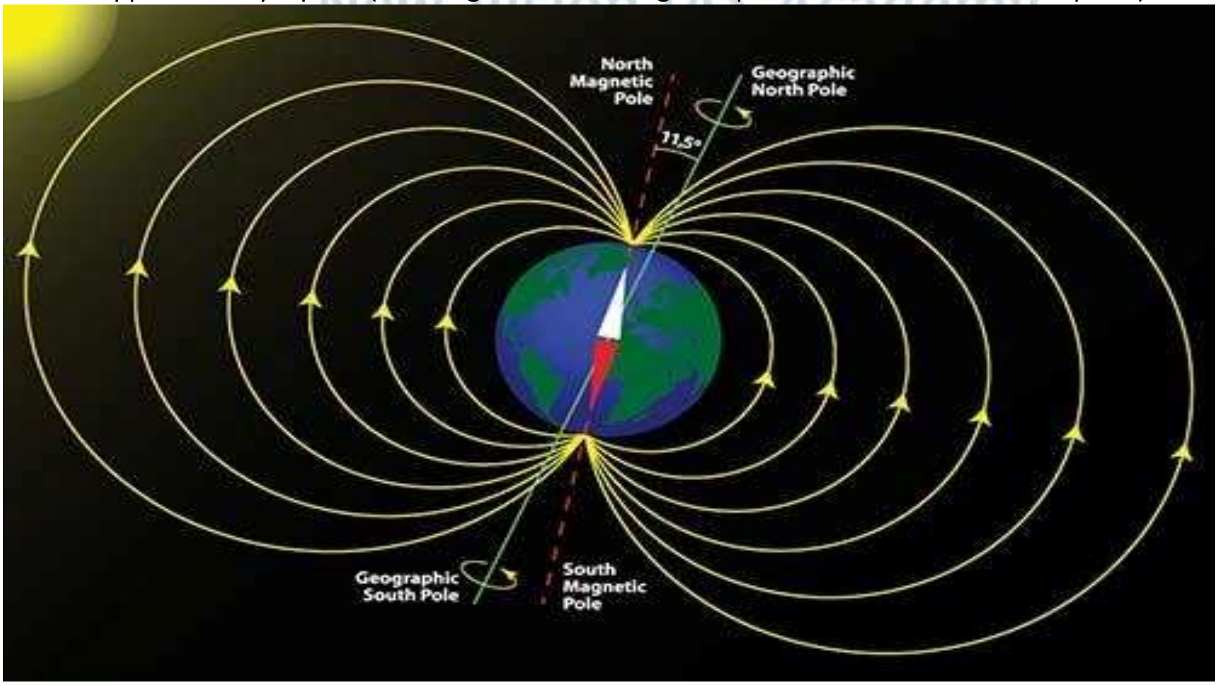
- Wegener's continental drift hypothesis states that, the Earth is not a static but is quite dynamic & its continents do shift from one place to others and left evidence of their movements in the form of natural remanent magnetism preserved in the marine basaltic rocks of ridges and rocks formed by surface volcanic eruptions.
- A study of magnetic characters of the rocks is known as palaeomagnetism.
- The Earth has its own magnetic field.
- Palaeomagnetism, primarily concerns with the ancient magnetic field of Earth and this study provided unquestionable support to the theory of drift of the continents and concept of seafloor spreading.

PALEOMAGNETISM

- Palaeomagnetism is the fossil magnetism that is retained in certain rocks.
- Palaeomagnetism is also the science which deals with the study of natural remanent magnetism of the geological past, which is preserved in the rocks.
- It clarify that the term palaeomagnetism refers not only to a phenomenon (i.e. magnetism of the past), but it also refers to a branch of science.
- Paleomagnetic studies helps to determine the direction and intensity of the magnetic poles of the Earth during the time of the formation of the rocks containing natural remanent magnetism (Wicander and Monroe, 2010).
- Paleomagnetism highlights :-
  1) History of earth's magnetic field in the geological time
  2) the measurement & evaluation of orientation of magnetic field preserved in the rocks.

