurasia** and southern **Gondwana,** separated by one Tethys Ocean. Laurasia, a combination of Eurasia (without India) and North America was located at north. Gondwana combining South America, Africa, India, Australia and Antarctica was at south. They were separated from Pangea since late Palaeozoic.

Later, this continental drift theory has been revised into **plate tectonics**. The idea developed from recent finding of sea-floor spreading.

One retired naval officer, **Matthew Fontaine Maury** (1806-1873) of USA, located in 1850 a central shallow region in the Atlantic ocean, named Telegraph Plateau. Around 1925, it became clear that the Telegraph Plateau is actually a submerged mountain range down the length of Atlantic with peaks like Azores, Ascension and Tristan-de-Cunha. It was renamed later as **mid-Atlantic range**. Further explorations revealed that the range bends around Africa at southern edge and goes up through Indian ocean to Arabia. This **mid-Indian Ocean range** then branches off to continue south of Australia and New Zealand and then turns north to encircle the Pacific ocean. The whole range is now called **mid-Oceanic range**. They are of basaltic origin, squeezed up from the hot depth below in contrast to continental ranges of folded sedimentary rocks.

The British geologist **Arthur Holmes** (1890-1965) suggested in 1929, a concept like convective currents. This generated within Earth's mantle and driven by radiogenic heat, might provide the driving mechanism of drifting of continents. The hypothesis remained neglected for sometime.

The US marine geologist **William Maurice Ewing** (1906-1974), gathered that the oceanic crust is only 5-8 km thick while the continental crust is roughly 40 km thick. He also noted the global extent of the mid-ocean ridge. Around 1957, a deep central rift was located in the ridge by **Bruce Charles Heezen** (1924-1977), referred to as **Great Global Rift**. The rift is not continuous but of short and straight sections set off from each other.

Based on all these facts, **Rear Admiral Harry Hammond Hess** (1906-1969), a geologist of Princeton University, improved the idea of mantle convection in 1960 and put forward basic premises of sea-floor spreading. He named flat topped submarine volcanoes as '**guyots'**. Inductively Hess integrated several disparate features - apparently early age of ocean floor, circum-Pacific island-arch system marked with many volcanoes and Earthquake sites suggesting faults, mid-oceanic ridge system having seismicity, high heat flow, local volcanicity and axial rift.

The crust above Moho, rides passively over convecting mantle and makes a gap on the ridge crest, which is continuously filled up by fresh lava welling up. Excess crust at opposite ends, descends into the mantle for recycling. In this way, new sea-floor is created that spreads out towards trenches. The continents are thus carried out. This new idea was called **sea-floor spreading** by the American oceanographer **Robert Sinclair Diatz** (1914-1995) and **Henry**

William Menard who discovered fracture zones in the Pacific basin due to lateral faulting. The rift is the weakest spot of crust through which hot molten rock or magma came up. The igneous rock-mass cooled, spread out and piled up to form the ridge. The spreading may be as fast as 16 cm/year. Due to this, sedimentary rocks of the ocean floor seldom become older.

The theory got support from another quarter, **rock-magnetism**. The subject was studied first by the French geographer, **Jean Bruhnes** (1869-1930), early 20th century (possibly around 1906). Recent lava are magnetised in the direction of present magnetic field. But Tertiary lava are found oriented in present or reverse direction and older lava in many different directions.

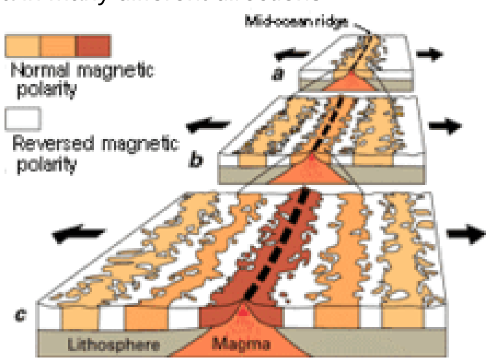

Fig:16.7. seafloor spreading & magnetic striping.

By the middle 1950s, **Stanley Keith Runcorn (1922-1995)**, **K. M. Creer** and **Edward Irving** (b1927) of Cambridge, obtained samples of rocks from Europe. Those showed steady changes of rock-magnetism with time. North Magnetic Pole changed its position from pre-Cambrian days from Hawaii. **Blackett** and a group of Imperial College, London, found similar results from rocks of other continents. Such anomaly of fossil magnetism suggested again migration of poles and drifting of continents. Checked with geological and palaeontological evidence, palaeo-magnetism provided an estimate of ancient climate of the region. For example, Palaeozoic glacial rocks of Australia determine high latitude of the island closer to south Pole. Runcorn further observed that magnetic anomaly disappeared if

North Atlantic was closed and North America was taken adjacent to Europe.

There is another aspect of fossil magnetism. Earth's magnetic poles did not remain fixed to its present locations but underwent several **polarity reversals**. It was noticed by Cambridge graduate scientist **J. Hospers** in 1950s when he studied lava rock-sequences in Iceland. It occurred irregularly at an average interval of every 700,000 years. Each reversal took only few thousand years. The last reversal took place 1 myr ago. The chemist-geologist, **Alan Verne Cox** (1926-1987) of Stanford University, measured among others this polarity reversal in lava sequences for 5 myr and established a magnetic time scale. Within 4 myr, we have identified *Brunhes normal phase* preceded by *Matuyama reverse*, *Gauss normal* and *Gilbert reverse*.

