

# PWE 210 SOLID EARTH PHYSICS

## LECTURE MATERIAL

### CHAPTER ONE: Earth's Origin

The study of Earth's origin involves understanding the processes and events that led to the formation of our planet. It's a complex topic that integrates knowledge from astronomy, geology, planetary science, and other disciplines. Understanding Earth's origin provides insights into the processes that shaped our planet's structure, composition, and environment.

#### Formation of the Solar System:

Earth formed approximately 4.5 billion years ago within the protoplanetary disk surrounding the young Sun. The solar system's formation involved the collapse of a molecular cloud, leading to the formation of the Sun and a rotating disk of gas and dust.

#### Accretion and Planetesimal Formation:

Within the protoplanetary disk, tiny dust particles collided and accreted to form larger bodies called planetesimals. These planetesimals further accreted through gravitational attraction to form protoplanets, including Earth.

#### Differentiation and Layering:

As Earth grew, it underwent a process called differentiation, where denser materials sank toward the center, forming the core, while lighter materials rose to the surface, forming the mantle and crust. This process resulted in the layering of Earth into distinct compositional zones namely: **core, mantle, and crust**.

#### Impact Bombardment:

During the early stages of Earth's formation, the planet experienced intense bombardment by large asteroids and comets known as planetesimals. These impacts played a significant role in shaping Earth's surface and contributing to the planet's composition.

#### Formation of the Atmosphere and Oceans:

Earth's early atmosphere likely consisted of gases released during volcanic outgassing, such as water vapor, carbon dioxide, nitrogen, and methane. As Earth cooled, water vapor condensed to form oceans, leading to the development of the hydrosphere.

### CHAPTER TWO: Shape of the Earth

The shape of the Earth has been a subject of scientific inquiry for centuries, with ancient civilizations proposing various hypotheses. Modern scientific understanding of Earth's shape is based on empirical evidence, mathematical models, and observational data. It has been concluded that the shape of the Earth is approximately an oblate spheroid, flattened at the poles and bulging at the equator. Scientific evidence from historical observations, geodetic surveys, theoretical models, and modern measurement techniques supports this understanding. Understanding Earth's shape is fundamental to various scientific disciplines, including geodesy, cartography, geophysics, and navigation.

**Historical Perspectives:** Early civilizations, such as the Greeks and Egyptians, speculated about the Earth's shape based on observations of the sky, shadows, and navigation. Pythagoras and later philosophers suggested a spherical Earth based on the symmetry of celestial bodies and the curvature of the Earth's shadow during lunar eclipses.

**Empirical Evidence:** The first direct evidence of Earth's curvature came from observations made by ancient navigators and explorers. Sailors noticed that the tops of distant ships disappeared over the horizon before the hulls, indicating the curvature of the Earth's surface.

**Geodetic Surveys:** Geodetic surveys conducted during the 18th and 19th centuries provided further evidence of Earth's shape.  
- Surveyors measured the angles and distances between points on the Earth's surface, revealing deviations from a perfectly flat plane.

**Theoretical Models:** Mathematical models, such as the geoid and ellipsoid, are used to represent the Earth's shape. The geoid is a hypothetical surface that represents mean sea level, accounting for variations in gravity and the Earth's irregular shape. The ellipsoid, or oblate spheroid, is a simplified model that approximates the Earth's shape as an oblate sphere flattened at the poles and bulging at the equator.

**Modern Measurement Techniques:** Advances in technology, such as satellite-based geodesy and global positioning systems (GPS), have enabled precise measurements of Earth's shape. Satellites orbiting the Earth can accurately measure the planet's gravitational field and variations in elevation, contributing to our understanding of its shape and structure.

**Origin of Life;** The origin of life on Earth remains a topic of scientific investigation and debate. Current evidence suggests that life may have originated in the oceans through chemical processes involving simple organic molecules.

## **CHAPTER THREE: Structure of the Earth**

The Earth's interior structure is characterized by layers of varying composition, density, and physical properties. Understanding the structure of the Earth provides insights into its formation, evolution, and dynamic processes.