GEOMAGNETISM

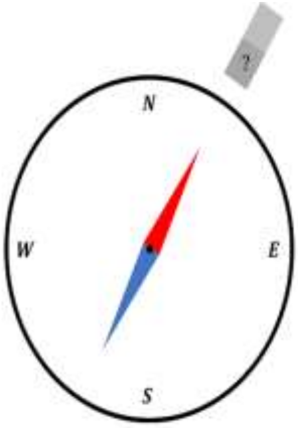
- The magnetic needle of a clinometer compass always aligns itself in rest with north-south direction.
- This property of a compass has been exploited by navigators for centuries
- Due to the magnetic properties in the Earth the magnet needle of a compass always rests in north-south direction
- Geophysicists keeps record of the magnetic behaviour and the magnetic field of Earth.
- Earth behaves like a giant bar magnet & therefore, the magnetic field of the Earth is often described as being approximately dipolar (meaning two unlike magnetic poles such as north & south poles)



- If the needle of compass allowed to rotate freely, it could freely get its orientation both horizontally and vertically & the alignment of the needle would vary continuously from one point in space to another.
- To measure the force on the magnetic needle causing it to assume its preferred alignment shows that the strength of this force, proportional to the intensity of the magnetic field, also varies continuously with position in space.

MAGNETIC ORIENTATION OF THE EARTH

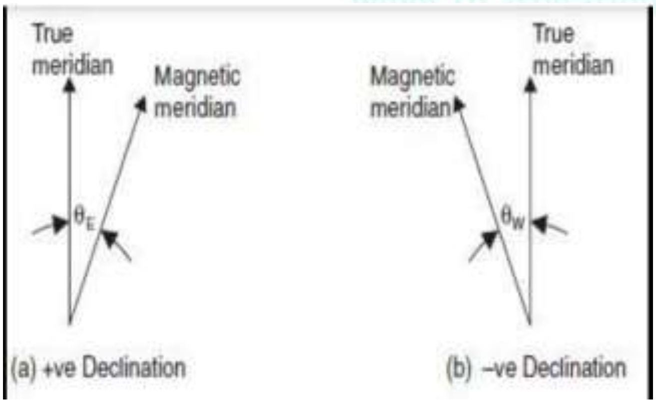
- The magnetic field of the Earth is described as dipolar, with field lines emanating from the south geomagnetic pole and converging at the north geomagnetic pole
- Although this description is useful for many purposes, it is not accurate.
- The magnetic axial line (obtained by joining magnetic pole with center of the Earth) of the Earth and the Earth's spin axis (obtained by joining geographic pole and Earth's center) are not same or parallel, but they have an angular relationship of approximately 11.
- Moreover, there are additional, non-dipolar ingredients in the geomagnetic field, all of which, when added together, are the total surficial field in all of its complex detail.
- Because of this complexity, not only does the direction of the compass needle deviate from true north, the amount of the deviation is called as the declination varies as a function of geographic location.
- At the north located geomagnetic pole, our freely moving magnetic needle would point down towards center of the Earth , whilst at the south geomagnetic pole, the needle would point up.
- For these reasons, the geomagnetic poles are sometimes referred to as dip poles.
- With the help of these two magnetic poles, the Earth as a sphere can be imagined having many latitudes and longitudes in the same way as we have the geographic ones.



- If the freely suspended magnetic needle is allowed to travel from north to south, one end of the needle (say N marked) would be vertically pointed downward at north pole, but the same would pointing upwards at south magnetic pole.
- It will have different inclination which changes gradually from one pole to the other, somewhere in the middle of its journey it will be completely rest as horizontal.
- Here is the inclination of the magnetic needle (magnetic dip) is zero.
- All the places on the globe, where the magnetic dip is zero, can be called as magnetic equator
- All points on the globe having same inclination (which may vary between 0° to 90°) form the magnetic latitudes.

MAGNETIC DECLINATION / VARIATION

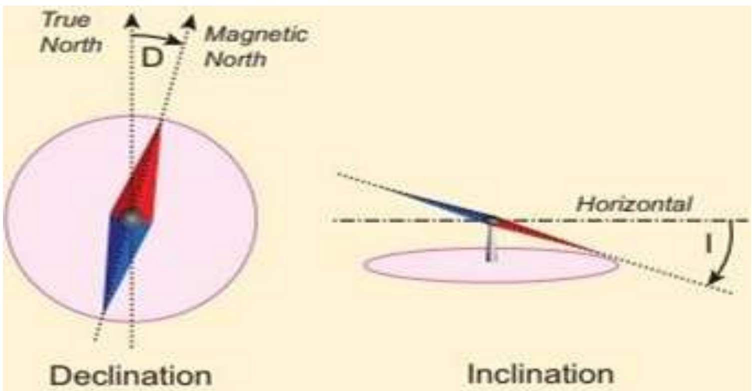
- It is the angle on the horizontal plane between magnetic north (the direction in which the north end of a compass needle points, corresponding to the direction of the Earth's magnetic field lines) and true north (the direction along a meridian towards the geographic North Pole)
- In other words, declination of a magnetic field is defined as the angle between the horizontal component of the field vector and the magnetic north.



