GEOCHEMISTRY

"Structure & Composition of the Earth"

(M.Sc. Sem IV)

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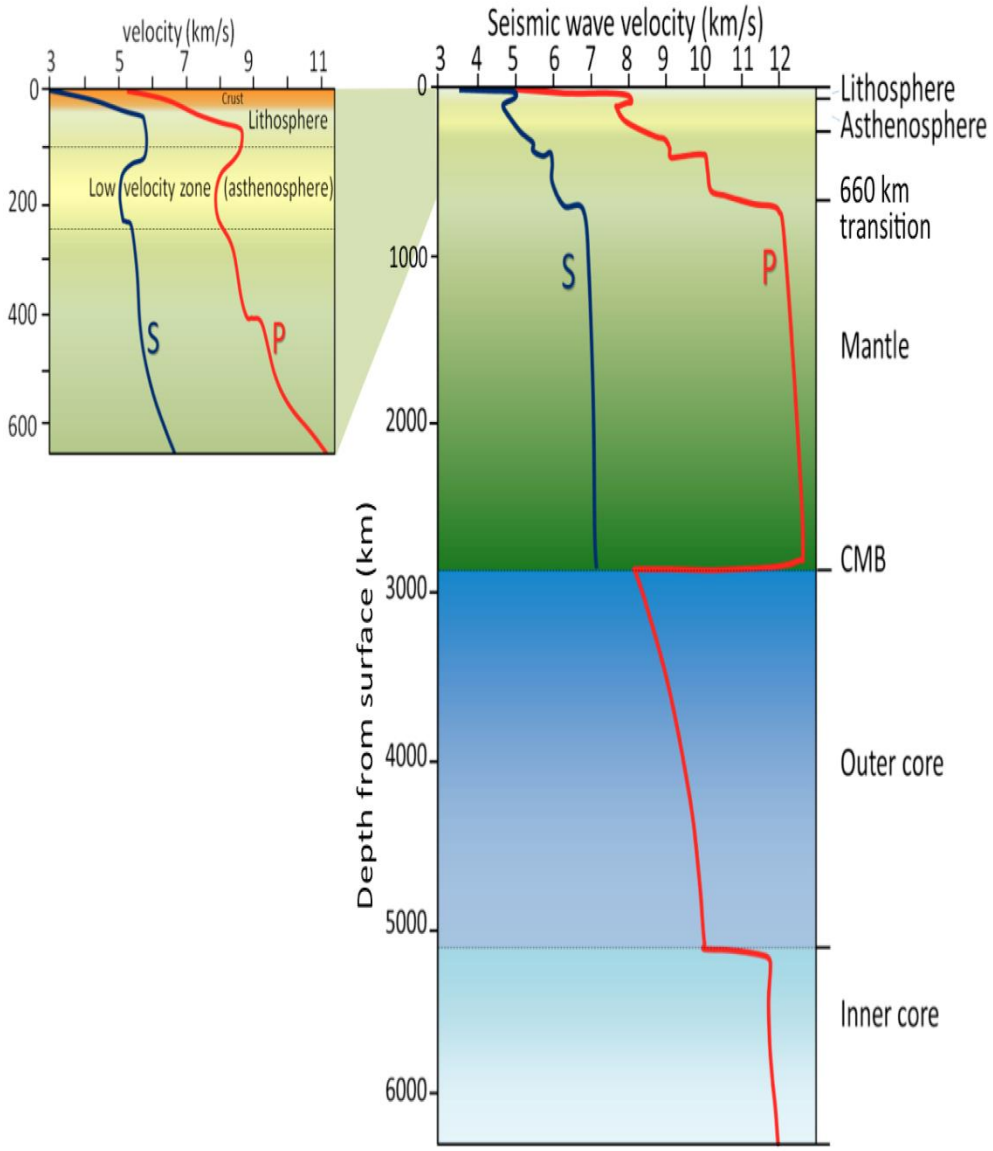
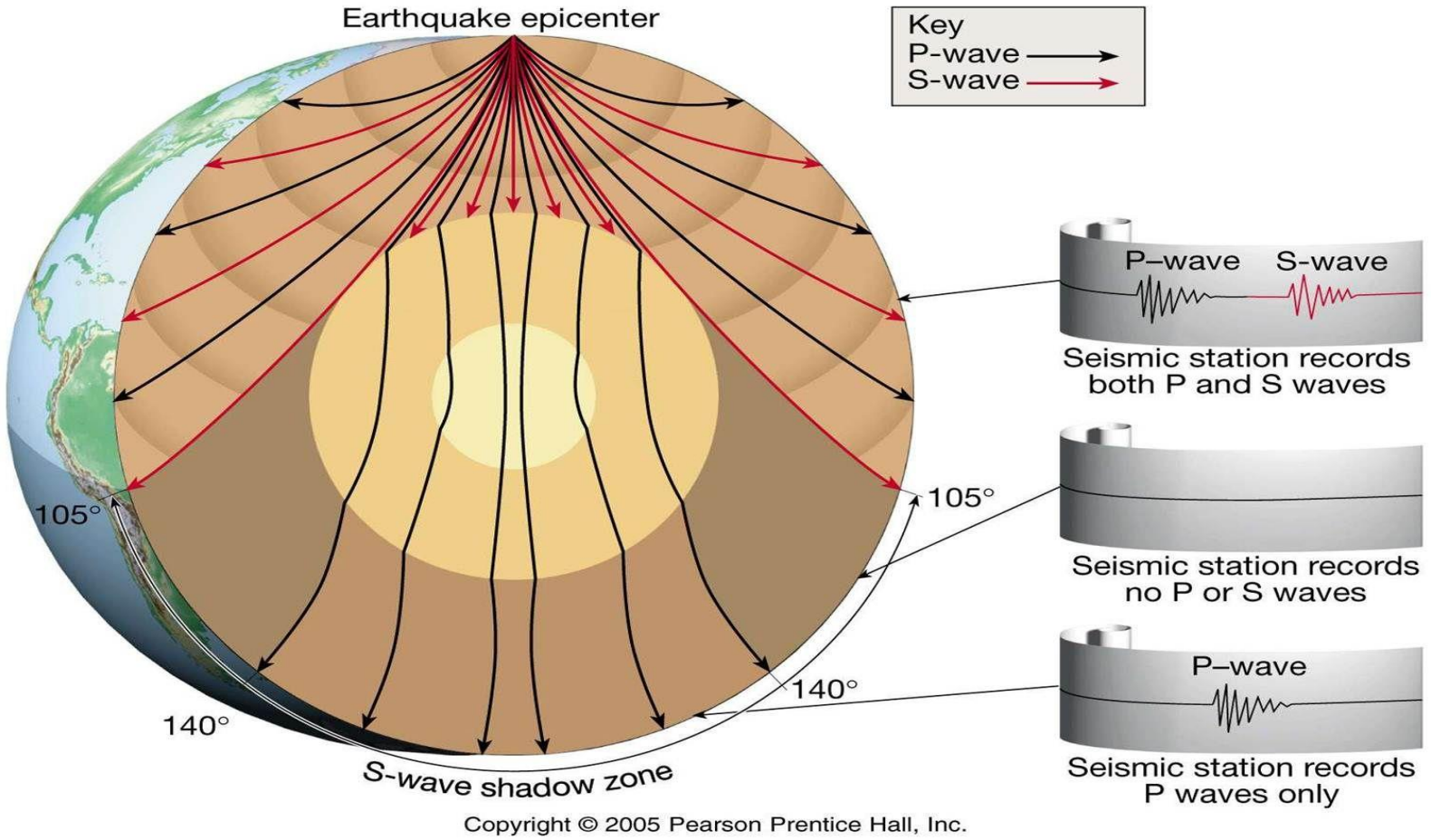
Structure of the Earth

