*Every time we drill a hole we find the unexpected. That's exciting, but disturbing.*

**

Nature has amazing richness across the range of spatial and temporal scales at which processes and their interactions occur. We know from our own experience that winds blow and oceans move. Our Earth is not solid, if we define *solid* to mean forever immovable in space. The drift of continents can have the major influence on both climate and life. Except for local phenomena such earthquakes, landslides, and mountain glaciers, the time frame for major continent-scale Earth motions is thousands to millions of years. How the “solid” Earth interacts with air, water, and life is essential for understanding the Earth as a system, as knowledge of how and why the Earth system changes over geologic time allows us to calibrate our tools needed to forecast global changes.

The Earth is a marvellous place and since its formation 4.6 billion years ago both living and non-living entities have developed. In a global environment that is structured within the relationship between the land, the air, the oceans and the biosphere. However, to appreciate our environment it is necessary to understand the basic physical science that regulates its development.

Hopefully, you'll be encouraged to become actively involved in classroom discussions and activities.

ATTENDANCE:

* Class attendance will be recorded.
* Student is responsible for all work during absence.

**The Planet Earth**

The Earth is one of the planets in the universe. It is made up of a variety of materials including air, water, ice, living organism, minerals, metallic ores, fuels and rocks. The components of the Earth’s surface are mainly ocean, basins and continents. The Earth can simply be described as a ball of different rock types, partly covered by water and totally wrapped by air. Within this closed system is the biosphere where all lives belong.

The ***atmosphere*** is a mixture of nitrogen, oxygen, water vapour, carbon dioxide and argon. It serves as the medium for many cycles like carbon dioxide, nitrogen and water cycles.

The ***hydrosphere*** consists of all the waters on the outer part of the Earth. Apart from the ocean, lakes, and rivers on the surface of the Earth, there is also water some few hundred metres below the ground surface. These underground sources can be tapped in wells and springs or in mines. Measurements show that more than two-third of the Earth’s surface is covered with water.

The ***biosphere*** consists of the several billions of animals, forests and grasses covering the surface of the landmass. They include the microscopic plants and animals, corals, fishes and insects. The biosphere has a lot of influence on both the present and the past.

**Origin and Evolution of the Earth**

There are various scientific theories of origin and evolution of the Earth,

* **Nebular Hypothesis**

Earth originated from Nebula. Nebula was large cloud of gas and dust. It rotates slowly, gradually it cooled and contracted and its speed increased. A gaseous ring was separated from nebular, later the ring cooled and took form of planet.

* **Planetesimal Hypothesis**

The sun existed before the formation of planets. A star came closer to the sun because of the gravitation pull of the star, small gaseous bodies were separated from the sun. These bodies on cooling became small planets. During rotation the small planets collided and form planets.

* **Gaseous Tidal Hypothesis**

Large star came near the sun, due to gravitational pull a gaseous tide was raised on the surface of the sun. As the star came nearer the tide increased in size. Gaseous tide detached when star move away. The shape of the tide was like spindle, it broke into pieces forming nine planets of the solar system.

* **Binary Star Hypothesis**
* **Gas Dust Cloud Hypothesis**

**Shape of the Earth**

The Earth is not exactly spherical; the equatorial radius is 21.4km longer than the polar radius. The Earth’s surface is of variable topography depending on several factors. ***Mt.*** ***Everest*** is the highest point on the Earth (8848m above sea level) while the ***Nero Deep*** in the ***Mariana’s trench*** is the deepest( 11055m below sea level). Although these are great dimensions by human standards, they are very minute when compared with the radius of the Earth (6370km). The heights and deeps are randomly distributed on the Earth’s surface. The mountains are within two main groups: the Cirum-Pacific group which rings the pacific through North and South America. The second group extends from Indonesia through the Himalayas to the Caucasus (Russia), Alps (Austria), Apennines (Italy), Carpathians (Russia), Pyrenees (France), and the Atlas (North Africa). The isolated ones are the Mts. Kenya (Africa), Kilimanjaro (Africa) and Mauna Loa (Hawaii).

Some originally high mountains have been severely eroded to much lower levels e.g. Appalachian mountain, Ural (Russia), and the Dividing Range (Australia). ***Plains*** also abound on the surface of the Earth. The largest of such plains extends from the Gulf of Mexico to the Arctic in the central part of Canada. Other plains are the Amazon Basin, the Pampas, and much of Australia.

Plains extend into the sea to form ***continental shelves*** which slope seaward with the gradient 1:1000. At average of about 50km from the shore, the shelf steepens at the top of the continental slope. The slope falls steeply seaward with the gradient between 1:20 and 1:6 and then onto the deep sea platform (or abyssal plain) which has slope between 1:7000 and 1:1000.