- The declination is considered positive when the magnetic north is east of true north.

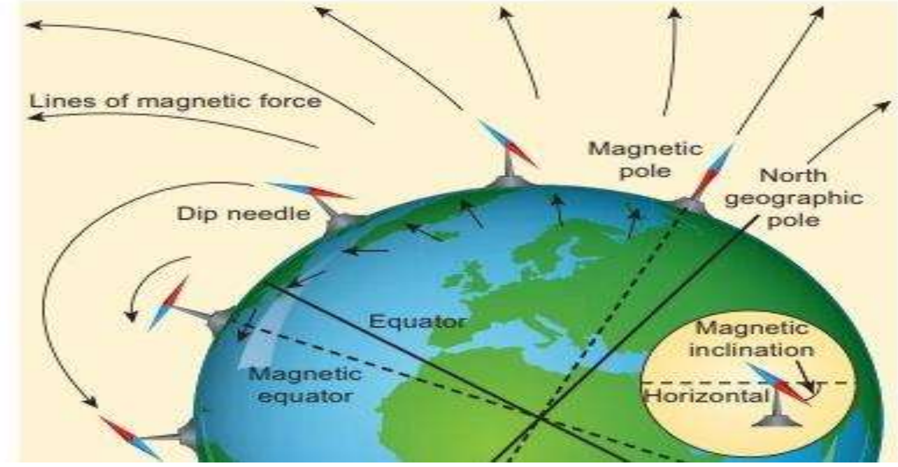
MAGNETIC DIP/DIP ANGLE/MAGNETIC INCLINATION

- It is the angle made with the horizontal by the Earth's magnetic field lines
- This angle varies at different points on the Earth's surface.
- The dip angle is in principle the angle made by the needle of a vertically held compass (though in practice ordinary compass needles may be weighted against dip or may be unable to move freely in the correct plane).



- The value can be measured more reliably with a special instrument, typically known as a dip circle.
- In the northern hemisphere, the N (north) marked end of the compass needle will point downwards, this is positive dip by convention, while the same needle will point upward in the southern hemisphere and it is negative.
- The north end of the magnetic needle is always attracted towards southern end of another bar magnet and vice-versa.
- The range of magnetic dip is therefore from –90° (at a magnetic pole in the southern hemisphere) to

+ 90° (at a magnetic pole in the northern hemisphere).



MAGNETIC COORDINATES

MAGNETIC LATITUDES

- Like geographic coordinates, the geomagnetic coordinates also refer to magnetic latitudes and longitudes.
- Magnetic Latitudes are also known as isoclinic lines and represent a locus of those points on the Earth's surface where magnetic dip is the same.
- The Earth's magnetic field is primarily dipolar, referred to as north magnetic pole and south magnetic pole.
- The magnetic poles are not the same as the geographic poles
- The axis formed by joining of magnetic N and S poles (i.e. Earth's magnetic axis) makes an angle of 11.5 Degrees with Earth's spinning axis

MAGNETIC EQUATOR & MAGNETIC LONGITUDES

- Magnetic equator: It is also known as aclinic line and represents locus of the points having zero dip on the Earth's surface.
- Magnetic longitudes: They are also known as magnetic meridians and like the geographic longitudes they are the imaginary lines, which run over the Earth's surface in magnetic N-S direction to reach to the magnetic poles.
- The magnetic longitudes may have azimuthal (directional) values between 0 to 360° to cover the entire globe.
- However, the geomagnetic poles are not antipodal (meaning that the lines joined by the center of the Earth and the two magnetic poles do not form a perfect straight line) and this is an asymmetry that is just another measure of the field's geometric complexity.
- Thus, we should not expect geographic latitude and longitude of a magnetic pole in the northern hemisphere as it may not have same values for opposite magnetic pole in the southern hemisphere.

