1. INTRODUCTION

1.1. The Earth

The Earth is a **dynamic**, constantly changing planet-its crust shifting to build mountains; lava spewing out of its warm interior; ice and water and windblown sand and gravity reshaping its surface, over and over.

1.1.1. Origin and History of the Earth

1.1.1.1. Origin of the Earth

Solar System: Sun and bodies orbiting it, the Sun and all the planets, satellites, asteroids, meteors, and comets those are subject to sun's gravitational pull.

There is no definite answer for what the origin of the Earth was? Particularly, where the material of the solar system (nebula) comes from? The manner in which the planets occur was explained by Nebular hypothesis.

Definition

Nebula: is space dust, a cloud of interstellar dust and gas appearing variously as a hazy bright or dark patch.

Nebular hypothesis: States that the solar system (the sun and planets) evolved from a single, large, flat, rotating dust that extended beyond the current position of the most distant planet (Pluto). As this nebula rotated the mass became increasingly concentrated towards the center and in doing so it would have rotated more rapidly to conserve angular momentum, until (at some period during the contraction) the speed of the outermost rim of the disc would have become sufficient for the centrifugal force to be as great as the inward gravitational attraction. At this position where the centrifugal force is equal to gravitational force, a ring of matter was left while the contraction of the remaining matter continued. In this manner successive rings of matter were left behind the contracting mass. Subsequently, the material within each ring was drawn together and planets and satellites were formed.

Now a days, the Big Bang theory that states **a fireball** (a single extremely dense mass of matter (nebula)) in which all matter and energy was concentrated, were **exploded (big banged)** due to which matter and energy spread outward in all directions started the universe, is getting better acceptance.

1.1.1.2. History of the Earth

1.1.1.2.1. The Composition of Early Atmosphere

The early atmosphere, when the Earth was created over 4½ billion years ago, wasn't like the present one.

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The First Billion Years

The Earth's surface was originally molten, as it cooled the volcanoes belched out massive amounts of:

- CARBON DIOXIDE,
- STEAM,
- AMMONIA and
- METHANE
- There was **NO OXYGEN**.
- Bacteria start flourishing 3.8 billion years ago so this means that life got under way about 700 million years after the Earth was created.

The Next Billion Years

These primitive life forms then took the next evolutionary step and started to PHOTOSYNTHESISE (using sunlight to convert carbon dioxide and water to food energy and oxygen).

- These green plants went on producing oxygen (and removing the CO_2). This was an important turning point in Earth's history because the carbon dioxide in the atmosphere was being converted to oxygen.
- Most of the carbon from the carbon dioxide in the air became locked up in sedimentary rocks as carbonates and fossil fuels.
- The ammonia and methane in the atmosphere reacted with the oxygen.
- Nitrogen gas was released, partly from the reaction between ammonia and oxygen, but mainly from living organisms such as denitrifying bacteria.

The Last 2½ Billion Years or So

- The oxygen was begun to be taken out again by reacting with other elements (such as iron).
- The concentration of oxygen increased markedly.

1.1.1.2.2.The Composition of Current Atmosphere

- However, the present composition of the atmosphere is:
  - 21% Oxygen
  - 78% Nitrogen
  - 0.04% Carbon dioxide
  - ~0.9% Argon
  - The rest others
- Life on Earth has included humans increasingly competing for space and survival on the planet's surface.

- By the combination of intelligence and manual dexterity, humans have learned to use plants and animal resources, minerals, fuels, and construction materials (aggregates, basalt, Ignimbrite, Pumice etc)

1.1.2. Age of the Earth and Approaches to Determine Age of the Earth

1.1.2.1. Age of the Earth

The age of the Earth was once, and still is, a matter of great debate. This is because, earlier many researchers used to give a relative age of the Earth. They use Age relative to Geological-formations and geological-events which are younger or older than the Earth. However, it wasn't until the discovery of radioactivity that scientists began to put a **timescale** on the history of the Earth. Therefore, the application of radio-active methods for the determination of the age of Earth, has been successful in the estimation of the age of Earth accordingly comes to about
4.55 billion years or **4550 million** years.