Notable oceanic features are the ***submarine canyons*** which mostly begin at the mouths of large rivers e.g. the Hudson and Congo and Ocean Ridges (Atlantic Ridge)

**The Internal Structure of the Earth**

The Earth is basically divided into the crust, mantle and core, with the radius being 6371km. The crust (also called lithosphere) ranges in thickness between 8 and 35 km. While the mantle is 2881 km and the core is 3473km. The physical properties of any material dictate the velocity of elastic waves transmitted through it. Such properties are modulus of rigidity, bulk modulus and density. Elastic waves are generated during Earthquake; the study of the velocities of such waves along the paths they follow through the Earth have helped tremendously in knowing the layers within the Earth. The elastic waves generated by the Earthquake are:

1. **Primary, P (or Compressional ) Waves**

These are longitudinal waves in which particles vibrate back and forth in the same direction as that of wave propagation, e.g. sound waves, waves along a spring. The travel velocity, Vp, of longitudinal waves is given as

Where K = Bulk modulus

µ= Rigidity or shear modulus

ρ= Density

1. **Secondary ,S (or Shear) Waves**

These are transverse waves that involve the vibration of particles of matters in a direction perpendicular to the direction of propagation of waves, e.g. waves produced by shaking a stretched string. The propagation velocity, Vs, or transverse waves is given as

Note: P and S waves are two kinds of body waves where P and S refer to primary and secondary arrivals. As a rule, P waves travel faster (at about 1.7 times the speed of S waves) and will arrive first at recording station.

1. **Surface, L (Rayleigh and Love) Waves**

They are limited to the Earth’s surface. They travel more slowly than the body waves and are generally more complex.

Using the wave generated during the Earthquakes, it is possible to estimate the depth at which the mantle material begins. The Earthquake vibrations have a velocity of about 7.2 km/sec in the crust, but as they pass the lower boundary, the velocity suddenly rises to about 8.1 km/sec. This boundary is known as the ***Mohorovicic discontinuity*** (or moho). It marks the base of the crust. The Moho is found to be deeper beneath mountain ranges (isostasy).

At a depth of about 2900 km, the velocity of the P waves suddenly decreases from 11 km/sec to about 5 km/sec with a total disappearance of the S-waves. Since S-waves are not transmitted by fluids, it is suggested that the Earth has a central core in fluid state surrounded by a solid outer shell, the mantle. The boundary between the core and the mantle is called the ***Gutenberg-Weichert discountinuity***. The core is a central mass consisting of solid inner part and a liquid outer part. It consist of Fe with minor amount of Ni, S, Si and Mg



Geologically, the Earth is composed of

1. **The Crust**

The crust is composed of crystalline rocks with sedimentary rock cappings. This outer layer is about 20 t0 30 miles (32.2 to 48.3 km) deep and the rock has a specific gravity of between 2.0 and 3.0. This outer zone is separated by a distinct break or discontinuity known as the Mohorovicic discontinuity. The crust has the **Outer Layer** made up of sedimentary and granitic rock known as SIAL and **Inner Layer** made up of dense basaltic rocks, known as SIMA.

1. **The Mantle**

The mantle or middle layer composed of ultrabasic rocks, suggested to contain Olivine and depth range of 1800 miles (2898 km). It is separated from the centre or core of the Earth by another discontinuity, known as the Gutenberg discontinuity. Sometimes the mantle is sub-divided into inner and outer mantle.

1. **The Core**

The core of the Earth known as the Astenosphere or Barysphere lies below 1800 miles (2899 km). It is thought probably to be metallic and to consist of Iron and Nickel. Recent researches suggest the barysphere may consist of two layers:

1. An outer core which is liquid or in a plastic state
2. An inner core which is most likely solid

**The Earth’s Magnetic Field**

The Earth is regarded as huge ball of magnet. The Earth’s magnetic field changes slowly with time, and from place to place. The variation with geographical position includes a gradual change of magnetic intensity from about 0.3 Oersted at the equator to 0.7 Oersted at the poles. Acute local differences of intensity from the normal background value of a region are called magnetic anomalies, and are caused by the presence of magnetised rocks in the ground.

**Main features of the Geomagnetic Field**

At every point along the Earth’s surface, a magnetic needle suspended at the centre and free to orient itself in any direction, will assume a position which will be determined by the Earth’s magnetic field F at that point.

The elements of the field vector describing the Earth s magnetic field.

X = north component of the vector,

Y = east component of the vector,

Z = vertical component of the vector (positive down) called vertical intensity,

H = horizontal intensity or the horizontal component of the vector along local magnetic

meridian (positive direction towards the north),

D = magnetic declination or the angle (positive east) between the geographic north direction

and the magnetic meridian (angle between X and H), and

1 = magnetic inclination or the angle between the horizontal intensity vector (H) and the

direction of the magnetic field vector of total intensity (F). I is positive downward.

