Introduction

Physics of the Earth as a Planet, Lecture 1

Summary of Main Points

The Earth's Internal Heat

(i) Present-day heat loss of the Earth is about 4×10^{13} watts or about 80 milliwatts per square meter (mW m^{-2}).

(ii) Sources of heat: (a) release of gravitational energy, (b) tidal dissipation of kinetic energy, and (c) radioactivity decay.

(iii) The present temperature field in the Earth depends on: (a) the initial temperature distribution, (b) the spatial and temporal distribution and intensity of heat sources, and (c) the mechanism of the internal heat transfer.

(iv) Heat flux is low in old continental shields and in old oceanic sea floor (¡ 40 mW m^{-2}) and is high in tectonically active continental regions and near ocean ridges (¿ 100 mW m^{-2}).

(v) Convection is the primary means of heat transfer.

The Earth's Gravity Field

(i) Gravitational acceleration at the surface of the Earth is close to 9.827 m s^{-2} , corresponding to a homogeneous sphere of mass 5.98×10^{24} kg and a radius of 6.371×10^{5} m.

(ii) Gravity varies by a small amount over the surface of the Earth, reflecting the asymmetrical distribution of mass within the Earth's crust and mantle.

(iii) The *reference ellipsoid* or *reference spheroid* is the equipotential surface that would coincide with mean sea–level on an imaginary rotating Earth with the same size and mass as the real Earth but with all masses uniformly distributed radially.

(iv) The *geoid* is the equipotential surface that coincides with mean sea level on the real Earth; it departs from the reference ellipsoid by up to ± 100 m.

(v) Major features like the continents and oceans do not show in the geoid — mass compensation at some depth in the Earth.

(vi) On time scales of $\sim 10^{4}$ years and greater, the Earth behaves as a viscous fluid.

The Earth's Magnetic Field

(i) The Earth's magnetic field has existed for at least 3.5×10^{9} years.

(ii) The field is approximately that of a dipole positioned at the centre of the Earth and tilted $\sim 10^{\circ}$ with respect to the rotational axis.

(iii) The field itensity ranges between $\sim 25,000$ nanotesla (nT) near the equator to $\sim 65,000$ nT near the poles.

(iv) There is a secular variation on a time scale of a year or more with a prominent *westward drift* of $\sim 0.2^{\circ}$/yr.

(v) Reversals occur at apparently random intervals ranging from less than 0.1 million years to as much as 50 million years.

Seismology

(i) Almost all information about the interior of the Earth comes from seismology.

(ii) On short time scales Earth materials behave elastically and transmit elastic waves.

(iii) Two kinds of waves — Compressional waves (P–waves) and shear waves (S–waves).

(iv) Main divisions of the Earth — Crust ($\sim 1\%$), Mantle ($\sim 68\%$), and Core ($\sim 31\%$)

(v) Locations and mechanisms of earthquakes show where faults are and how they move during an earthquake.

Composition

(i) The principal evidence for the Earth's composition comes from: (a) meteorites and (b) volcanic nodules.

(ii) The dominant upper mantle mineral is olivine, a magnesium/iron/silicon oxide.

(iii) The core is mainly composed of iron, with some nickel and few percent of lighter elements.

(iv) High pressure effects studied by: (a) large presses, (b) shock waves, and (c) diamond cells.

(v) Experiments show that upon compression, olivine atoms rearrange to pack more closely.

(vi) The seismic profile of the upper mantle shows zones where the seismic velocity is relatively constant, alternating with zones in which the velocity increases more rapidly with depth.

(vii) Laboratory simulation of the pressures within the upper mantle at these depths suggest these zones are the result of changes of the solid phase, or rearrangement of the atoms that make up the crystalline structure of the solid, rather than a result of change in composition.

Governing equations

(i) The continuum mechanics equations used in geophysics are all derived in the same way from standard conservation laws of classical physics.

(ii) Three equations underlie what will be covered in the course – conservation of mass (here for an incompressible fluid),

$$\nabla \cdot \mathbf{v} = 0,$$

Cauchy's equation which describes momentum transport in a continuum,

$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = \nabla \cdot \underline{\underline{\boldsymbol{\sigma}}} + \mathbf{f},$$

and conservation of energy (heat)

$$\rho C_p \left(\frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T \right) = \nabla \cdot (k \nabla T) + \rho H.$$