The British geologist, **Frederick John Vine** (b1939), then a research student, and his supervisor **Drummond Hoyle Mathews** (b1931) of Cambridge, substantiated Hess's idea in 1963, based on this reversal of magnetic polarity. They published an article in '*Nature'*. Lava coming out of oceanic crest acquired geomagnetic polarity. Subsequent injections acquired subsequent geo-magnetism and forced earlier lava to move away laterally from the ridge. Thus blocks of alternately normal and reversely-magnetised material would drift away from the centre of the ridge and parallel to the crest. Since the planet records reversal of polarity in fossil magnetism, anomalies of polarity would spread on flanks of the oceanic ridge.

Vine tested this idea by plotting widths of anomalies in the oceanic crust against reversals signed on land. It confirmed that sea-floor spreading rate ranges from 2cm/year in North Atlantic to more than 15cm/year in central South Pacific.

The Canadian palaeo-magnetist **Lawrence Morley** (b1920) independently arrived at the same conclusion, though he was somewhat late to earn credit. The hypothesis thus demonstrates conclusively that the ocean floor is continuously renewed after destroying the old. It solves the paradox of old continents and young oceans that we observe.

Our Nature creates some forms and destroys them to recycle into another form at the same time. Is it not an unique scientific way to establish some otherwise non-testable facts?

Two years later, the Canadian geophysicist **John Tuzo Wilson** (1908-1993), of Toronto, Canada, added further confirmation to drifting and sea-floor spreading, by explaining the **mechanism of transform fault**.

When continental plates slide past one another, instead of one sinking below the other, transform faults occur. Mid-oceanic ridges often have a series of offsets connected by transform faults. This accounts for volcanic activity and earthquake in certain zones of the fault.

In 1967, the British geophysicists, **Dan Peter McKenzie** (b1942) and **Robert Parker** of Cambridge, next year the American geophysicist **Jason Morgan** (b1935) of Princeton, USA and the geophysicist **Xavier Le Pichon** (b1937) of France further developed the theory from marine geo-physics and seismology study into 'plate tectonics'. Morgan divided our Earth into twenty blocks or plates of large and small areas with various type of boundaries.

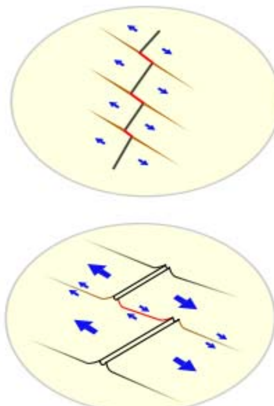

Fig:16.8. Transform fault shown in red lines. (source: Wikipedia)

Le Pichon recognised six major plates. The whole terrestrial surface is covered with segments of tectonic plates, delineated by trenches, mid-oceanic ridges and transform faults. San Andreas fault in California, faults at north Anatolia, the Caucasus and Iran are examples of these faults. Most plates carry both ocean and continent (ex. South American, North American or Australian plates). The Pacific plate contains ocean only.

As the magma wells up from hot layers below through cracks of plates, it pushes plates apart or forces them to get closer. Atlantic ocean was formed by such push between South America and Africa

in the south and North America and Europe in the north. Europe and Africa were pushed apart to form Mediterranean sea and Red sea. Red sea in particular is a young ocean in the making, formed due to rift between Africa and Arabia. When plates approach slowly towards each other, the crust buckles and bulges up and down to make fold mountains. When plates approach rapidly, the surface of one plate may go under the other, thereby forming deep trenches, chains of islands, volcanoes etc as found in western Pacific area.

Thus we know that the top crust of our planet is not a continuous shell of granite and basalt. It is a mosaic of some rigid segments or plates of lithosphere so broken that each plate is movable over ductile asthenosphere below. These plates carry oceans and continents. Each plate moves in a single independent body. At the mid-oceanic ridges of Pacific, Atlantic and Indian oceans, we encounter plate boundaries. The lithospheric plates, comprising of crust and thick slice of mantle, are generally 80-90 km thick but sometimes they may be as thick as 100-120 km. They move slowly over plastic or molten layer of asthenosphere.

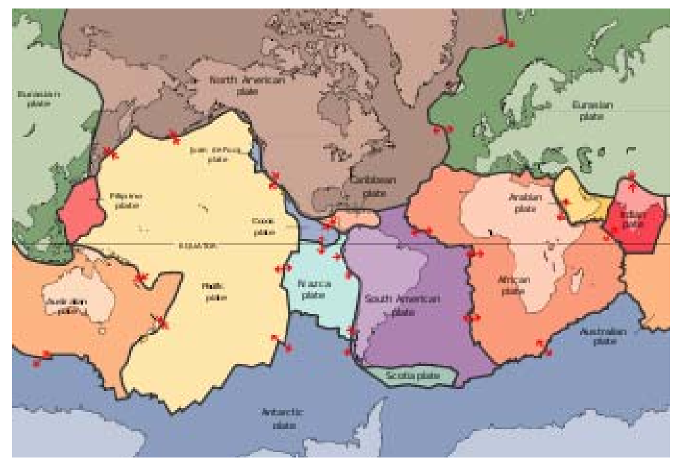

Fig:16.9. Major tectonic plates of Earth.

Some **8 major plates** and about **10 minor plates** are identified so far. One major plate is the Pacific ocean plate. Other seven major plates are Antarctic, Indian, Australian, African, North American, South American and Eurasian plates. Some small plates are Arabian, Somalian, Phillipine, Nazca, Cocos and Juan de Fuca plates.

There occurred three types of plate-boundaries : (1) **divergent boundary** where ocean rises and new crust is created, (2) **convergent boundary** where ocean goes in trenches and crust is destroyed and (3) **transform faults** where crust is not created or destroyed but move horizontally.

Earthquakes occur commonly along plate boundaries. Pacific Plate boundary includes Earthquake regions of East Indies, Japan, Alaska, California etc. Mediterranean Plate boundary between Eurasian and African plates also include Earthquake regions. Volcanoes are common in plate-boundary regions. Pacific Plate is well-marked for such active or passive volcanoes.

