- **Overview of Lecture Topics**
  - Formation of the Earth
  - Materials of the Earth and their behavior
  - Connection between Earth's evolution and structure
  - Space hazards related to Earth's position in the solar system
- **Formation of the Earth**
  - Earth formed from a rotating cloud of dust and gas from a supernova.
  - Coalescence took around 50 to 100 million years.
  - Examples of formation snapshots:
    - **Crab Nebula**: Young gas and dust cloud, formed from a supernova in 1054 AD.
    - **HL Tauri**: Proto-planetary disk, approximately one million years old.
- **Accretion Process**
  - Accretion: Particles accumulate into planetesimals, then proto-planets.
  - Collisions generated intense heat causing proto-Earth to melt and differentiate.
  - **Differentiation**: Separation of chemical constituents into distinct layers (core, mantle).
    - Core formed from molten iron; lighter materials formed the mantle.
- **Meteorites and Their Importance**
  - Meteorites as fragments of proto-planets and planetesimals.
  - Identification of meteorites easier in deserts and icy regions.
- **Classes of Meteorites**
  - **Stony Meteorites**:
    - 75-90% silica-based minerals, 10-25% nickel-iron alloy.
    - **Chondrites**: 86% of meteorites; represent primitive materials.
    - **Achondrites**: Lack chondrules; from differentiated bodies.
  - **Stony Iron Meteorites**:
    - Mixture of silicates and nickel-iron alloy; from boundary regions of planetesimals.
  - **Iron Meteorites**:
    - Primarily nickel-iron alloy; originated from cores of differentiated bodies.
- **Historical Scientific Estimates of Earth’s Age**
  - **Lord Kelvin's Method**:
    - Estimated Earth's age at ~100 million years based on cooling from a molten state.
  - **John Perry's Revision**:
    - Considered convection in the mantle, yielding ages of 2-3 billion years.

- **Discovery of Radioactivity (Henri Becquerel, 1896)**:
    - Radioactive decay contributes to Earth's internal heat.
    - Radiometric dating developed from decay series measurements.

- **Current Age of Earth**
  - First dated in 1956: 4.55 billion years using Canyon Diablo meteorite.
  - Solar system formed ~4.56 billion years ago; accretion and differentiation occurred in ~30 million years.

- **Geological Time Scale**
  - Established with reference to fossils.
  - Representation of animal existence indicates humans as a recent presence in Earth's history.

- **Natural Radioactivity as a Hazard**
  - Naturally occurring radioactivity affecting exposure levels.
  - High radiation areas (e.g., Cornwall) correlate with geology.

- **Impact Events and Space Hazards**
  - Definition: Collisions between Earth and extraterrestrial objects (asteroids, comets).
  - Most asteroids are found in the asteroid belt and Kuiper belt.

- **Characteristics of Asteroids and Comets**
  - Asteroids: Range from hundreds of meters to kilometers; largest objects in asteroid belt.
  - Comets: Contain ice; tails formed when near the sun.

- **Frequency of Impact Events**
  - Small cosmic dust constantly entering atmosphere.
  - Larger impacts (>100 meters) every ~10,000 years.
  - Catastrophic events (1 kilometer or larger) every 500,000 years.

- **Significant Impact Events**
  - **Manicougan Crater**: Formed 214 million years ago by a 5 km meteorite.
  - **Sudbury Crater**: Formed 1.85 billion years ago by a 10-15 km impactor.

- **Historical Incidents:**
  - **Tunguska Event (1908)**: Airburst explosion with significant energy release, no fatalities.
  - **Chelyabinsk Meteor (2013)**: Exploded over Russia, significant shockwave, undetected prior.

- **Mass Extinction Events**
  - Related to asteroid impacts; notable events during the Devonian and Cretaceous periods.
  - Evidence connects extinction events to climatic changes and impacts, with distinct geological markers.

- **Asteroid Impact Avoidance**

    - Proposed methods to divert near-Earth objects on collision courses with Earth identified in recent decades.