If we take observation with our magnetic needle at various points over the Earth, we shall find that in the magnetic northern hemisphere, the north seeking end of the needle will dip downward, while in the magnetic southern hemisphere, the south seeking end will be lowermost. In the magnetic equator, the needle is horizontal, i.e. the inclination is zero. The Earth’s north and south magnetic poles are displaced from the geographical poles by about 18° of latitude.

**Main field and secular variation**

The main field of the Earth is that part of the field which has its origin in the core. The change of the main field is called secular variation, which well describes the slow character of the variation.

The global magnetic field is usually represented by spherical harmonic coefficients (Chapman and Bartels, 1940). The spherical harmonic expression of the magnetic field is based on the assumption that the Earth’s field is a pure potential field *(*). That seems to be true within the accuracy of the measurements. The expressions above yield the Laplace equation

**Regular variations of the magnetic field**

The regular variations of the magnetic field are related to rotation and/or orbital movements of the Earth, Sun and Moon. The most prominent is the diurnal variation or solar daily variation, having amplitude of the order of 10-100 nT. Solar radiation ionizes the higher atmosphere during the daylight hours, and the gravitational forces of the Sun and the Moon force the ionospheric layers in a tidal motion. So the ionized gas in the ionosphere moves in the magnetic field of the Earth, creating electric currents which are seen as daily variations in magnetic recordings. There are two well-known periodic variations, ***the solar daily variation and the lunar daily variation.***

**Magnetic disturbances**

Big magnetic disturbances are mainly caused by particle radiation from the Sun. The flow of these particles is called the ***solar wind****.* The interaction of the solar wind with the Earth’s magnetic field creates a system of magnetospheric and ionospheric currents. Also the solar X-rays and UV-radiation can enhance the ionospheric current systems so much that the magnetic field experiences strong disturbances. At the Earth’s surface, the effects of these currents are seen as ***magnetic storms****,* which are usually a sum of several *substorms,* if the currents are strong. During strong magnetic sorm, auroras may be seen at unusually low latitudes, radio propagation may be severely disturbed and radio connections over polar areas completely cut.

As a result of some severe storms, electric power lines have suffered from induced currents. Breaks in power have sometimes lasted several hours and caused remarkable economic losses. As a consequence of magnetic storms, satellites suffer from enhanced density of particles from the Earth’s expanding atmosphere and disturbances in radio connections.

**Magnetometers**

**Superconducting magnetometers**

SQUID (for superconducting quantum interference device) is the m8ost sensitive instrument for the recording of variations of the magnetic field. A SQUID can reach 10-6 nT resolution, which is 10000 times more than is needed in the recording of magnetic pulsations today.

**Fluxgate magnetometer**

The fluxgate magnetometers are based on the nonlinearity of the magnetization of "soft" magnetic materials. The sensitive element of a fluxgate magnetometer consists of an easily saturable core made of material with high permeability. Around the core there are two windings: an excitation coil and a pick-up coil.

**Optically pumped magnetometers**

The operation of optically pumped magnetometers is based on Zeeman splitting of the energy levels of atoms into sublevels, whose energy separation depends on the orientation of the magnetic moments relative to the ambient field. The energy separation corresponds to the frequency which is a measure of the ambient magnetic field.

**Overhauser magnetometer**

The detection and measurement of the signal of the precessing protons is done in principle the same way as in normal proton magnetometers. In the Overhauser system the continuous signal allows, however, sampling rates up to several samples per second.

**Proton precession magnetometer**

The proton precession magnetometer or simply proton magnetometer is based on free precession of protons in a liquid. The angular precession ω of protons depends linearly on the magnetic field.

Others are **Photoelectric feed-back magnetometer, Torsion variometers**, **Quartz horizontal magnetometer QHM, Declinometer,** and **Torsion magnetometers.**

**Remanent Magnetism in Rocks**

Remanent magnetism, or remanence, is that magnetisation remaining in a substance in a zero applied field. Thermoremanent magnetisation is the remanence acquired upon cooling through a certain temperature interval in the presence of a magnetic field.

A mineral is ferromagnetic only at temperature below its curie point (usually about 500 °C). The magnetic minerals crystallize from lava or magma at temperature greater than the curie point, but do not become magnetised until the temperature falls below 500 °C. It has been shown that igneous rocks acquire a strong thermal remanent magnetism as they pass through the temperature interval 500 °C to 450 °C. The magnetic minerals mainly responsible are within the system FeO – Fe2O3 – T1O2.