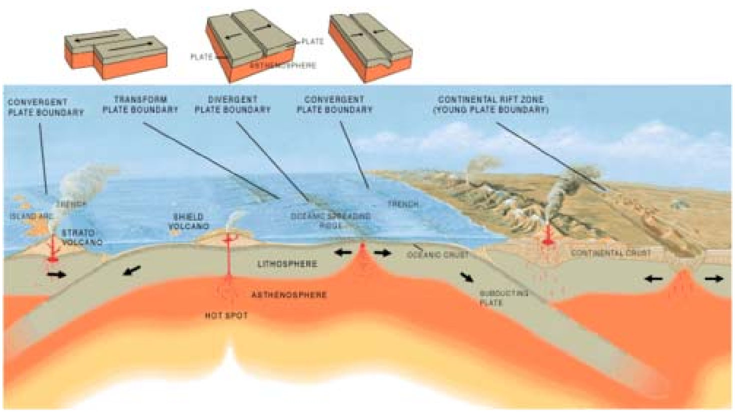

Fig:16.10. Three types of plate boundary - Divergent and convergent plates with transform faults.

Some seismic and volcanic activity is observed within plates instead of at boundaries, as in Hawaiian islands chains. The geophysicists John Tuzo Wilson and **W. Jason Morgan** (b1935) explained this feature by the mechanism of **hot-spots**.

Hot-spots are magma-producing volcanic regions located deep within the mantle. Plumes of mantle material rise due to convection currents. As the plate pass over this region, volcanic islands are formed to discharge molten magma. As the plate moves on, old volcano dies and a new one is formed over the same hot-spot,

leaving a chain of volcanoes. They may be on, near to, or far from tectonic plate boundaries.

How this hot-spot area is originated, is yet to be explained. There are two hypotheses. One suggests that they are due to hot mantle plumes that rise as thermal diapirs from the core-mantle boundary. The other hypothesis postulates that it is not high temperature that causes the volcanism, but lithospheric extension that permits the passive rising of melt from shallow depths. So the term "hotspot" is a misnomer. They assert that the mantle source beneath them is, in fact, not anomalously hot at all.

Yellowstone National Park of North America is a site of continental hotspot. Some other hotspot chains are Hawaiian-Emperor seamount chain (Hawaii hotspot) Louisville seamount chain (Loiusville hotspot) etc.

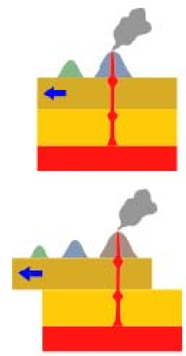

Fig:16.11. Hotspot - Diagram showing a cross section though the Earth's lithosphere (in yellow) with magma rising from the mantle (in red).

16.10. OUR GEOLOGICAL PAST

We may now attempt to reconstruct our geological past and see how vast land masses, continents and oceans, evolved with time. The picture is not full-proof but demonstrates essential idea of evolution of Nature occurring at so many different levels.

The Earth came into being roughly 4.6 byr ago.

Earliest matter we know about, are grains of mineral zircon that shows an age of 4.3 byr.

The oldest rock of Slav Lake region of Canada showed an age of 3.96 byr. Slightly younger in age are rocks (gneisses) at Ishua in Greenland (3824 myr as per radiometric dating). Nearly same age-old rocks were found on the Limpopo river in South Africa, and in north-east India. In 1983, slightly older rocks, eclogites, were recovered from volcanic pipes in South Africa yielding a date of 4 byr.

On the whole, planet's history during its first 640 myr remains largely unknown. All we can say that it evolved from the ball of cosmic dust of solar nebula into solid grains which gradually accreted into rocks of planetesimals. These further agglomerated. In the process, constituent heavier metals sank towards centre, keeping lighter elements on the surface. Lightest matter (hydrogen and helium) escaped into space. During the accretion, heat was generated from the release of gravitational energy, radio-active decay and meteor impact. This melted planetary material and allowed lighter matter to rise up. They crystallised to form the crust. Iron-nickel sank towards the core. Outgassing of light volatile matter, associated with volcanism, occurred and formed secondary atmosphere containing water vapour. When the planet cooled down, water vapour formed oceans. The process of melting, separation of matter and outgassing is described by the term **differentiation of the Earth**.

The newly formed crust must be thin and unstable. These collapsed and recycled into mantle and then again into crust by convection cells. The process continued in rapid succession for nearly 700 myr. Oceans emerged possibly around 3,900 myr ago. Gradually the planet grew into layered structure producing landmass, oceans, hydrosphere and atmosphere.

Some 2,500 myr ago, Archean crust regions were formed. No large stable continent existed. They all emerged later. Mountain building activities occurred in the margin of and between continents. **Greenstone-granite belts** formed in the upper Archean crust and **granite-gneiss belts** in the mid-lower crust. Some Archean cratons, shield or regions, can be identified in the North Atlantic craton (included in north-western Scotland, central Greenland, Labrador), Kaapvaal & Zimbabwean cratons (South Africa), Dharwar craton (India), Aldan & Anabar shield (Siberia), Baltic shield (in Sweden, Finland & Kola peninsula of Russia), Superior & Slave province (Canada), and Yilgarn & Pilabara blocks (Australia).

Possibly around 2,500 mybp, one large **supercontinent-I** appeared on the scene with one superocean. By early Protorezoic, this supercontinent broke up into several small continents. Orogenic belts formed in long linear forms. During the end of Protorezoic, crustal growth and orogenic activity began to produce large continental blocks. Limpopo, Mozambique and Damaran belts of Africa, Labrador trough and Eastern Ghats of India show regions of old Protorezoic era. These large continental blocks later joined to form **supercontinet-II** in the Palaeozoic era.