The age of a rock is really just a measure of how long it has been since the rock cooled to become a rock. If you take your rock, melt it, and let it cool back to a rock, it will be a new rock with its clock reset to 0.
A more relevant example: Let us say that a rock is sitting on the surface of the Moon. A billion years after that rock was formed, the rock is covered and remelted by a lava flow. Two billion years after the lava flow that rock is uncovered by an impact and thrown to the surface. The rock is then picked up by an astronaut, brought back to the Earth, and dated. The age determined for that rock will be two billion years old, NOT three billion years old. This is because remelting restructures and changes compositional constitute of the earlier rock.

1.1.2.2. Approaches to Determine Age of the Earth

Different people have used various factors to determine or estimate the age of the Earth. The two distinct method of estimation are:

1. Relating the Earth to Geological-formations and geological-events by **indirect** methods (relative age).

   For instance:

   a. Determination of **annual sedimentation rate**
   The average annual rate of deposition of sediments and the thickness of all strata deposited during the whole geological history are taken into account.
   b. **In 1650** Archbishop Ussher used the **Bible** to calculate that the Earth was created in 4004BC.
   c. Later on, **in the mid-nineteenth century**, Charles Darwin believed that the Earth must be extremely old by taking into account the evolutionary developments of animals.

2. **Radio-active** methods or **direct** method for determining the actual age

For instance:

a. **Dating** of Geological-**formations/rocks** by radioactive methods.

For example,

1. The oldest volcanic rock (Acasta gneiss, northern Canada) found so far has been dated at ~4.0 billion years old using radioactivity.
2. The oldest terrestrial minerals dated so far are ~4.4 Ga old (Zircon, Western Australia)

b. Radioactive dating of **meteorites** created at the same time as the Earth shows that they are about 4.55 billion years old.

Definition

Radioactivity: Spontaneous changes in a nucleus accompanied by the emission of energy from the nucleus as a radiation.

Radioactive Half-Life: A period of time in which half the nuclei of a species of radioactive substance would decay.

The basic principle behind radioactive methods is that “a radioactive parent element decays into a stable daughter element at a constant rate”. Usually the “half-life” period is determined and accordingly it is equated to find out the age of the Earth. Rocks often contain heavy radioactive elements which decay over long periods of time, the decay is unaffected by the physical and chemical conditions and different elements decay at different rates.

For instance, in lab a sample of rock which contains uranium will be analyzed chemically for what percentage of Uranium and lead it contains. Now a rock with known amount of Uranium and lead will artificially obliged to decay in the lab and the decrease in the proportion of uranium to lead will be distinguished to determine the rate of decay. A parent Uranium atom with atomic number 238 decays at constant rate to daughter lead with atomic number of 208 in nature. It involves emission of radiations as (alpha, beta, or gamma rays) that can be detected by counters such as a **Geiger counter**. Each time an emitted particle passes through the Geiger counter, the counter makes a **clicking sound**. The **number of clicks per unit time** of the counter tells us how **many decays per unit time** are occurring. But the rate of clicks decreases with time because the rate is directly proportional to the number of radioactive nuclei in the substance that can decay. Hence, as time goes on, we know that the number of radioactive nuclei in the substance must also be decreasing. It is therefore possible to know what percent of uranium changes to lead in a specified time gap. Finally this will change to **half-life**. Therefore, in this way a time required for half of the uranium to change to lead in the rock will be calculated.

The following are common radioactive elements used for the purpose of determining the age of Earth:

1. Uranium-lead method
2. Thorium-lead method
3. Potassium-argon method
4. Rubidium-strontium method

5. Radio-carbon method

The age equation

The mathematical expression that relates radioactive decay to geologic time is:

$$D = D_0 + N (e^{\lambda t}-1)$$

t = age of the sample

D = number of atoms of the daughter isotope in the sample

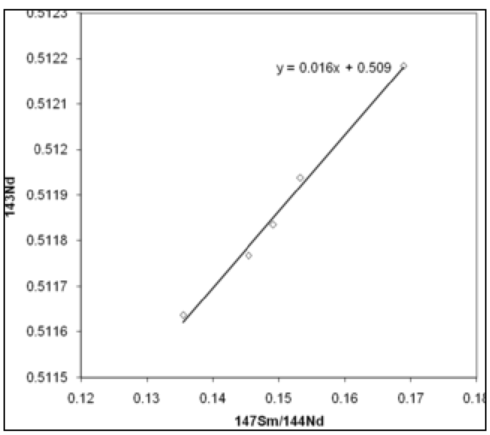
D_0 = number of atoms of the daughter isotope in the original composition