The intensity of primary magnetisation may decay with time, which is called viscous demagnetisation or viscous decay. Also a new magnetisation may be acquired at temperature below the curie point over long time spans and this is called Viscous remanent magnetisation. Viscous decay and VRM in a prevailing field different from that of the original NRM will tend to obscure the primary magnetisation

**Seismology and the Earth Interior**

Seismology is the study of Earthquake and seismic waves. Literally, the word seismology means the study of Earthquakes, but it has come to include the study of elastic waves, not only from Earthquakes, but also from artificial explosions, and of all the parameter that can be deduced from the propagation of these waves.

Seismology is the discipline that provides the most certain information on those parts of the Earth which cannot be directly examined. Analysis of seismic waves, together with laboratory studies of rocks, helps us to infer the composition and the state of the Earth interior.

By studying the pattern of Earthquake occurrence, seismologist have provided one of the essential clues to the development of the concept of plate tectonics; Earthquake belts demarcate plate boundaries, the zones along which plates collide, diverge, or slide past one another. The modern seismograph, which record the waves generated by Earthquake and explosions, provides the most important means of probing the deep interior.

**The Nature of the Earthquake**

In general terms, an Earthquake may be regarded as a sudden release of strain energy in a comparatively localised region of the Earth’s crust or upper belt. The tremors vary greatly in their intensity and effects; some are so light as to pass unnoticed while others may be very severe and catastrophic in their effects.

During Earthquake, vibrations are set up in solid bodies by sudden blow or rupture, or by the scarping together of two rough surfaces. The ultimate causes of Earthquake are still being debated but the immediate causes of Earthquakes in the Earth crust are volcanic explosion, the initiation of faults and the movements of rocks along fault planes. The majority of natural Earthquake are the tectonic types, which are accompanied by terrible shocks. The principal shock from Earthquakes which generally last only a few seconds, may be preceded by fore-shocks and is invariably followed by a series of after -shocks.

**Note:**

Fore- shocks: preliminary shattering of small obstructions along a fault plane or zone

After - shocks: a long series of minor movements that accompany the gradual settling down of the region.

**Causes of Earthquake**

Earthquake can originate in various ways but one principal cause is responsible for all large Earthquakes and for a majority of small ones. These causes can be

1. Natural
2. Artificial

**Natural Causes**

1. **Rock Fracture**

This is the fracturing of rocks in the outer part of the Earth as a result of the gradual accumulation of stress in rocks in the subsurface until they are strained to break point, when they suddenly fractured and move. Generally, rupture follows established lines and surface of weakness, which are active geologic faults. Fracture usually begins at depth and often extends to the surface in large Earthquakes. The fault displacement may be vertical, horizontal, or both. When rocks are nearly at their breaking-point, Earthquake may be triggered off by some extraneous agent such as a high tide, a heavy rainfall or flood, the tremors from an independent Earthquake originating far away, and the shock waves from exploding hydrogen bomb.

Once the rupture is initiated and the frictional bond is broken, the elastic strain energy, which had been slowly stored over the years, is suddenly released in the form of intense seismic vibrations, which constitute the Earthquake. The seismic waves are propagated large distances in all direction away from the fault. Near the focus the waves can have large, destructive amplitudes.

**Note:**

1. The focus of an Earthquake is the point within the Earth from which the elastic waves radiate.
2. The term epicentre refers to the point on the Earth’s surface immediately above the focus.
3. The point diametrically opposite to the epicentre is called the anticentre.
4. Isoseismal line or isoseismic line is a line joining places with identical degrees of Earthquake intensity during a specific Earthquake.
5. **Volcanism**

The most important minor causes of Earthquakes is volcanism. Earthquakes are caused not merely by explosions and other eruptive processes, but also by gradual displacement of subterranean volcanic material or magma

**Artificial Earthquakes**

Artificial Earthquakes include all quake events that are in some way induced by man, or related to man’s activity. These range from vibration produced by machinery and common vehicular traffic to shocks of underground nuclear explosions. Two other means of inducing Earthquakes involve dam and reservoir construction and the underground injection of liquids through walls.

**The Seismograph, Seismometer, and Seismogram**

The earliest known instrument for indicating the arrival of a seismic tremor from a distant source is reputed to have been invented by a Chinese astronomer called Chang Heng in 132 A.D. The science of seismology dates from the invention of the ***seismograph***by the English scientist John Milne in 1892. Its name derives from its ability to convert an unfelt ground vibration into a visible record. The seismograph consists of a receiver and a recorder. The ground vibration is detected and amplified by a sensor, called the ***seismometer***or, in exploration seismology, the *geophone.* In modern instruments the vibration is amplified and filtered electronically. The amplified ground motion is converted to a visible record, called the ***seismogram****.*

The seismometer makes use of the principle of inertia. If a heavy mass is only loosely coupled to the ground (for example, by suspending it from a wire like a pendulum as in the motion of the Earth caused by a seismic wave is only partly transferred to the mass. While the ground vibrates, the inertia of the heavy mass assures that it does not move as much, if at all. The seismometer amplifies and records the relative motion between the mass and the ground.