Paleo-geographers use the term *supercontinent* to refer to a single landmass consisting of all the modern continents.

The earliest known supercontinent was called now **Vaalbara**. It formed from protocontinents 3.1 byr ago and broke up around 2.8 byr ago.

The super-continent **Kenorland** was formed after that and broke up some 2.5 byr ago into the protocontinent Cratons — Laurentia, Baltica, Australia and Kalahari.

The super-continent **Columbia** or **Nuna** or **Hudsonland** formed during a period of 2.0–1.8 byr ago and broke up at about 1.5–1.3 byr ago.

The supercontinent **Rodinia** formed about 1.1 byrs ago and was surrounded by superocean **Mirovia.** The Rodinia broke up roughly 750 myr ago. When Rodinia broke up, it split into three pieces — the supercontinent of **Proto-Laurasia** and the supercontinent of **Proto-Gondwana**, and the smaller **Congo craton**.

Proto-Laurasia and Proto-Gondwana were separated by the **Proto-Tethys Ocean**. Soon Proto-Laurasia itself split apart to form continents of **Laurentia**, **Siberia** and **Baltica**. The rifting also produced two new oceans, the **Iapetus Ocean** and **Paleo-asian Ocean**. Baltica was then situated east of Laurentia, and Siberia northeast of Laurentia.

Around 600 myrbp, most of these masses came back together to form the relatively short-lived supercontinent of **Pannotia.** This included large amounts of land near the poles and only a relatively small strip near the equator connecting the polar masses. Some 60 million years after its formation, about 540 myr ago, near the beginning of the Cambrian epoch, Pannotia broke up, giving rise to the continents of **Laurentia**, **Baltica**, and the southern supercontinent of **Gondwana**.

Fig:16.12. Pannotia 550 Ma.

In the Cambrian period (some 550-540 mybp), we get two continents, **Gondwana** and **Laurentia**. The independent continent Laurentia had three bordering oceans — the **Panthalassic Ocean** to the north and west, the **Iapetus Ocean** to the south and the **Khanty Ocean** to the east. The Laurentia in the northern hemisphere, was formed by North America and Greenland and some other small continents.

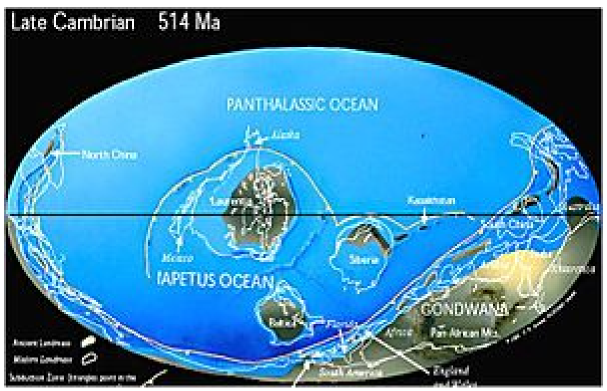

Fig:16.13. During Late Cambrian around 514 Ma.

The southern continent, Gondwana, was extended from low northern latitudes to high southern latitudes just before the South Pole. Antarctica, Australia, China were in low latitudes. China may be

attached to Gondwana or separate. Siberia and Kazkhstania were near China or equatorial Gondwana on separate platforms.

Then Baltica, containing northern Europe and Scandinavia, was in mid-southern latitudes. It advanced towards warm climate near the equator to join with Laurentia during Devonian period. Palaeo-atlantic or Iappetus ocean occurred between Laurentia and Baltica. Sea level rose up in middle Cambrian time but dropped down during the onset of late Cambrian.

In the Earliest Ordovician, around 480 Ma, the microcontinent of **Avalonia**, a landmass that would become the northeastern United States, Nova Scotia and England, broke free from Gondwana and began its journey to Laurentia.

In late Ordovician period (450-480 mybp), Gondwana extended from South Pole to tropics. It consisted of Africa, Australia, South America, southern Europe, Middle-East and India. Then it was moving towards the South Pole. The South Pole was found located at north-western Africa. Laurentia, Siberia, Kazakhstania, North China, part of South East Asia, Australia and part of Antarctica, remained in the tropical region. The continents of northern hemisphere approached each other and resulted in building up of margins of Siberian and North American land. Northern hemisphere continued to be oceans, connected with **Panthalassa** between Gondwana and Laurentia. Iapetus ocean reduced in size while the a new ocean, **Palaeo-tethys** appeared.

During Silurian age, the world was made of north polar ocean, six equatorial continents, and south polar Gondwana. Laurentia consisted of North America, Greenland, north-western Ireland, Scotland, Chukotsk peninsula of Russia. One micro-continent Barentsia possibly joined with Laurentia. The narrow Iapteus Ocean still separated Baltica. The micro-continent Avalonia was attached with Baltica. Siberia was separated by **Pleionic Ocean** from Baltica. Another ocean **Rheic** occurred between Gondawana and Baltica. The super-continent Gondawana contained Australia, Antarctica, India, Arabia, Africa, South America, and small landmass of Florida, southern Europe, Turkey, Iran, Afghanistan, Tibet and Malay Peninsula. Brazil was then at South Pole.

In the first half of Devonian period, some 370-390 myrbp, Laurentia started to combine with Baltica during Caledonian orogeny to produce **Laurussia** or **Euro-america**. Modern mountain edifices of Appalachians and Scandinavia were the result of that collision. South Pole was located in today's Argentina or in South Africa. Siberian, Chinese and Australian continents with eastern parts of Euroamerica were at the tropical and equatorial latitudes. Siberia and Kazakhstania began their joining during late age of the period. They later joined with Laurussia, forming Ural mountains. An advance between Gondwana and Laurussia started.