Earth's Interior Structure

- **Concept of Rheology**: Study of how materials strain or deform under stress.
- **Earth's Mass Distribution**:
    - Gravity is almost constant; mass uniformly distributed in concentric spherical shells.
    - Earth's average radius: 6,370 km.
- **Historical Measurements**:
    - Eratosthenes (240 BC): Determined Earth's size.
    - Skihalion experiment (1774):
        - Estimated Earth's density (~5.5 g/cm^3) by measuring pendulum deflection due to a nearby mountain.
        - Revealed density increases inward (surface rocks: 2-3 g/cm^3).

Earth's Crust

- **Observed Depth**: Up to a few km; crust is the outermost solid layer.
- **Composition**:
    - Dominated by silica-rich igneous rocks (granite, basalt).
    - Thickness:
        - Oceans: 5-10 km.
        - Continents: 30-40 km.
- **Kola Superdeep Borehole**:
    - Deepest artificial point (12,226 m), reached in 1989.
    - Stopped due to high temperatures (180 °C) and pressure.

Mantle Composition

- **Xenoliths**: Volcanic lavas can bring up foreign rocks (e.g., peridotite).
- **Laboratory Experiments**:
    - Olivine (upper mantle) transforms under pressure (up to 5 g/cm^3).

Seismic Studies

- **Seismic Waves**:
    - P-waves: Compressional, travel through solids and liquids.
    - S-waves: Shear, do not travel through liquids (indicates molten outer core).
- **Boundary Identification**:
    - Core-mantle boundary: 2,900 km depth; significant density contrasts.

Rheological Structure

- **Stress and Strain**:
    - Stress: Force per unit area (Newtons/m^2 or Pascals).
    - Strain: Change in shape/deformation (unitless).
    - Types of stress:
        - Tensional: Extension strain.

        - Compressional: Shortening strain.
        - Shear: Simple shear strain.
- **Rheology Types**:
    - Elastic solids: Recoverable deformation.
    - Brittle solids: Break upon exceeding elastic limit.
    - Plastic solids: Permanent deformation; may flow under stress (ductile deformation).

Heat Transfer Mechanisms

- **Conduction**: Particles collide within solids; heats the handle of a metal pan.
- **Convection**: Movement of heated particles in liquids (water in a pan).
- **Radiation**: Transfer of heat via electromagnetic waves.

Earth's Geothermal Gradient

- **Temperature vs Depth**:
    - Upper 100 km: Linear increase (~25 °C/km).
    - Below 100 km: Gradual cooling through convection.
- **Peridotite Melting**:
    - Solidus: ~1,200 °C at surface.
    - Liquidus: ~1,800 °C at surface.

Rheological Layers

- **Lithosphere**: Rigid solid (up to 100 km) - brittle.
- **Asthenosphere**: Soft, ductile plastic (partial melting).
- **Mesosphere**: Stiff, plastic solid; no melting due to convection.

Types of Crust

- **Oceanic Crust**:
    - Composition: Basalt (3.0 g/cm^3 density).
    - Thickness: ~5-10 km.
- **Continental Crust**:
    - Composition: Granite and sedimentary rocks (2.8 g/cm^3 density).
    - Thickness: ~30-40 km (thicker in mountain ranges).

Space Hazards: Geomagnetic Storms

- **Magnetic Field Generation**:
    - From convective flow of liquid iron in the outer core.
    - Extends into space (magnetosphere) and deflects solar wind.
- **Solar Wind**: Energetic stream of charged particles from the sun; causes auroras and can disturb Earth's magnetic field.
- **Coronal Mass Ejections (CMEs)**:
    - Large releases of gas and magnetic field; can have severe effects on technology.

Historical Example: Carrington Event (1859)

- **Impact**:
    - Disrupted telegraph systems; fires and auroras visible worldwide.
- **Modern Implications**:
    - Potential impacts of modern analog (e.g., 1989 Quebec blackout due to geomagnetic storm).
    - Estimated economic damage from a severe solar storm could reach $40 billion/day.

Summary

- Reviewed Earth's evolution, interior structure, and the effects of space hazards, emphasizing the importance of understanding both for studying geological and atmospheric phenomena.