**Energy and Magnitude of an Earthquake**

The effects of an Earthquake are strong at the epicentre and decreases outward. The magnitude of an Earthquake is expressed in terms of the observed destruction. It has been observed that the amount or extent of damage depends on:

1. Population density
2. Building standards and
3. Nature of the ground e.g. weak alluvium is more susceptible than strong bedrock

While it takes time to build up the elastic strain energy in the rock adjacent t a fault, it takes little time for the stored energy to be released because an Earthquake lasts only a few minutes. The amount of stored energy can be estimated by measuring the energy of the released seismic waves. Energy released is the most precise way of measuring the size of an Earthquake, but it is long, complicated process, because it involves the determination of faults dimensions, the slip and other factors needed to compute it.

Seismologists have therefore adopted the Richter Magnitude Scale (developed by C. F. Richter of California Institute of Technology) which is based on the amplitude of seismic waves recorded by seismographs. The magnitude of a tectonic Earthquake is now defined so that it is closely related to the total amount of elastic energy released when the overstrained rocks suddenly rebound and so cause a shock. The relationship between the magnitude M, and the energy released, E, is given by the equation

Where the energy, E, is expressed in ergs (1 joule = 107ergs; 1 erg is the energy required to make 1 gram move 1cm per second).

The largest Earthquake recorded in modern times was in Assam, India in 1952 and had a Richter magnitude of 8.7. The Alaska shock of March 1964 had a magnitude of 8.4.

**Classification of Earthquakes**

In terms of depth of occurrence, tectonics Earthquakes can be classified as:

1. Shallow – when the depth of origin (focus) is less than 70km
2. Intermediate – when the focus is between 70km and 300km
3. Deep – when the focus is more than 300km but less than 700km

**Seismic and Aseismic Regions of the World**

Seismicity chart has shown that Earthquakes occur in belts called seismic belts. Seismologists have known for decades that Earthquakes tend to occur in belts surrounding the Pacific Oceans. New seismicity maps shows that narrow belts of epicentres coincides almost exactly with the crest of the mid-Atlantic, the east Pacific, and other oceanic ridges, where plates separates. Although most Earthquakes are recorded at plate boundaries, the seismicity map shows that small percentages originate within plates.

**Tsunamis**

Tsunamis are sea waves of long wavelengths commonly generated by submarine Earthquakes. They are due to sudden subsidence or uplift of large areas of sea floor, or possibly combinations of both subsidence and uplift in adjacent areas. The waves sweep across open Ocean at high speeds and have caused severe damage to coastal areas thousands of miles from the Earthquakes which generated them. The Pacific Ocean is particularly affected by Tsunamis because so much of its perimeter is seismically active.

**Earthquake Hazards Reduction Measures**

Even though no major scientific breakthroughs have been made so far, damage and loss of life can be reduced by:

1. Encouraging sound building practices
2. Public education and involvement programmes
3. Construction on unstable soil or avalanche prone areas should be prohibited
4. Residential area should not be located on active fault zones
5. Engineers should design structures that will withstand most Earthquake
6. Introduction of fluids to unlock a pre-existing fault and strain etc

**Earthquake Prediction**

Today seismologists in many countries are actively working on Earthquake prediction. For example, in February 1975 an Earthquake was predicted five hours before it occurred near Haicheng in Northeast China. However, much research will be needed to achieve this important goal. In other words, strategy of Earthquake prediction has not been perfected yet. Such strategy could be different from country to country.

**Earthquake Destructiveness**

Earthquakes cause destruction in several ways, ground vibrations can shake structures and stress them to the point of failure and collapse, certain kinds of soil lose their rigidity and “liquefy” when subjected to repeated seismic shocks. The ground simply slides away, taking man’s creation with it. Coastal Earthquakes on some occasions generated the awesome waves called Tsunamis, which can form walls of water as much as 50ft high and sweep over low-lying coastal areas. Avalanches, mudflows, and fire may accompany Earthquakes and take their toll.

**Continental Drift and Plate Tectonics**

About 200 million years ago the continents were all together in one supercontinent. The present day distribution of the continents is due to the breaking up by drifting of an original single major landmass called PANGEAE. As a result of this breaking two continental land mass came into existence:

1. A northern block called LAURASIA, comprising most of the present day North America and Eurasia
2. A southern block called GONDWANALAND, including most of South America, Africa, Arabia, India and Australia.

Today the majority of geologists accept as a fact that the present distribution of the continents result from the breaking-up and joining together of previous distributions of the continents. This process is known as continental drift.