In early Carboniferous period, about 320-340 mybp, five major landmass, namely, Gondwana, Laurussia, Siberia, Kazakhstania and China occurred. The continents approached more towards each other. Orogenic regions and mountain edifices, such as Urals, Tien Shan, mountains of South Mongolia and West China, and Salair mountains arose on collisions of plates. The ocean, **Paleo-tethys** separated Chinese and Siberian-Kazakhstania landmass from Laurussia-Gondwana.

Fig:16.14. Supercontinent Panagaea (300-200 myr ago).

In mid-Carboniferous period, considerable part of Gondwana turned in the polar region of the southern hemisphere, which led to greatest glaciation.

During late Carboniferous, Laurussia joined with Gondwana and closed Tethys ocean. The fusion was accompanied with

Appalachian-Hercynian orogeny. The super-continent-III, **Pangaea** or **Pangea**, began to form again, consisting of Gondwana in the south and Laurasia in the north. The United States and northern Europe remained in northern hemisphere with Siberian and Chinese plates.

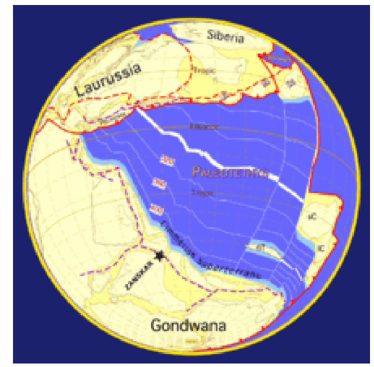

Fig:16.15. Permian period 290 Ma

In the Permian period, Gondwana joined with western Euramerica. Angaran region of Siberia joined with Euramerica at some later date. The new super-continent Pangaea became complete during the mid-Permian. It stretched from Pole to Pole in a narrow belt of 60° latitude. The macro-continent was surrounded by the mega-ocean **Panthalassa** with its branch **Tethys**. Glaciation continued during early Permian but later subsided by gradual warming.

Continental drifting began in late Triassic period. In the 2nd half of the period, at about 200-220 mybp, Chinese continent joined Eurasian landmass. Isolated small continents survived within its limits. The super-continent Pangea began to disintegrate. Laurasia was the first to break away in the area of today's Atlantic and Arctic oceans. The Panthalassa ocean moved westward between Gondwana and Laurasia with Tethys extending further in late Triassic.

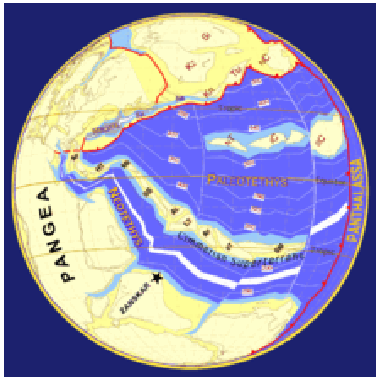

Fig:16.16. Landmass during Permian & Triassic age.

By early Jurassic, continents were grouped closely in the Pangean form but divergence was taking place. The super-continent caused development of geosynclines on coastal margins. Active plate collisions occurred around the Pacific margin. In late Jurassic epoch, some 140-160 mybp, Laurasia moved with the opening of North Atlantic ocean basin and mid-oceanic ridges. Tethys continued to evolve, a system of island-arcs was located in its north in the area of today's Lesser Caucasus, Elburz and mountains of Afghanistan. The continents moved latitudinally throughout late Jurassic and Cretaceous. South Pole was south of Antarctica. North Pole was in the Arctic sea. The equator ran through the Pacific ocean and Tethys.

The Cretaceous period began with two continental assemblies. They were almost separated by Tethys sea. North America began its drifting away from Eurasia in earlier Jurassic period. South America began to split away from Africa in Cretaceous period. South Atlantic Ocean joined hands with expanding North Atlantic Ocean. India, Australia and Antarctica were on the verge of separation.

By the end of Cretaceous. Madagascar separated from Africa. Isolated India began to move northward. Australia was connected till then with Antarctica. Greenland separated from North America. Sea level was higher for most of the time in Cretaceous. It was a time great inundation.

Fig:16.17. Plate tectonics during Cretaceous period.

Several great mountain ranges were formed during the Cenozoic era. The Alpine orogeny produced Alps, Carpethians and Atlas mountains (37-24mybp). Rocky mountains were raised. Greenland and Scandinavia separated and Norwegian-Greenland Sea began to form by early Palaeocene (56-55 mybp). Australia separated from Antarctica in late Palaeocene and moved northward.

India joined with Asia about 45 myr ago in mid-Eocene and blocked Tethys flowing westward. Tethys continuously reduced throughout Cenozoic era, north and east of the Indian plate, leaving its relic in the Mediterranean Sea. The ocean was severely reduced in the eastern part with the uplift of Himalaya. Final closure came in 18 myr ago with the joining of Africa and Asia. The modern Mediterranean Sea is the remnant of ancient Tethys.

Subsidence of South Tasman Rise joined Indian Oceans with Pacific by late Eocene (40mybp) and mid-Oligocene (32 mybp). The formation of Labrador sea was completed by 35 mybp.

In the Eurasia, Ural trough linked waterways between Tethys and Arctic Ocean. By the end of Eocene, this water link was closed thereby joining Asia and Europe. The collision of Africa and Europe generated Alpine-Caucasus mountain system around 18 mybp. Gibraltar Straits opened at early Pliocene (5mybp). Panama Isthmus emerged around 3 mybp and joined two American continents.

The climate was warmer during early part of Cenozoic. Cooling began 50 myr ago. Antarctica was glaciated about 35 myr ago. The major glaciation over the northern continents occurred 3-2.5 myr ago. From records of last 730,000 years, we get eight major glaciation period inter-spread with interglacial events. The last glaciation in the Pleistocene period occurred around 12,000 year ago.