### **Layers of the Earth:**

1. **Crust:** The Earth's outermost layer, ranging in thickness from 5 to 70 kilometers. Composed of solid rock and divided into continental crust (thicker, less dense) and oceanic crust (thinner, more dense). The crust is the layer on which humans live and where geological processes such as earthquakes and volcanoes occur.
2. **Mantle:** Beneath the crust lies the mantle, extending from the base of the crust to about 2,900 kilometers below the Earth's surface. Composed of solid rock, although it can deform slowly over geological time scales. The mantle is subdivided into the

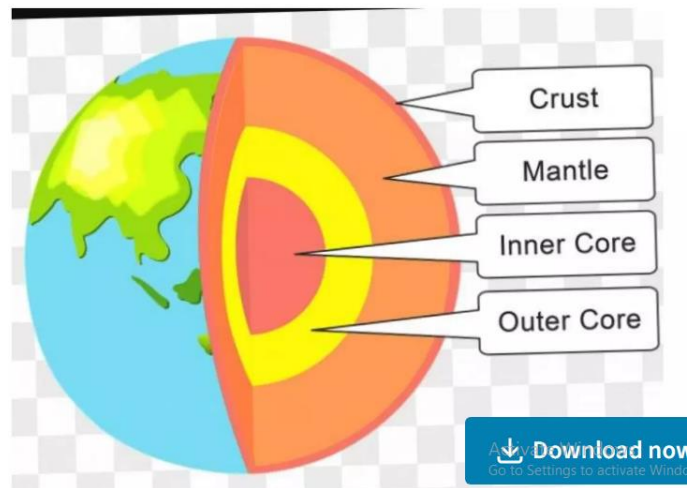
upper mantle (where convection currents drive plate tectonics) and the lower mantle (deeper, under higher pressure).

3. **Outer Core:** Below the mantle is the outer core, extending from about 2,900 to 5,150 kilometers below the surface. Composed of molten iron and nickel, with temperatures and pressures sufficient to prevent solidification. The motion of the liquid outer core generates Earth's magnetic field through the geodynamo process.

4. **Inner Core:** At the center of the Earth lies the inner core, extending from about 5,150 to 6,371 kilometers below the surface. Composed of solid iron and nickel due to higher pressure despite extremely high temperatures. The inner core is believed to rotate slightly faster than the rest of the Earth, contributing to the planet's magnetic field.

These three layers are.

- **Crust**
- **Mantle**
- **Core**



### Methods of Study:

1. **Seismology:** Seismic waves generated by earthquakes provide valuable information about the Earth's interior structure. By analyzing the propagation of seismic waves through the Earth, scientists can infer properties such as density, composition, and layer boundaries.

2. **Geophysical Surveys:** Geophysical techniques, including gravity measurements, magnetic surveys, and electrical resistivity surveys, help map variations in the Earth's structure and properties.

3. **Laboratory Experiments:** Laboratory experiments simulate the high-pressure and high-temperature conditions found within the Earth's interior, providing insights into the behavior of materials under such extreme conditions.

**Implications:** The structure of the Earth influences geological processes such as plate tectonics, volcanism, and mountain building. Understanding Earth's interior structure

is crucial for natural resource exploration, earthquake monitoring, and predicting geological hazards.

## **CHAPTER FOUR: Major Divisions of the Earth**

The Earth can be divided into several major divisions based on various criteria such as composition, physical properties, and dynamic processes. Understanding these divisions is essential for studying the Earth's structure, composition, and processes.

1. **Lithosphere:** The lithosphere is the outermost solid layer of the Earth, comprising the crust and the uppermost part of the mantle. It is relatively rigid and divided into tectonic plates that float and move on the semi-fluid asthenosphere beneath them. The lithosphere is involved in plate tectonics, which drives geological processes such as earthquakes, volcanism, and mountain building.

2. **Asthenosphere:** Beneath the lithosphere lies the asthenosphere, a semi-fluid layer within the upper mantle. The asthenosphere is characterized by partial melting and plastic deformation, allowing the lithospheric plates to move and slide over it. It plays a crucial role in the mechanics of plate tectonics and the movement of Earth's crustal plates.