- Earth structure and it's composition is the essential component of Geochemistry.
- Seismology is the main tool for the determination of the Earth's interior.
- Interpretation of the property is based on the behaviour of two body waves travelling within the interior.



Structure of the Earth



Variation in seismic body-wave paths, which in turn represents the variation in properties of the earth's interior.

Structure of the Earth

Based on seismic data, Earth is broadly divided into-

i. The Crust

ii. The Mantle

iii. The Core

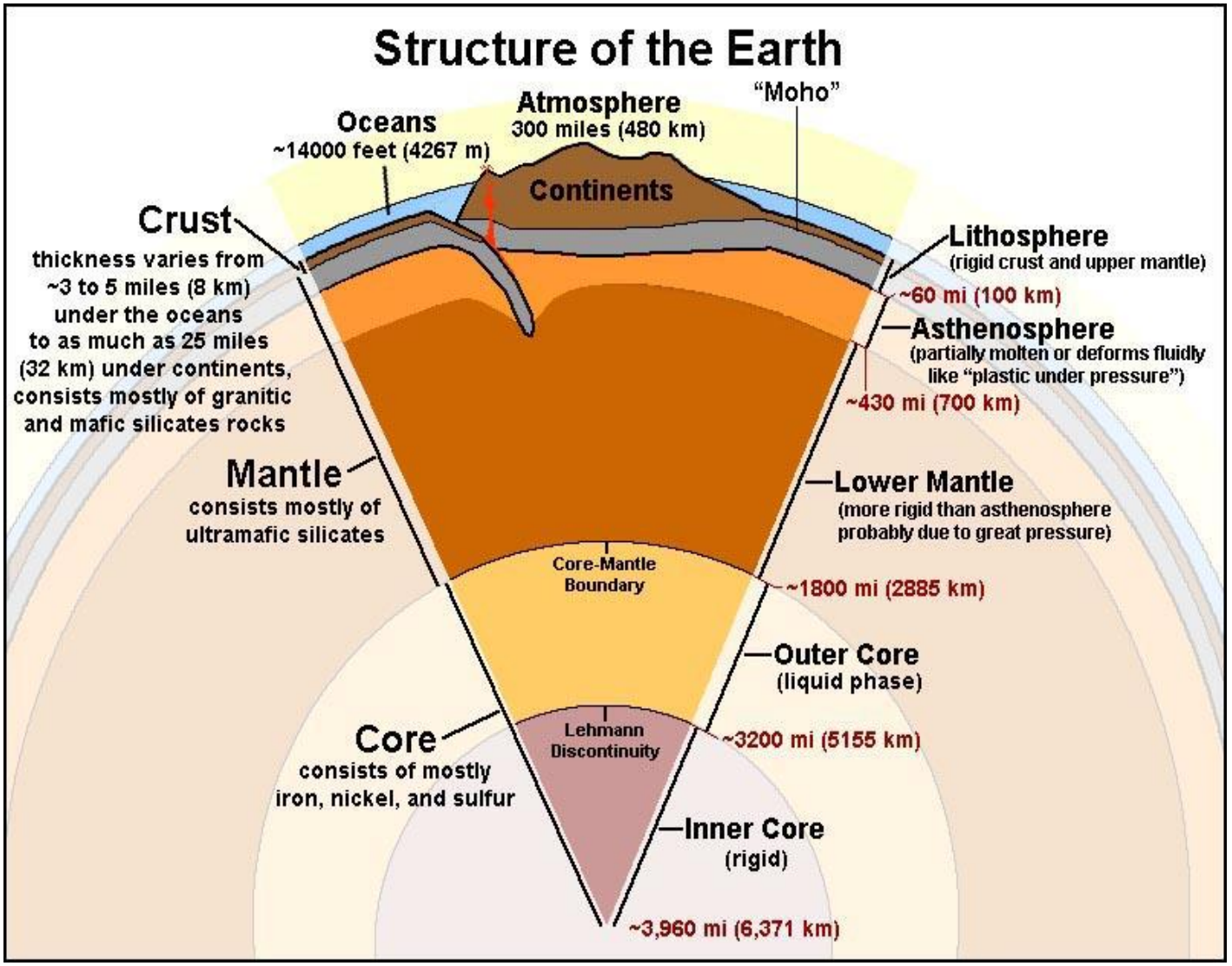
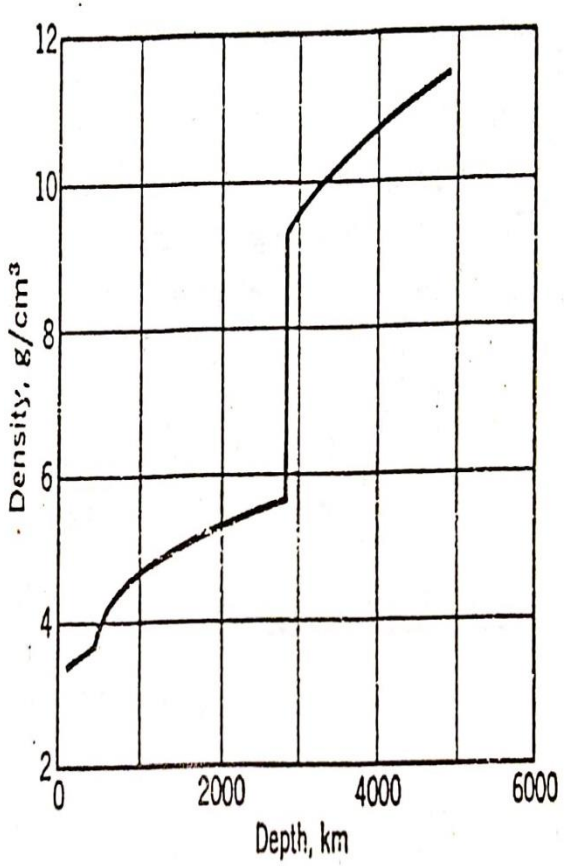
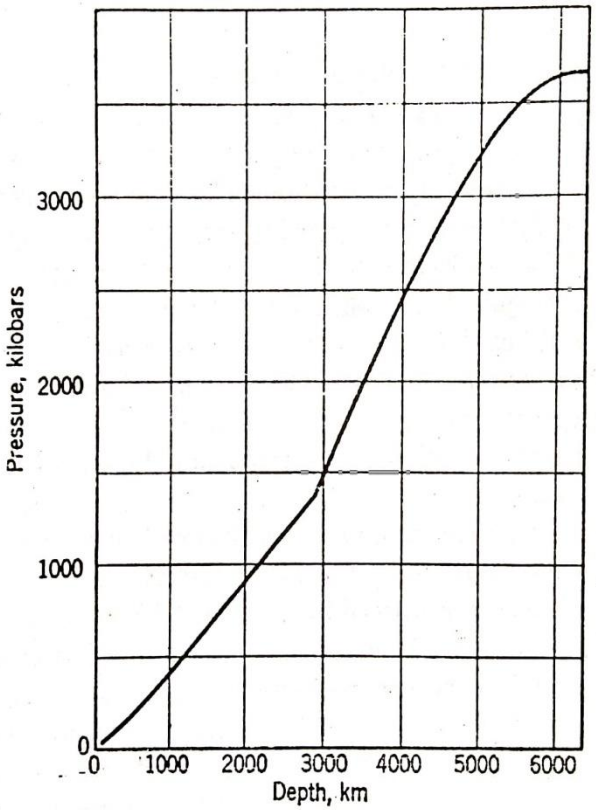
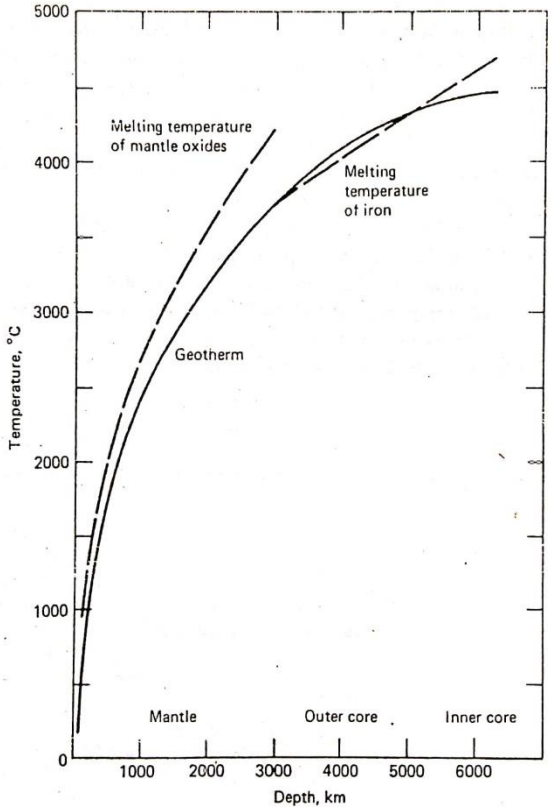