16.11. OROGENY

Generally short periods of active volcanism was intervened by long periods of calm magmatism. Tectonic activities resulting into mountain building, occurred during such active periods. If we can determine the age of igneous rocks of the period, age of such rock formation and tectonic activity can also be known. This provides us a time-table about the major tectonic activity in far geological past. **Orogeny** is the study of folding and thrusting, metamorphism, intrusion of igneous rocks and uplift that build most mountain ranges.

We have very little information about rocks of earliest period. Basaltic and ultra-basaltic volcanism was active before 3,500 mybp. Granitisation happened at about 3,500 mybp.

Formation of sedimentary basins occurred during the earliest **Belozerian** and **Kola** orogeny, in the Archean eon. Sands and clays deposited. Carbonate rocks formed. In the next **Kenoran** orogeny (3,000-2,400 mybp), nuclei of major stable geo-structural elements were built up. Those structures, named **hedreo-cratons**, paved the way towards formation of nuclei of **cratons**.

In the next few orogenies, bases of all major known ancient hedreo-cratons, such as, the East-European, Siberian, Chinese, Tarimian, Hindustan, African-Arabian, North American, South American and East Australian hedreo-cratons, were formed. The ancient granite layer of crust was formed during the period of 2,700-1,670 mybp. Carbonate sedimentary rocks intruded. Huge granite-based plutons, surrounded by most ancient sedimentary rocks, fixed the stable crustal formations within the hedreo-cratons. These are known as **shields**. Baltic, Canadian, Brazilian, Arabian shields were formed in this period. There existed a huge single super-continent (supercontinent-I) in this Proterozoic eon within one world ocean.

After subsequent activities and movements, we may locate five large hedreo-cratons in the southern and four in the northern hemisphere. The southern group converged into **Gondawana** super-continent. The northern group, a combination of East European, North American, Siberian and Chinese cratons, gradually grew into the super-continent **Laurasia** due to increased volcanic activities in the Caledonian orogeny (410 mybp). The term

'Caledonian' was introduced by Suess and was applied to a belt of strongly folded rocks found in Great Britain and Scandinavia. The ocean, **Tethys**, separated these two super-continents. During Caledonian orogeny, some major fold mountains appeared, such as, Appalachian mountains in the North American craton, Altai, Sayans, Mongolia, Kazakhstan mountains in the Central Asia, mountains of eastern Australia, Tasmania and Antarctica.

Table.16.6. some major orogenic activity; age in myr.

era	age	orogeny	details
Cenozoic	50	Alpine	Alps, Dinarides, Himalayas.
Mesozoic	90	Cimmerian	Gondwana-Laurasia formed.
Paleozoic	260	Hercynian (Varscan)	Panagea formed, Tibet, Hindukush, Karamoram, Tiensan, Altai, Kumlun, Ural, Appalachian, Cordilleras.
	410	Caledonian	Appalachian, Altai, Mongolia, Kazakasthan.
	520	Salairian	
Proterozoic	650	Katanginian	
	860	Dehlian	
	1090	Grenville, Satpu-rian)	
	1360	Gothic, Elsonian	
	1670	Karelian, Hudsonian	
	1980	Baltic	
	2230	Early Karelian	
	2440	Algonkian (Algoman)	
Archean	2700	Kenoran	major hedreo-cratons formed
	3050	Kolian	granitization contd.
	3500	Belozerian	granitization following basaltic formation before 3500 my.

During the Hercynian orogeny (260 mybp), Gondwana and Laurasia collided to produce again the single super-continent **Pangea** and single World ocean. There occurred intense mountain building activities on the borders of cratons. Tibet, Hindukush, Karakoram, Tienshan, Altai, Kunlun, Ural mountain systems came up. Mountain systems of central and northern Europe, north-west Africa and eastern Australia arose. Appalachians, Cordilleras were built up in North America and South America. Some young platforms like Scythia, Turan, west Siberia were established in west Europe,.

Pangea broke up in the next Cimmerian orogeny (90 mybp) into Gondwana and Laurasia, separated by young Tethys and South Atlantic oceans. It continued throughout Triassic, Jurassic and early Cretaceous period. Crimean mountains arose.

The Alpine orogeny (50 mybp) of late Cretaceous formed the young mountain chains of Alps, Dinarides, Himalayas, Andes and Cordilleras.

16.12. ICE-AGES

In the past, colder climates often occurred at intervals, marked by intense global glaciation. These colder periods are known as **ice-ages**. Intense glaciation took place during these ages. We may identify several reasons for that - varying solar output and availability, changes in Earth’s orbital geometry with changes in tilting and precession, orogenic activity and continental uplift, volcanism, variation of Earth’s surface albedo, fluctuations in oceanic characteristics and changes in continental locations.

Ice ages greatly affected landscape formation.

The earliest evidence of glaciation is the **Huronian glaciation** (2,700-1,800 mybp) that left pre-Cambrian deposits in Lake Huron region of Canada. Three separate horizons of glacial deposits had been found separated by non-glacial sediments.

Table:16.7. Ice-ages (with warm-ages in italics), age in myr before present.

Cenozoic	*Cretaceous*	?	*Triassic*	Permo-Carboniferous		*Devonian*
75	150		225	300	375	
Ordovician	Cambrian		Varangian	? Sturtian	?	Gnejso
450	525		600	675 750	825	900

Between 1000-600 myr in late Pretorezoic period, the largest glaciation took place on Earth. In fact, three glaciation (around 850-800, 750, 720-670 mybp) occurred during that period. From 900 mybp onwards, glaciation occurred almost at an interval of 150 myr with intermediate warm age.