3. **Mesosphere (Lower Mantle):** The mesosphere, also known as the lower mantle, extends from the base of the asthenosphere to a depth of about 2,900 kilometers. It is composed of solid rock but can deform slowly over geological time scales due to high temperature and pressure. The mesosphere is involved in convection currents that drive plate movements in the overlying lithosphere.

4. **Outer Core:** Below the mesosphere lies the outer core, extending from about 2,900 to 5,150 kilometers below the Earth's surface. Composed of molten iron and nickel, the outer core generates Earth's magnetic field through the geodynamo process. Convection currents in the outer core generate electrical currents, which in turn create the Earth's magnetic field.

5. **Inner Core:** At the center of the Earth lies the inner core, extending from about 5,150 to 6,371 kilometers below the surface. Composed of solid iron and nickel due to high pressure despite extremely high temperatures. The inner core is believed to rotate slightly faster than the rest of the Earth, contributing to the planet's magnetic field.

## **CHAPTER FIVE: Electrical Theory of Earth's Core and Origin of the Magnetic Field**

### **Earth's Magnetic Field**

Earth possesses a magnetic field that extends from its core out into space, playing a crucial role in various geophysical phenomena and navigation.

### **Electrical Theory of Earth's Core**

The core of the Earth consists primarily of iron and nickel. Under extreme pressure and temperature conditions, the core exists in a molten state. This molten iron-nickel alloy is conducive to electrical conductivity due to the presence of free electrons.

### **Dynamo Theory**

The dynamo theory proposes that Earth's magnetic field is generated by the motion of molten iron alloy in the outer core. This motion, driven by heat from the Earth's interior and the planet's rotation, creates electric currents through the process of convection. These electric currents, in turn, generate magnetic fields, resulting in the Earth's overall magnetic field.

### **Origin of Earth's Magnetic Field**

The origin of Earth's magnetic field lies in the dynamo action within its outer core. Convection currents caused by heat gradients and the rotation of the Earth generate electric currents. These electric currents induce a magnetic field, resulting in the formation of the Earth's magnetic field. This process is sustained over geological timescales, contributing to the stability of the magnetic field.

### **Seafloor Spreading and Magnetic Field Reversals:**

Seafloor spreading is a geological process where new oceanic crust is formed through volcanic activity along mid-ocean ridges. As new crust is created, iron-rich minerals in the magma align with the Earth's magnetic field. As the magma solidifies and moves away from the ridge, it preserves the orientation of the magnetic field at the time of its formation. Over time, as the Earth's magnetic field undergoes reversals, the alternating magnetic polarity of the seafloor creates magnetic stripes parallel to the mid-ocean ridges. These magnetic anomalies provide evidence for the phenomenon of magnetic field reversals and support the theory of plate tectonics.

### **Important point to note;**

- I. The electrical conductivity of Earth's core, combined with the dynamo action driven by convection currents, forms the basis of the planet's magnetic field.
- II. Seafloor spreading and the recording of magnetic reversals in oceanic crust provide valuable insights into the Earth's geological history and the dynamic nature of its magnetic field.

## **CHAPTER SIX: Earth's Magnetic Field and its Distribution**

### **Earth's Magnetic Field:**

The Earth has a magnetic field that extends from its core into space. It plays a crucial role in protecting the planet from harmful solar radiation and cosmic particles. It is a dynamic and complex phenomenon that plays a vital role in various geological, environmental, and technological processes. Understanding its distribution and behavior is essential for a wide range of scientific disciplines and practical applications.

### **Origin of Earth's Magnetic Field**

The Earth's magnetic field is generated by the motion of conductive materials, primarily molten iron and nickel, in the outer core. This motion generates electric currents, which in turn produce a magnetic field through the geodynamo effect.

### **Structure of Earth's Magnetic Field:**

The Earth's magnetic field is often represented as a dipole, with a north magnetic pole and a south magnetic pole. However, it is not perfectly aligned with the geographic poles and exhibits deviations known as magnetic declination and inclination.