N = number of atoms of the parent isotope in the sample

λ = decay constant of the parent isotope - this is equal to the inverse of the radioactive half-life of the parent isotope (which can be obtained from tables such as the one on next page) times the natural logarithm of two.

The above equation makes use of information on the composition of parent and daughter isotopes at the time the material being tested.

Construction of an isochron does not require information on the original compositions, using merely the present ratios of the parent and daughter isotopes to a standard isotope. Plotting an isochron is used to solve the age equation graphically and calculate the age of the sample and the original composition.



Fig…..Sm/Nd isochron plotted of samples from the Great Dyke, Zimbabwe. The age is calculated from the slope of the isochron (line) and the original composition from the intercept of the isochron with the y-axis.

Number of half-lives elapsed	Fraction remaining	Percentage remaining
0	$^1/_1$	100
1	$^1/_2$	50
2	$^1/_4$	25
3	$^1/_8$	12.5
4	$^1/_{16}$	6.25
5	$^1/_{32}$	3.125
6	$^1/_{64}$	1.563
7	$^1/_{128}$	0.781
...	...	...
n	$1/2^n$	$100(1/2^n)$

The table at left shows the reduction of the quantity in terms of the number of half-lives elapsed.

1.1.3. The Earth, Then and Now

The early Earth was very different from what it is today:

The Early Earth

- Was undifferentiated, homogeneous material,
- Lacks the modern oceans and atmosphere,
- It resembles the barren, cratered surface of the moon.
- The continents of the world had once been part of the same land mass (**Pangea**) as suggested by the concept of **Continental drift**.

All the continents of the world were part of one original giant continental mass called **Pangea** occupying 40% of the Earth's surface, which was surrounded by a huge water body called **Panthalasa** ("all Oceans"), covering 60% of the Earth's surface. Over vast period of time beginning about 200-180 Ma years ago, Pangea broke up into **two** supper continents:

1. The **Gondwanaland** which consisted of all the continents now in the southern hemisphere (South America, India, Australia, Africa and Antarctica) and
2. The **Laurasia** which consisted of all the continents now in the northern hemisphere (North America, Greenland, Europe and Asia).

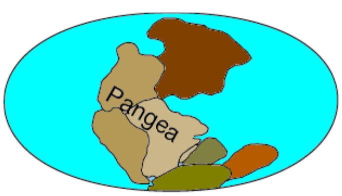


Fig. 3.1 200 million years ago all of the present-day continents combined to form a single super continent called Pangea.

The Earth Today

- Is differentiated into different layers,
- Modern oceans and atmosphere are apparent,
- It is dissected and eroded by surface process,
- The continents of the world are broken up in to today's seven continent,

The following are supporting evidences that indicate the continents of the world have indeed moved:

1. **Similarity in outline** of the eastern coast of South America and the western coast of Africa; The two continents fit together in **jigsaw-puzzle** fashion. (Figure 3.1)
2. Evidence of **glaciations in places** now located in the tropics, in parts of Australia, Southern Africa, and South America. That is glacial deposits across the southern continents **suggest past juxtaposition** (3.12)
3. The **fossil remains of an ancient life** (some plants and animals) seem to have lived only in a few very restricted areas, which now are widely separated geographically on different continents (Figure3.13).

Example.1 The fossil plant, **Glossopteris**, remains of which are found in limited areas of **India, Southern Africa, and even Antarctica**.
Example.2 The fossils of small dinosaurs, **Mesosaurus**, are similarly dispersed across two continents (South America and Africa).