**Evidence in support of continental drift**

1. Striking parallelism of the opposing coast of the Atlantic, and also of some coasts elsewhere in the world. If they are drawn together they make a rough jig-saw fit
2. Fossil plants and animals believed to be incapable of crossing deepwater are distributed in limited geographical regions on both sides of the Atlantic and on continents separated by other oceans. Their distributions suggest that there were former land connections between Europe and north America, and between south America, Antarctica, India and Africa
3. There are closer structural resemblance and many geological similarities especially between the eastern coast of south America and the western coast of Africa

**Polar Wandering**

The polar wandering hypothesis is generally understood to mean that the outer shell of the Earth, involving the crust and probably part of the mantle, has shifted as a whole relative to the axis of rotation which remains almost fixed. The concept of polar wandering also conveys the idea that while the geographic pole remain fixed relative to the rotating Earth, an outer shell of the Earth becomes decoupled from the mantle and shifts as a whole relative to the pole. On the summary, it can be inferred that in the past geological ages the continents have occupied positions relative to the poles very different from those of today’s familiar geography i.e. continents have moved relative to one another.

The plate tectonic theory briefly says that the surface of the earth is made up of six major moveable plates. These are African, American, Eurasian, Antarctic, Pacific and India; the smaller ones are the Arabian, Caribbean and the Philippine.

The plates are bounded by mobile belts which are characterized by earthquakes and volcanic activities. Each plate has its axis of rotation which passes through the centre of the earth. Three basic types of boundaries can be recognized: convergent boundary, divergent boundary and Transform fault

1. In plate tectonics a ***Convergent Boundary***, also known as a destructive plate boundary is an actively deforming region where two or more tectonic plates or fragments of the lithosphere move toward one another and collide. As a result of pressure, friction, and plate material melting in the mantle, earthquake and volcanoes are common near convergent boundaries. When two plates move towards one another, they form either a subduction zone or a continental collision. This depends on the nature of the plates involved. In subduction zone, the subducting plate, which is normally a plate with oceanic crust, moves beneath the other plate, which can be made of either oceanic or continental crust. During collision between two continental plates, large mountain ranges, such as the Himalayas. Where a dense oceanic plate collides with a less-dense continental plate, the oceanic plate is typically thrust underneath because of the greater buoyancy of the continental lithosphere, forming a subduction zone. At the surface, the topographic expression is commonly oceanic trench on the ocean side and a mountain range on the continental side.
2. At ***Divergent Boundaries***, two plates move apart from each other and the space that this creates is filled with new crustal material sourced from molten magma that forms below. The origin of new divergent boundaries at triple junctions is sometimes thought to be associated with the phenomenon known as hotspots. Divergent boundaries are typified in the Oceanic lithosphere by the rifts of the oceanic ridge system, including the Mid-Atlantic Ridge and the East Pacific Rise and in the continental lithosphere by Rift valleys such as the famous East African Great Rift Valley. Divergent boundaries can create massive fault zones in the oceanic ridge system.
3. ***Transform Faults*** or transform boundary also known as conservative plate boundary since these faults neither create nor destroy lithosphere, is a type of fault whose relative motion is predominantly horizontal in either sinistrial or destrial direction.

The major evidence of plate tectonics is the theory of seafloor spreading which explains that the floor of the ocean is moving away from ridges (accretion zones) so that two reference points on either side of a ridge get progressively farther from one another while new materials are being brought into place from the mantle. Symmetrical magnetic stripes associated with midoceanic ridges point to this theory which is said to provide magnetic records of seafloor spreading.

**Geothermometry**

Several hypotheses have been proposed to explain the origin of the Earth’s internal heat:

1. The modern view is that the Earth grows as an initially cold body by accretion, that is, a progressive collision and coalescence of grains and particles (planetestimals) in space, to form the larger body. The heat generated by the impact of the various materials as they collided with the growing Earth, and the one resulting from the compression of the interior during accretion process, has been retained as part of what constitutes today’s Earth’s internal heat.
2. The phenomenon of radioactivity has also been supposed as the major source of the Earth’s internal heat. When radioactivity isotopes decay, there is a loss of molecular binding energy, this energy is dissipated as heat in the immediate vicinity of the decaying isotopes.
3. Heat energy liberated during differentiation of the Earth from relatively homogeneous material into core, mantle and crust.
4. Heat released by the decay of short-lived radioactive elements (Al26, Cl36, Fe60).
5. The gravitational pull of the sun and the moon on the Earth also accounts for Earth geothermal heat.

**Geothermal Gradient**

The increase in the temperature of the Earth with increasing depth is called the geothermal gradient. The increase does not occur at a constant rate. It has been calculated that temperature increases downward from the ground surface at an average of 1°C for every 28.6m or 30.5°C for every km.