### **Distribution of Earth's Magnetic Field:**

#### 1. **Magnetic Equator:**

The magnetic equator is an imaginary line around the Earth where the magnetic field is horizontal. It does not coincide with the geographic equator due to irregularities in the Earth's magnetic field.

#### 2. **Magnetic Poles:**

The magnetic poles are locations where the Earth's magnetic field lines are vertical. The magnetic north pole is currently located in the Arctic region of Canada, but it is not fixed and undergoes slow drift over time. The magnetic south pole is located in Antarctica, near the geographic south pole.

#### 3. **Magnetic Anomalies:**

Magnetic anomalies are variations in the Earth's magnetic field strength across the globe. Positive anomalies indicate areas where the magnetic field is stronger than average, while negative anomalies indicate weaker areas. These anomalies are caused by variations in the composition and magnetization of rocks in the Earth's crust.

### **Measurement and Mapping of Earth's Magnetic Field:**

Earth's magnetic field is measured using magnetometers, which detect changes in magnetic field strength. Magnetic surveys are conducted on land, sea, and air to map variations in the Earth's magnetic field and identify geological structures and mineral deposits.

### **Applications of Earth's Magnetic Field:**

1. Navigation: Earth's magnetic field has long been used for navigation, with compasses aligning with magnetic north. However, magnetic declination must be taken into account for accurate navigation.

2. Geological Exploration: Magnetic surveys are used in geological exploration to map subsurface structures, locate mineral deposits, and identify geological hazards.

3. Space Weather and Solar Activity: Earth's magnetic field protects the planet from solar wind and cosmic radiation, influencing space weather and auroral activity.

## **CHAPTER SEVEN: Continental Drift and Plate Tectonics**

**Continental Drift:-** Continental drift is a geological theory proposed by Alfred Wegener in the early 20th century. Wegener suggested that continents were once joined together in a single supercontinent called Pangaea and have since drifted apart to their current positions.

### **Evidence for Continental Drift:**

1. Geological Evidence: Similar rock formations, mountain ranges, and geological structures found on separate continents suggest they were once connected.
2. Fossil Evidence: Identical fossils of plants and animals found on continents separated by vast oceans indicate that these landmasses were once contiguous.
3. Paleoclimatic Evidence: Evidence of past glaciations and climate patterns, such as glacial striations and coal deposits in regions that are now tropical, support the idea of continents moving over time.

### **Plate Tectonics Theory:**

Plate tectonics is a comprehensive theory that explains the movement of Earth's lithosphere, which is divided into several large and small plates that float on the semi-fluid asthenosphere below. The theory combines elements of continental drift, seafloor spreading, and the concept of plate boundaries.

### **. Components of Plate Tectonics**

- i. Lithospheric Plates: These rigid plates comprise Earth's crust and the upper portion of the mantle.
- ii. Plate Boundaries: Zones where plates interact, leading to various geological phenomena.
- iii. Plate Motions: Plates move due to the convective currents in the underlying asthenosphere.

### **Types of Plate Boundaries:**

1. Divergent Boundaries: Plates move away from each other, leading to the formation of new crust. Examples include mid-ocean ridges.
2. Convergent Boundaries: Plates collide with each other, leading to subduction zones, mountain formation, and volcanic activity. Examples include the Andes Mountains and the Pacific Ring of Fire.
3. Transform Boundaries: Plates slide past each other horizontally, causing earthquakes. The San Andreas Fault is a well-known example.

### **Mechanisms Driving Plate Motion:**

- Mantle Convection: Heat from Earth's interior drives convection currents in the semi-fluid asthenosphere, which, in turn, drag the overlying lithospheric plates.
- Ridge Push and Slab Pull: Additional mechanisms, such as ridge push (the force exerted by the elevated mid-ocean ridges) and slab pull (the sinking of dense oceanic crust at subduction zones), contribute to plate motion.

### **Significance of Plate Tectonics:**

- I. Geological Hazards: Plate tectonics is responsible for earthquakes, volcanic eruptions, and tsunamis, posing risks to human populations.
- II. Continental Drift: The theory of plate tectonics provides a mechanism for continental drift and explains the dynamic nature of Earth's surface.