REASONS OF GEOMAGNETISM

- The Earth's interior is invisible as well as complicated and the interior is broadly consists of three layers namely, crust, mantle and core.
- The inner parts are composed of a solid-iron inner core, a liquid-iron outer core, and an electrically-insulating, rocky overlying mantle.
- The geomagnetic field is believed to originate from a dynamic process involving the convective circulation of electrical charges in the fluid outer core
- These electrical charges get their energy for circulation from the convection driven by chemical differentiation and the heat of internal radioactivity.
- The core is, therefore, like a naturally occurring electric generator, where kinetic energy is converted into electrical-magnetic energy. This process is commonly known as magnetohydrodynamics. The Earth, therefore, behaves like a dynamo, which is self-sustaining.
- Physicists tell us that if you curl the fingers of your right hand in the direction of the current, your thumb points in the direction of the magnetic north pole
- This rule is known as the right-hand rule.
- Depending on the geometrical relationship between the electrically charged fluid flow in the outer core and the magnetic field, the north and south magnetic poles of the Earth are decided.
- If there is a change in patterns of the flow inside the core in the history of the Earth, the locations of the magnetic poles are also liable to change over the Earth, and can reverse even.
- Although, the magnetic field at the Earth's surface is predominantly an axial dipole, the actual magnetic field is more complicated.
- Yet, it is convenient to retain the dipole model for simplicity because this allows simple calculations that can be made to predict the geomagnetic field at any point on the Earth.

ROCK MAGNETISM

- The rocks are the aggregates of minerals and the constituting minerals of the rocks may have different natural properties.

- There are some like those of iron minerals, which are susceptible to magnetism (hence known as magnetic minerals). And, because of their (iron minerals) presence, the rocks also exhibit some magnetism.
- Some minerals have special electronic configuration of their constituting atoms because of which they are capable to act as small magnets (or dipoles). Such minerals are referred to as paramagnetic materials.
- When a paramagnetic substance is placed in a weak external magnetic field, such as Earth's field, the atomic dipoles rotate so as to become parallel to the external field direction.
- This magnetisation from the substance is lost as soon it is removed from the external magnetic field because now the dipoles return back to their original orientations.
- Ferromagnetic materials like iron and nickel contain large number of unpaired electrons and they may retain magnetisation even after the removal of the external magnetic field (Kearey and others, 2009).
- The magnetisation remains preserved only if the material has not crossed a critical temperature known as 'Curie temperature' (temperature above that magnetisation is lost).

NATURAL REMANENT MAGNETISATION

- There are two types of magnetic behaviour shown by the rocks when kept under external magnetic forces such as those of the Earth. Their magnetic behaviour may be temporary or permanent.
- Induced Magnetisation: In this type of magnetisation, if any material is placed under the applied magnetic field, the material will get magnetisation. But its magnetisation disappears after removal of that field because the dipoles of the material return back to their original orientations. Paramagnetic substances show this type of magnetisation because of their special electronic configurations .
- Permanent or Remanent magnetisation: The ferromagnetic minerals get magnetised under some external magnetic forces. But when somehow the external magnetic field is removed the preferred magnetic directionality of the material is still retained or preserved in the minerals because of its ferromagnetic behaviour.
- This retained magnetisation is known as remanent magnetisation or permanent magnetisation. When this remanent magnetisation denotes preservation of naturally (not experimentally) occurring phenomena such as Earth's magnetism, it is known as Natural Remanent Magnetisation (NRM).
- The rocks and minerals on the Earth that preserve the record of the past directions of magnetic field of the Earth are very useful in palaeomagnetism (Kearey and others, 2009).
- Paleomagnetic techniques make use of those phenomena by virtue of which certain paramagnetic and ferromagnetic minerals retain the records of the past directions of the Earth's magnetic field preserved in the ancient rocks.

PRESERVATION OF NATURAL MAGNETISM

PRIMARY NRM IN IGNEOUS ROCKS

- Two categories :
- Primary NRM: It is acquired by the rock at the same time as the formation of the rock itself;
- Secondary NRM: It is acquired later after the formation of the rock.
- The igneous rocks are formed by cooling of magma from the molten condition. As magma cools down, a set of mineral starts solidifying At this stage, its ferromagnetic minerals such as magnetite, hornblende etc. pick up the prevailing magnetism and that is retained during its subsequent history. This type of primary remanence of igneous rocks is known as Thermo-Remanent Magnetisation (TRM).

PRIMARY NRM IN SEDIMENTARY ROCKS

- The sedimentary rocks are formed in a variety of ways, which might be clastic or non-clastic.
- The primary remanence in the clastic sedimentary rocks is known as Detrital Remanent Magnetisation (DRM).
- As the sedimentary particles settle through the water column, the ferromagnetic minerals align themselves in the direction of then occurring geomagnetic field.