**Heat flow Measurement Techniques**

* Thermal method

Determination of heat flow requires measurement of temperature gradient in the crust and of the thermal conductivities of the actual rocks in which the gradient is measured. Heat flow (q) is the product of the temperature gradient ( and the thermal conductivity (K) of the actual rock material involved. Hence

**Regional Variation of Heat Flow**

Within continental and oceanic regions there are inequalities of heat flow. The most stable region, characteristic of Precambrian shields, show low heat flow values. The most active tectonic regions, characteristic of post-Palaeozoic orogenic and tertiary volcanic areas, show higher than average values. In oceanic areas, high values of heat flow are concentrated almost exclusively on mid-oceanic ridges and rises.

The most important discovery in terrestrial heat flow is that the average heat flow over the continents does not differ significantly from that over the ocean.

**Transfer of Heat within the Earth**

Heat transfer can take place essentially through three processes:

1. **Conduction**: in which the transfer occurs gradually through a body that may be solid. Most of the lost heat reaches the surface by thermal conduction through the rocks of the crust.
2. **Convection**: in which fluid moves in a closed circuit and carries heat. Convective power is supplied by differences in temperature. Thus, convection transports heat upward and not downward.
3. **Radiation**: at temperature above 800-1500°C, it is likely that a significant amount of heat can be transferred.

**Geothermal Resources**

Hot formations, where any form of heat extraction by flowing water is possible, constitute the geothermal reservoirs. Almost all type of rock, igneous, sedimentary or metamorphic may be involved. Natural steam and hot water are available for power generation and heating purposes in many volcanic regions of the world.

**Geophysics**

The science of geophysics applies the principles of physics to the study of the Earth. Geophysical investigations of the interior of the Earth involve taking measurements at or near the Earth’s surface that are influenced by internal distribution of physical properties. Analysis of these measurements can reveal how the physical properties of the Earth’s interior vary vertically and laterally.

There is a broad division of geophysical surveying methods into those that make use of natural fields of the Earth and those that require the input into the ground of artificially generated energy. The natural field methods utilize the gravitational, magnetic, electrical and electromagnetic fields of the Earth. Artificial source methods involve the generation of local electrical or electromagnetic field that may be used analogously to natural fields or the generation of seismic waves whose propagation velocities and transmission paths through the subsurface are mapped to provide information on the distribution of geological boundaries at depth.

A wide range of geophysical surveying methods exists, for each of which there is an operative physical properties to which the method is sensitive. The methods are listed below.

**Seismic Method**

The physical property of earth materials that is measure in seismic studies is the rate at which acoustic wave energy propagates through the various units of the subsurface. The rate of propagation in a specific medium is generally called the velocity of the medium. Seismic method is based on two important assumptions; acoustic velocity generally increased with depth and that sufficient acoustic velocity contrast exists between layers to allow differentiation between adjacent strata of interest. Travel time equation(s) have been developed for various earth models.

1. In **Seismic Reflection** surveys the travel times are measured of arrivals reflected from subsurface interfaces between media of different acoustic impedance. The equation for the travel time **t** of the reflected ray from a shot point to a detector at a horizontal offset, or shot detector separation, ***x*** is given by the ration of the travel path length to the velocity,
2. The **Seismic Refraction** surveying method utilizes seismic energy that returns to the surface after travelling through the ground along refracted ray paths. For a two layer case with horizontal interface, the total travel time along the refracted ray path is,

**Gravity Method**

In gravity surveying, subsurface geology is investigated on the basis of variation in the Earth’s gravitational field generated by differences of density between two subsurface rocks. An underlying concept is the idea of a causative body, which is a rock unit of different density from its surroundings. A causative body represents a subsurface zone of anomalous mass and causes a local perturbation in the gravitational field known as gravity anomaly.

The basis of the gravity survey method is Newton’s Law of Gravitation

Consider the gravitational attraction of a spherical, non-rotating, homogeneous Earth of mass M and radius R on a small mass m on its surface.

The gravitational field is most usefully defined in terms of the gravitational potential U:

The gravitational potential U is a scalar, having magnitude only. The first derivative of U in any direction gives the component of gravity in that direction. Consequently a potential field approach provides computational flexibility.

The mean value of gravity at the Earth’s surface is about 9.80ms-2. Variation in gravity caused by density variations in the subsurface are of the order of 100µms-2. The unit of the micrometre per second per second is referred to as **Gravity Unit.** The c.g.s. unit of gravity is the millgal (1mgal=10-3 Gal), equivalent to 10 gu.

Modern instruments capable of rapid gravity measurement are known as gravity meters or gravimeters. Examples are LaCoste and Romberg gravimeter and Worden gravimeter.