It is difficult to imagine one distinctive Varity of animal or plant developing simultaneously in two or more small areas thousands of kilometers apart, or some how migrating over vast expanses of ocean. Besides, Glossopteris was a land plant, Mesosaurus a freshwater animal. The organism may have lived in a single, geographically restricted area, and the rocks in which its remains are now found may subsequently have been separated and moved in several different directions by drifting continents.

1.2. Interior of the Earth

1.2.1. Structure and Composition of Interior of the Earth

The Earth is not composed of a homogeneous mixture of materials rather the materials are arranged in a series of concentric layers of differing nature.

1.2.1.1. Anatomy of Interior of the Earth

The Earth's interior is **chemically differentiated** into three major zones (Figure 1.3):

- The outer shell of the Earth is called the **CRUST** (breadcrumbs)
  The crust is very thin (average 20Km). The **thinnest** parts are under the oceans (**OCEANIC CRUST**) and go to a depth of roughly 10 kilometers. The **thickest** parts are the continents (**CONTINENTAL CRUST**) which extend down to 35 kilometers on average. The continental crust in the Himalayas is some 75 kilometers deep.
- The next layer is called the **MANTLE** (sausage meat)
  The mantle is the layer beneath the crust which **extends about half** way to the centre.
- The next layer is the liquid **OUTER CORE** (egg white)
  The outer core is the layer beneath the mantle **depth of 2,890-5,150 kilometers**.
- The middle bit is called the solid **INNER CORE** (egg yolk)
  The inner core is the bit in the middle **at depth of 5,150-6,370 kilometers**. It's unattached to the mantle, suspended in the molten outer core.

1.2.1.2. State and Composition of the Earth's Interior

As a result of the **molten nature of Earth**, dense materials, like **metallic iron**, would have tended to sink toward the middle of the Earth. As cooling progressed, lighter, **low-density minerals** crystallized and **floated out** toward the surface. The eventual result was an earth differentiated into several major compositional zones.

- Crust is made of Solid low-density buoyant minerals dominated mostly by quartz (SiO_2) and feldspars (metal-poor silicates).
    - **Continental crust: depth of 0-75 kilometers.** This is the outer part of the Earth composed essentially of **crystalline rocks**. These are low-density buoyant minerals dominated mostly by quartz (SiO_2) and feldspars (metal-poor silicates). The crust is the surface of the Earth. Because cold rocks deform slowly, we refer to this rigid outer shell as the lithosphere (the rocky or strong layer).

    - **Oceanic crust: depth of 0-10 kilometers.** The majority of the Earth's crust was made through volcanic activity.

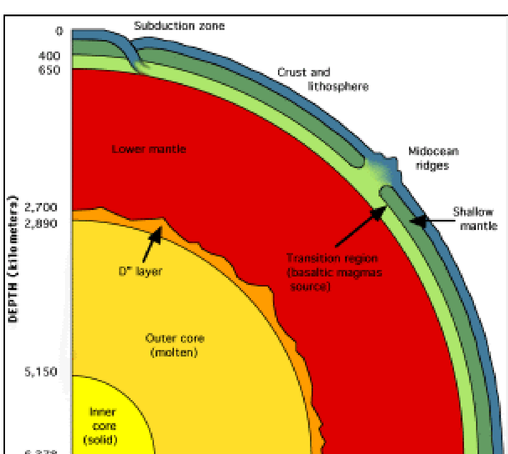
- Mantle is made of solid rock with magnesium and Iron and behaves like an extremely viscous liquid - (This is the tricky bit... the mantle is a solid which flows).

    - **Upper mantle: depth of 10-400 kilometers.** Solid fragments of the upper mantle have been found in eroded mountain belts and volcanic eruptions. Olivine $(Mg, Fe)_2 SiO_4$ and pyroxene (Mg, Fe) SiO3 have been found. Part of the upper mantle called the asthenosphere might be partially molten.

    - **Transition region: depth of 400-650 kilometers.** The transition region or mesosphere (for middle mantle), sometimes called the fertile layer and is the source of basaltic magmas. It also contains calcium, aluminium, and garnet, which is a complex aluminium-bearing silicate mineral. This layer is dense when cold because of the garnet. It is buoyant when hot because these minerals melt easily to form basalt which can then rise through the upper layers as magma.
    - **Lower mantle: depth of 650-2,890 kilometers.** The lower mantle is probably composed mainly of silicon, magnesium, and oxygen. It probably also contains some iron, calcium, and aluminium.