SECONDARY NRM

- Chemical Remanent Magnetisation (CRM) - After the formation of rocks sometimes if it is subjected to ferromagnetic minerals formation by chemical reactions, they get magnetised when exposed to magnetic fields is called as Chemical Remanent Magnetisation.
- Isothermal Remanent Magnetisation (IRM): This type of magnetisation occurs when the rock is subjected to local, but strong magnetic fields due to sudden & external reasons such as striking of lightning.
- Viscous Remanent Magnetisation (VRM): It may develop when a rock remains in a relatively weak magnetic field over a long period of time. Its ferromagnetic minerals may acquire the external magnetic field direction.
- Magnetometer is used for measuring the magnetic field, to measure the direction, strength or relative change of magnetic field at a particular location.

- A compass is a simple type of magnetometer, which is commonly used to measure the direction of an ambient magnetic field.

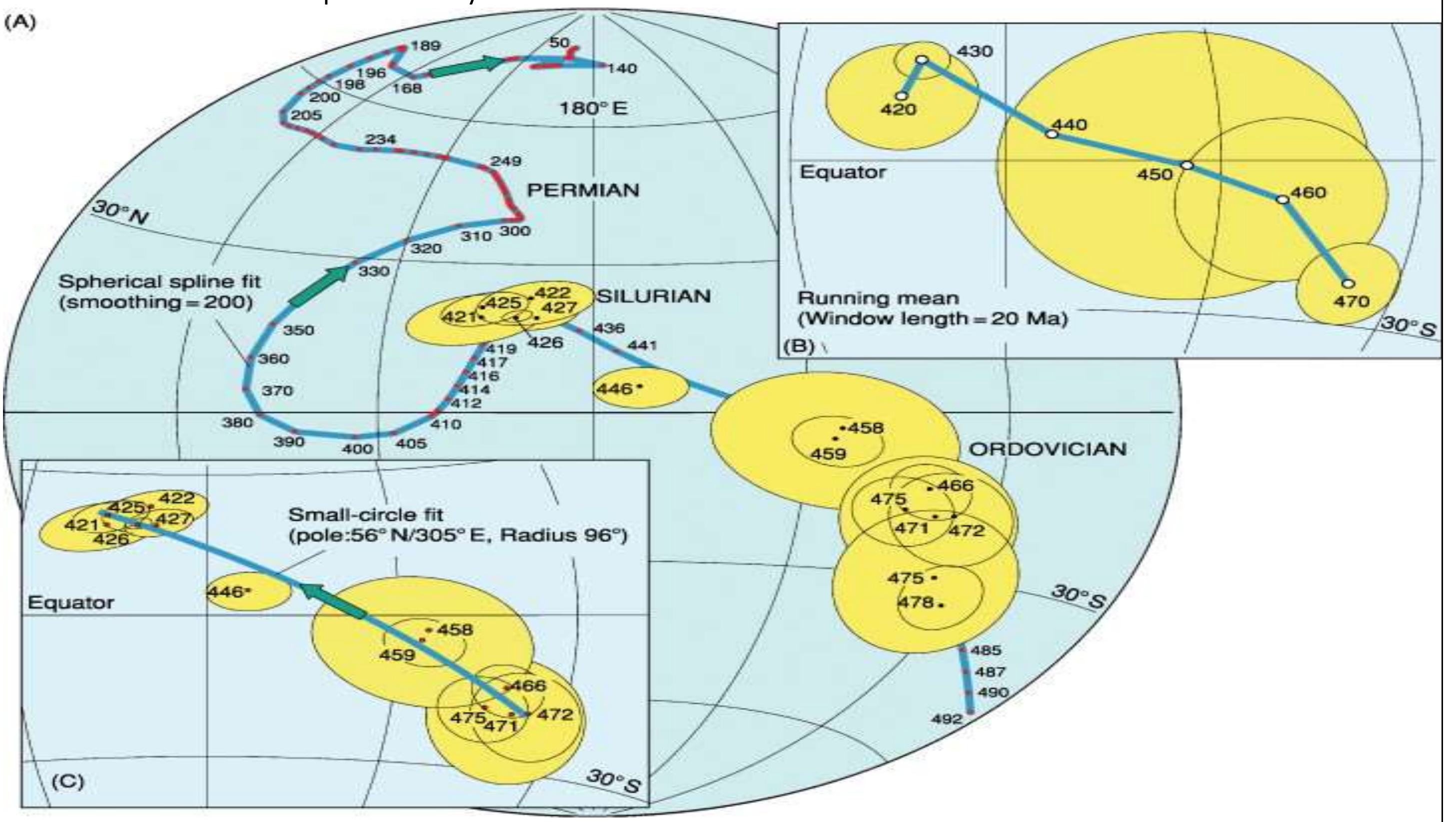
GEOMAGNETISM

- The geomagnetic field undergoes progressive changes with time, resulting from variations in the convective circulation patterns in core, known as secular variation.
- Direction of the magnetic field at a particular geographic location rotates irregularly about a dipolar axis in a period of few thousand years.
- If a palaeomagnetic study provides a magnetic pole position different from the present pole, it may imply any of the three conditions :
  - ➢ The poles have been wandering;
  - ➢ The poles were stationary, but the sample site has moved, in other words continents have been drifted
  - ➢ Both polar wandering & continental drift have occurred in the geological past.
- Large amount of the studied sample gave a reverse sense of magnetisation wherever one is expecting the north magnetic pole but finds south pole in that area is called as polarity reversal.

POLAR WANDERING

APPARENT POLAR WANDERING

- It is the way of presenting magnetic pole location by considering that the continent remained at a fixed position & then plots represent the apparent position of the magnetic poles in different geological times.
- This representation does not reflect real events, but facilitates the display of information from different regions on the same diagram.
- The palaeomagnetic studies showed that the APW paths were different for different continents.
- Thus, the APW not only confirmed that the continental drift has actually occurred, but it also provided a tool to measure the drift quantitatively.



- APW paths have been used to interpret motions, collision and disruption of continents.
- APW are especially useful for the study of pre-Mesozoic continents such as Pangaea.

TRUE POLAR WANDERING

- It utilises a motion of the plates with respect to magnetic north pole and the spin axis or the Earth.
- The other is with respect to the hotspots that are considered near stationary in the mantle, so their trajectories provide a record of the motions of plates with respect to mantle.

GEOMAGNETIC POLARITY