**Magnetic Method**

The aim of magnetic surveying is to investigate subsurface geology on the basis of anomalies in the Earth’s magnetic field resulting from the magnetic properties of the underlying rocks. Although most rock-forming minerals are effectively non-magnetic, certain rock types contain sufficient magnetic minerals to produce significant magnetic anomaly.

The force F between two magnetic poles of strength m1 and m2 separated by a distance r is given by

Where and are constants corresponding to the magnetic permeability of vacuum and the relative magnetic permeability of the medium separating the poles. The magnetic field B due to a pole strength m at distance r from the pole is defined as the force exerted on a unit positive pole at that point.

Magnetic fields can be defined in terms of magnetic potentials

The c.g.s. unit of magnetic field strength is the Gauss(G), numerically equivalent to 10-4T. The tesla is too large a unit in which to express the small magnetic anomalies caused by rocks, and a subunit, the nanotesla (nT), is employed (1nT = 10-9T). The c.g.s. system employs the numerically equivalent gamma (), equal 10-5G.

**Electrical Method**

There are many methods of electrical surveying. Some make use of naturally-occuring field within the Earth while others require the introduction of artificially-generated currents into the ground.

1. **Resistivity Method**

In the resistivity method, artificially-generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the pattern of potential differences expected from homogeneous ground provide information on the form and electrical properties of subsurface inhomogeneities.

The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material. For conducting cylinder of resistance , length and cross-sectional area , the resistivity is given by

The SI unit of resistivity is the ohm-metre (ohm m) and the reciprocal of resistivity is termed conductivity (Siemens per metre). For a single current electrode on the surface of a medium of uniform resistivity , the potential , at distance *r* is

1. **Induced Polarization**

If, when using a standard four-electrode resistivity spread in a DC mode, the current is abruptly switched off, the voltage between the potential electrodes does not drop to zero immediately. After a large initial decrease, the voltage suffers a gradual decay and can take many seconds to reach a zero value. Also, instead of using a DC source for the measurement of resistivity, a variable low frequency AC source is used, it is found that the measured apparent resistivity of the subsurface decreases with increasing frequency. This is because the capacitance of the ground inhibits the passage of direct currents but transmits alternating currents with increasing efficiency as the frequency rises.

The capacitive property of the ground causes both the transient decay of a residual voltage and the variation of apparent resistivity as a function of frequency. The two effects are representation of the same phenomena in the time and frequency domains, and are linked by Fourier transformation. These two manifestations of the capacitance property of the ground provide two different survey methods for the investigation of the effect.

The measurement of a decaying voltage over a certain time interval is known as time domain IP surveying. The most commonly measured parameter is the chargeability M, defined as the area A beneath the decay curve over a certain time interval normalized by the steady-state potential difference

Measurement of apparent resistivity at two or more low AC frequencies is known as frequency domain IP survey. Two measurements are commonly made. The percentage frequency effect (PFE) is defined as

Where and are apparent resistivities at measuring frequencies of 0.1 and 10Hz.

The metal factor (MF) is defined as

1. **Self potential Method**

The self potential or spontaneous polarization method is based on the surface measurement of natural potential differences resulting from electrochemical reactions in the subsurface.

**Electromagnetic Method**

EM surveying method makes use of the response of the ground to the propagation of EM fields which are composed of an alternating electric intensity and magnetizing forces. Primary EM fields may be generated by passing alternating current through a small coil made up of many turns of wire or through a large loop of wire (Transmitter). The response of the ground is the generation of secondary EM fields and the resulting fields may be detected by the alternating currents that they induced to flow in Receiver coil by the process of EM induction. Electromagnetic fields are attenuated during their passage through the ground, their amplitude decreasing exponentially with depth. The depth of penetration d can be defined as the depth which the amplitude of the field is decreased by a factor compared with the surface amplitude .

**Geophysical Well logging**

Down-hole geophysical surveying or wire-line log is used to derive further information about the sequence of rocks penetrated by a borehole. It is a continuous recording of a geophysical parameter along the borehole. The value of the measurement is plotted continuously against depth in the well. The most common types of logs include the following; conventional Resistivity logs (micro resistivity, short normal, medium normal and long normal), Laterologs, Sonic logs, Neutron logs, Density logs, Caliper logs, Temperature logs, Dipmeter logs and Gravity logs. The geological properties obtainable from borehole logging are: differentiation between shale, hardrock and reservoir, determination of depth and thickness of reservoir, stratigraphic correlation of the wells, determination of the dip of the formation, porosity of the formation and salinity of pore water, detection of hydrocarbon and determination of hydrocarbon, oil and water saturation, location of gas and oil contact, oil and water contact, and determination of temperature of formation.