- **D" layer: depth of 2,700-2,890 kilometers.** This layer is 200 to 300 kilometers thick. Although it is often identified as part of the lower mantle, seismic evidence suggests the D" layer might differ chemically from the lower mantle lying above it. Scientists think that the material either dissolved in the core, or was able to sink through the mantle but not into the core because of its density.

- **Core**
    - **Outer Core** is made of electrically conducting **liquid iron and nickel**. This conductive layer combines with Earth's rotation to create **a dynamo effect** that maintains a system of electrical currents creating the Earth's magnetic field. This layer is not as dense as pure molten iron, which indicates the presence of lighter elements. Scientists suspect that about 10% of the layer is composed



of sulphur and oxygen because these elements are abundant in the cosmos and dissolve readily in molten iron.

- **Inner Core** is made of **solid** iron and nickel. It's solid due to the massive pressure.

Fig………A diagram showing a detailed picture of the Earth's interior

For the fact that only the crust and a few bits of uppermost mantle that are drilled and carried up into the crust can be sampled and analyzed **directly**, we nevertheless have a **good deal of information** on the composition, Structure and all information of the Earth's interior stated above with direct access. However, scientists used the following **indirect methods** to study the interior structure and composition of the Earth:

- The overall density of the Earth is much higher than the density of the rocks we find in the crust. This tells us that the inside must be made of something much denser than rock.
- Meteorites (created at the same time and under same conditions as the Earth, 4.55 billion years ago) have been analysed. They contain iron, silicon, magnesium and oxygen (Others contain iron and nickel). A meteorite has roughly the same density as the whole earth. A meteorite minus its iron has a density roughly the same as Mantle rock (e.g. the mineral called olivine).
- Iron and Nickel are both dense and magnetic.
- Scientists can follow the path of seismic waves from earthquakes as they travel through the Earth. The inner core of the Earth appears to be solid whilst the outer core is liquid (**s waves do not travel through liquids**).

1.2.2. Sources of Heat in the Interior of the Earth

As we go deeper and deeper into the earth the temperature and pressure rises. The core temperature is believed to be an incredible 5000-6000°c. Interior of the Earth was **heated by several processes**:

- The impact of the **colliding dust particles and meteorites** at the time they came together to form the Earth,
- **Compression of the interior by gravity** (that materials heat up when compressed. This can be demonstrated by pumping up a bicycle tire and then feeling the barrel of the pump), and
- Energy released from **decay of natural radioactive elements** that the Earth contains.

1.3. Geology

1.3.1. Definition of the Science of Geology

The literal meaning of Geology is "Studying the Earth". However, other fields of science like **Geography** and **Astronomy** also study the Earth. Therefore Geology can be more precisely defined as the scientific study of the physical structure of the Earth, composition of the Earth, origin of the Earth, substances of the Earth and processes that have formed the Earth over time.

1.3.2. Scope and Objectives of Geology

1.3.2.1. Scope

Geology covers the whole spectrum of the Earth (oceans and continents) from the surface (the crust) to the centre (the core). Therefore, it is a very wide, multi-disciplinary science which necessarily involves the basic natural science disciplines (biology, chemistry, physics), and also geography, economics, mathematics, computer science etc.

1.3.2.2. Objectives

The major **objectives** of Geology are to:

- Describe and interpret the surface physical features of the earth explaining at the same time their mode of origin;
- decipher and elucidate the history of the earth's evolution and of its past lift from the records preserved in the rocks;
- Study the Earth processes that formed it, continuously modifying it and the materials that constitute it;
- Study the materials (the natural resources) which are of economic importance;
- Locate those natural resources and know their extent;
- Extract the natural resources (such as oil, coal, water, economic minerals and rocks) and use them in a sustainable manner;
- Study natural Earth hazards (e.g. earthquakes, volcanism) that have an influence on human welfare, and study the influence of human activities on the natural earth materials and processes in order to investigate the environmental impacts.