The Pleistocene period (1.6 myr) is marked by several glaciation. Ice sheets and glaciers advanced to cover large areas of America, Asia and Europe. Different names are given to Pleistocene ice-ages in different countries. Four such major advances are distinguished as **Wurm**, **Riss**, **Mindel** and **Gunz** (as per Alpine system). The most recent one ended 11,000 years ago. Four **flood Ages** in between the major ice ages are named as Cageran, Kamasian, Kanjeran and Gamblian.

In recent studies, Quaternary ice-age of northern hemisphere counted some 30 glacials, each followed by brief interglacial period.

The oldest northern glaciation dates some 3 myr ago. Oxygen isotope studies (^{18}O/ ^{16}O) show glacials at 75,000 ybp and 18,000 ybp with interglacial period around 125,000 ybp.

How large-scale glaciation occurred?

Due to uneven solar radiation, water remains as ice in Polar Regions and at high altitudes. A fall of 3.5°c of annual temperature is enough by any means to cause these polar glaciers grow and approach an ice-age. Ice then reflect more sunlight than it could absorb and this would result into formation of more ice. More ice means more reflection (or less absorption) and more formation of ice. The process would gradually develop into an ice-age. Earth's rotational changes with diminishing solar radiation, may cause to initiate this glaciation-process. Perihelion of Earth circles once in 21,310 years. Its axial direction circles once in 25,780 days i.e. about 70/71 years. Actual tilt of Earth also undergoes oscillating changes. All these variations affect temperature-cycle.

The climatologist, **Milutin Milankovich** (1879-1958), of Yugoslavia spent thirty years in computing radiation received by Earth for past 650,000 years. At last, he could establish that changes in solar radiation bear some relations with ice-ages. In 1920, he suggested a cycle of 40,000 years, known as **Milankovich cycle**, with Great spring, Great Summer, Great Fall and Great Winter of 10,000 year each. In 1976, **John D. Hays** and **John Imbrie** (b1925) of USA and **Nicholas John Shackleton** (1937-2006) of Britain, confirmed it from the study of core of sediments collected from Indian Ocean.

The Jewish-American chemist **Jacob Bigeleisen** (1919-2010) of USA and **Harold Clayton Urey** (1893-1981), studied ancient fossils of sea animals and developed an interesting technique to assess sea-temperature. At about 100 myr ago, average ocean temperature was 21°c that cooled down to 16°c within 10 myr. It then rose to 21°c in the next 10 myr. From thereon, average temperature lowered steadily. The Italian-US geologist, **Cesare Emiliani** (b1922), further studied on the same line and observed that average ocean temperature was 10°c some 30 myr ago, 6°c for 20 myr ago from the present day average of 1.66°c.

The change in average temperature of oceans, may be the result of green house effect. Atmospheric carbon dioxide absorb more infrared radiation and block escape of heat from our warm Earth. It then raises atmospheric temperature and results into deglaciation. On the contrary, when there is less carbon dioxide in the atmosphere, it cools the atmosphere and results in glaciation. Volcanoes discharge carbon dioxide while weathering of rocks absorb it. Hence, as a general rule, period of volcanic activity may initiate deglaciation while period of mountain building activity may initiate glaciation.

Human activities and industrialisation in our present age, are of extreme importance to such glaciation or deglaciation. Civilisation or in other words conscious human activity, has come into play to affect Natural system in a profound way.

16.13. ORIGIN OF ATMOSPHERE

Our atmosphere was created at some stage of planetary evolution. During the origin of planetary bodies when dust and gas cloud condensed into planets, some gases were entrapped inside rocks. When the planet, acted upon its gravity, condensed more and more and squeezed out that entrapped gases, it began to form initial atmosphere.

Helium and neon being the lightest and chemically most inert gas must have escaped into space. Hydrogen though lighter, reacted with oxygen to form water. Some estimate show that the Earth retained 1 out of 50 billion neon atoms, 1 out of 5 million hydrogen atoms, 1 out of 800,000 nitrogen atoms and 1 out of 6 original oxygen atoms. Water was then mostly in the form of water vapour. When the planet cooled, it poured heavily to form oceans. Some suggest that Earth's interior released entrapped water vapour and filled up oceans. Scientists now think that this is the major source of oceanic water.

According to Harold Urey, the original atmosphere was predominant with **ammonia and methane**. Hydrogen, the most abundant element in the Universe followed by helium, carbon, nitrogen and oxygen, combined with carbon to form methane, with nitrogen to form ammonia and with oxygen to form water. Helium and excess hydrogen escaped. These methane-ammonia mix was retained by gravity.

When water filled up oceans, possibly due to degassing from interior, ultraviolet radiation broke down water molecules of the upper atmosphere into hydrogen and oxygen. Hydrogen escaped leaving oxygen molecules in the air. The process is called photo-dissociation. These oxygen molecules reacted with methane to form carbon dioxide and water and with ammonia to form nitrogen and water. The nitrogen reacted with the crust forming nitrates. In this

way, the ammonia-methane atmosphere slowly converted into **nitrogen-carbon dioxide atmosphere**.

atmosphere-I (ammonia-methane) $\rightarrow$ atmosphere-II (nitrogen-carbon dioxide) $\rightarrow$ atmosphere-III (nitrogen-oxygen)

With the release of more free-oxygen in the atmosphere, some amount of it, formed a thin layer in the upper atmosphere. This layer blocked ultraviolet radiation to react with lower atmosphere and prevented further photo-dissociation. Then life-forming reactions in the oceans broke down nitrogen compound into free nitrogen and reacted with water to break down water into hydrogen and oxygen. Hydrogen reacted with carbon dioxide to form complex molecules of life. Oxygen was retained in the atmosphere. Thus nitrogen-carbon dioxide atmosphere slowly converted into **nitrogen-oxygen atmosphere**. Present day oxygen rich atmosphere came up quite recently. Some 2000 myr ago, oxygen content was merely 1% of the present level. It reached present level some 400 myr ago.