- Earth has two magnetic poles (a) one that seeks the N end of the compass needle, this is also called negative pole or north seeking pole and (b) the other is the south seeking pole or magnetic positive pole

- This pattern of polarity has not remained constant in the Earth's geological history; rather it has been changing or even reversing
- Normal polarity: It refers to the configuration of Earth's magnetic field when magnetic negative (i.e., north seeking) pole is located near present-day geographic north pole
- Reversed polarity: It is in the opposite direction as compared to the normal polarity. In reversed polarity, the magnetic positive (i.e. south seeking) pole is located near present-day geographic north pole.
- The Earth has witnessed reversed polarity several times in the geological past.

MAGNETIC ANOMALIES

- Magnetic anomalies are measurements of the variation of Earth's magnetic field relative to some locally defined reference.
- This can be understood with the help of magnetic surveys carried out for the ocean-floor rocks where many interruptions in the overall normal polarity may be observed.
- These deviations from a regular magnetic data pattern has been called as magnetic anomaly.

CONTINENTAL RECONSTRUCTION

- Continents in their long geological histories have been fragmented and assembled many times.
- Supercontinent Pangaea was existed before the Mesozoic times (about 250 Million years ago) which later on fragmented and individual fragments drifted at different locations all over the globe.
- In the 4200 million year old long history of the Earth, the oldest floor of the Pacific Ocean is only 300 million years old and that may be closed completely in next 200 Ma due to ongoing plate tectonic activities
- The periodicity of ocean formation and closure is known as the 'Wilson Cycle' in the honour of J. Tuzo Wilson – who proposed first time idea of opening and closure of ocean basin.
- Following the example of Pacific, if one takes 500 million years duration from birth to death (disappearance) of an ocean then continents must have witnessed operation of Wilson Cycle many times as each cycle is of approximately 500 million year duration.
- Apparent Polar Wandering (AWP) paths have been successfully used in the reconstruction of the continents wherein the use of the pole & angle of rotation necessary to bring the APW paths of two continents together are determined
- Paleomagnetic data, however, do not provide information about the paleo-longitudes, therefore east-west separation of the continents needs to be treated more carefully.
- The framework of the continental margins and their fitting without overlapping are also taken into consideration in this regard.
- More accurate reconstructions can be made for Mesozoic and Cenozoic movements by making use of oceanic magnetic anomalies.
- However, for Palaeozoic and Precambrian times, paleomagnetic methods are the only tool available which can provide quantitative measurements regarding the continental reconstruction.