1.4. Applied Branches of Geology

The applied branches of Geology uses the principles of basic geology and other sciences to understand the nature of the Earth, Earth processes, Earth materials, and to extract the natural resources of the Earth.

Some of the common applied branches of Geology are:

1. **Engineering Geology:** The application of the geologic sciences to engineering practice for the purpose of assuring that the geologic factors affecting the location, design, construction, operation and maintenance of engineering works are recognized and adequately provided for. Engineering geologists investigate and provide geological and geotechnical recommendations, analysis, and design.

2. **Hydrogeology**: deals with surface and groundwater.

3. **Geophysics**: deals with the Earth's internal structure and processes by applying the principles of physics and basic Geology.

4. **Mining Geology**: deals with the techniques of exploration and extraction of economic minerals and rocks;

5. **Environmental Geology (science)**: deals with the impact of human activity on the natural environment (Earth) and vice Versa;

6. **Remote Sensing and GIS**: Apply the principles of space and computer sciences to study the Earth and its resources and to store and manipulate geological and geographic information.

The following are also applied geology though they are <u>relatively new</u> and of <u>little application</u>.

1. **Military Geology**: The application of geologic knowledge to warfare.

2. **Medical Geology**: The study of the effects of geologic materials and processes on human, animal and plant health.

3. **Forensic Geology**: The application of the principles of Earth sciences to law enforcement, like using soil evidence to trace crimes and criminals.

1.5. Importance of Geology in Civil Engineering

An engineering geologist applies the geologic skills to conduct investigations for the suitability of the site for civil engineering works, to identify and provide solutions for engineering problems. Engineering projects are developed not only on engineering basis but also on Geological considerations.

Therefore, if a given Civil Engineering Structure is not suitable from engineering point of view; it may be made suitable by geological investigation and selection of alternative options with less finance and engineering problems.

For instance**,**

- Highly significant geological structures (Joints, Faults, folds, foliation and bedding planes) might affect **building structures** directly by influencing mass properties (strength, modulus of deformation or permeability) of the in situ rocks and indirectly by determining the groundwater pattern (the alteration products of faulting (impervious clay materials) may hinder or stop the movement of groundwater from one side of the fault to the other and so create hydrostatic heads.
- For instance, if encountered in a **tunnel**, it may also reduce sliding friction along the fault plane.
- Stability of hillsides, cut slopes, and quarry faces may often be controlled by the **geometric arrangement** of the geologic structures.

- Folds may influence the proper function of a **dams or other reservoirs**; e.g. when the reservoir is located over a monocline containing **pervious strata**, there may be excessive **seepage** if the monocline dips downstream.

Therefore, Knowledge of Engineering Geology, structural geology, geomorphology, hydrogeology, petrography and other branches of geology can be related to the engineering problems and is very important in civil engineering works.

Assignment 1

1. A radioactive substance has a half-life of 5 days, initial mass of 12kg. How much the original isotope will remain after 10 days?
2. What's the definition of half-life? In this example, what happens after 5 days?
3. Suppose one of a rock samples returned by the Apollo missions are impact breccias. These kinds of rocks are a mixture of different rock samples that have been “welded” together by the impact process. The impact that uncovered the rock has melted part of the rock and left a portion of the rock intact. How did this affect age determination of the rock sample and explain on the age of Breccias?
4. Let us say that you start with 1000 Rubidium-87 atoms and the half-life of Rubidium-87 is 47.5 billion years.
    a. What amount of Rubidium-87 atoms will have decayed into Strontium-87 after 47.5 billion years later?
    b. In another 47.5 billion years what will be Rubidium-87 and Strontium-87?
5. Suppose you had a radioactive isotope X whose half-life in disintegrating to daughter product Y is 120,000 years. By calculating how much it took to make the present amount of Y, you determine that, originally, the rock contained 8 grams of isotope X. At present only ¼ gram of X is in the rock. How many half-lives have gone by? How old is the rock?
6. The Earth is sphere (as is the Scotch egg!) with a diameter of about 12,700Kilometres. The deepest anyone has drilled so far into the earth is around 12 kilometers; and this is only few part of the crust. Therefore, How do we know what's going on deep underground?