Table:16.7. Oxygen content in % in million years before present

2000 mybp = 1%; 1000 mybp = 5%; 670 mybp = 7%; 550 mybp = 10% ; 400 mybp = 100%.

The Earth could retain its atmosphere due to its gravity. To escape gravity of the Earth, a rocket needs a velocity of 11.23 km/sec. Air particles fly constantly at varying speeds. Their average speed may be determined by Maxwell-Boltzmen Law. Accordingly, the mean velocity of oxygen in the air at room temperature is 4.8 km/sec, of hydrogen 1.92 km/sec. Some amount of molecules can go even faster than the escape velocity. In the lower atmosphere, collisions of air particles prevent them to escape but in the upper atmosphere where radiation energises particles more, such collisions are less operative. From there, some amount of air possibly leaks in the space. This may explain partly near-absence of hydrogen and helium in the atmosphere at present.

16.14. REMARKS

The Nature abounds in various features of land and water and air, interplaying among themselves and influencing one another. We tried to grasp the Nature of the planet as part of Great Nature.

The evolutionary process working in this Grand Nature was active upon the planet for past 4,600 myr. During this period our planet evolved into what we observe today all around. It began from altogether different Earth accreting from grains, agglomerate and planetesimals. Its interior settled down; its crusts were formed and recycled; its depressions collected water; its atmosphere emerged slowly changing into the present air. Continents and oceans drifted over the whole globe, united and fragmented several times. Mountains were formed. Even the magnetic polarity reversed and trotted the globe. It is not that things took so much time to settle now. Things settle itself at one hand and unsettle again on its own. Rocks weather and erode and deposit and form new rocks. Old rocks change into new. From inside, matter wells up through cracks and volcanoes while old crust goes down. Forces of Nature destroy and remake its creations. It recycles some matter in the old form while transforms some into new forms. This is the story of our planet and of our Nature.

Our mother planet has produced another aspect, the living world. The planetary body with this biological life, formed the unique biosphere. Biosphere is actively modulating the working of our planet while itself being modulated by the planet and stellar system. This close dynamic interaction is reflected in the global and regional ecosystems of which we the human being is a part.

So far we have grossly traversed the course this Universe have passed through to produce galaxies and stars. We have looked into possibilities of how the solar system evolved into planets and other bodies. We have also explored the ways how a planet, our dear planet, evolved into this present form through plate tectonic, climatic changes, ice-ages, evolution of atmosphere. While undergoing these evolutions, this physical world evolved into the living world. Dead and inert matter of this Universe, once created, evolved into many complexities in dead and inert galaxies, stars, planets, rocks, soils, mountains, oceans, rain and wind.

How that dead and inert matter can give rise to life, to conscious life? That's the million dollar question.

Table:16.09. Geological Time Table

(figures are in million years before present unless mentioned otherwise. The chronology has been revised by four eons – see GTT in chapter-23)

I. **Azoic**	(4600-3960) :	no life; chemical, bioorganic evolution.

II. **Cryptozoic eon**: (3960-570)

Archean	(3960-2500) :	mountain & sea formation; biochemical evolution; emergence of living cell; bacteria.
Proterozoic	(2500- 570) :	Increase of oxygen in air; appearance of eukaryotes-metazoans; earliest forms of algae, protozoa, sponges, worms etc

III.**Phanerozoic Eon** :

1. **Palaeozoic era**: (from 570-245 mybp)

Cambrian	(570- 505) :	Explosion of living forms - Trilobites, brachiopods, echinoderms, shelled mollusc.
Ordovician	(505- 438) :	many sea animals mostly invertebrate; First corals, first vertebrate & jawless fish.
Silurian	(438- 408) :	oldest amphibians - the first air Breathing animals.
Devonian	(408- 360) :	Fish in great number. Earliest land plant. Coal beds put down.
Carboniferous (360-286) :		
lower carboniferous (Mississippian):		First fossil & winged insects. Coal bed formed.
upper carboniferous :		First. great reptiles and amphibians. Great development of Archegoniatae.
Permian	(286- 245) :	Sea vertebrates common. Trilobites to end. Appalachian mountains formed.

2. **Mesozoic era**: (from 245-66.4 mybp)

Triassic	(245- 208) :	Great developments of reptiles and ammonites; first mammals; Gymnosperms chief plants.
Jurassic	(208- 144) :	Grasses and flowering plants; great Winged and other reptiles; first birds; Sierra Nevada and other Atlas mountains formed; opening of North Atlantic Ocean.
Cretaceous	(144-66.4) :	Extinction of Great reptiles;. Andes And Pyrrenes formed; opening of South Atlantic Ocean; first angiosperm; first marsupials.

3. **Cenozoic era**: (from 66.4-1.6)

Palaeocene	(66.4 -57.8):	Earliest mammals; radiation of placental mammals; first primates; flowering plants.
Eocene	(57.8- 36.6):	Earliest horses; appearance of primates; Alps and Himalayas formed; Australia separated from Antarctica.
Oligocene	(36.6- 23.7):	present day mammals; primates without tail.
Miocene	(23.7- 5.3):	Increase of mammals; Hominids.
Pliocene	(5.3- 1.6) :	Greatest development of mammals; Australopithecus genus.

4. **Quaternary era**: (from 1.6 to present)

Pleistocene	(1.6-0.010):	appearance of Homo genus; Earliest human; period of glaciation.
Holocene	(0.010-present):	Human civilisation.