*Figure courtesy Geologycafe.com

Density, Pressure & Temperature variation with Depth







*From Bullen, An introduction to the theory of seismology. Courtesy of Cambridge Cambridge University Press

*Figure courtesy Brian Mason: Principle of Geochemistry

The crust

- The crust is the outermost layer of the earth.
- It consist 0.5-1.0 per cent of the earth's volume and less than 1 per cent of Earth's mass.
- The average density is about "**2.7 g/cm^3**"

  (average density of the earth is 5.51 g/cm^3).
- The crust is differentiated into-

  i) Oceanic crust

  ii) Continental crust

The Oceanic crust

- Covers approx. ~ 70% of the Earth's surface area.
- Average thickness ~ 6km

(~4km at MOR : ~10km at volcanic plateau)

- Mostly mafic in nature.
- Relatively younger in age.

The Oceanic crust

Seismic study shows layered structural arrangement.

- *Seawater*
- *Sediments*
- *Basaltic layer*
- *Gabbroic layer*

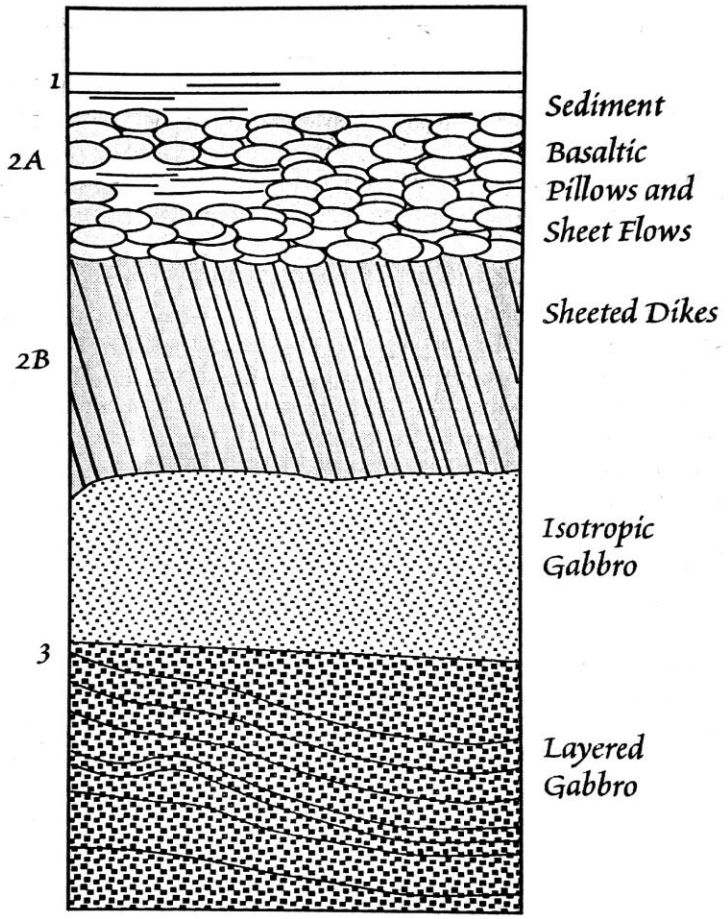


Figure 12.1. Schematic cross-section of the oceanic crust. Numbers on the left indicate the designation of seismically identifiable layers.

**Figure courtesy W.M.White: Geochemistry*

The Continental crust

- Heterogeneous in nature.
- Average thickness ~ 35km – 40km
- Relative older than oceanic crust.
- It is further divided into 3 layers-

    i) Upper crust

    ii) Middle crust

    iii) Lower crust

The Continental crust

- ***Upper crust:***

  - includes upper 10km - 15km.
  - formed by the differentiation of the lower crust.
  - mostly granodioritic/tonalitic in composition.
  - Si and Al enriched.
  - weathering of the rock results in the formation of – sand, clay, solution.

The Continental crust

- ***Lower crust: (middle+lower)***

  - mostly *granulitic* in composition.
  - highly metamorphosed.
  - evidence of both *prograde & retrograde* metamorphism.
  - mostly *anhydrous minerals*.
  - richer in Si, Fe, Mg.

The Continental crust

Abundance of element and the oxides in the Earth's crust

Elements	Oxides
Oxygen	SiO_2
Silicon	Al_2O_3
Aluminium	CaO
Iron	FeO
Calcium	MgO
Sodium	Na_2O
Magnesium	K_2O
Potassium	TiO_2

The Mantle

- It forms about **83 per cent of the earth's volume and holds 67% of the earth's mass**.
- The average density is about "**4.5 g/cm^3**"

  (average density of the earth is 5.51 g/cm^3).
- It extends from Moho's discontinuity to a depth of 2,900 km.
- The mantle is composed of **silicate rocks that are rich in iron and magnesium** relative to the overlying crust.
- The mantle is made up of **45% oxygen, 21% silicon,** and **23% magnesium (OSM)**.

The Mantle

- The *mantle* is further differentiated into –
  - *Upper mantle*
  - *Lower mantle*

The Upper Mantle

- The density of the upper mantle varies between **2.9 g/cm^3 and 3.3 g/cm^3**.

- *Olivine* is thought to be the dominant mineral phase, followed by *orthopyroxene*, *clinopyroxene*, and an *Al-bearing phase* (plagioclase, spinel, or garnet).

- An alternative term is coined by A. E. Ringwood-

  "***Pyrolite"*** (pyroxene-olivine rock)

The Upper Mantle

- Pyrolite, however, is associated with a specific composition.
- Pyrolite → 1 basalt + 3 dunite

- Ampholite → olivine + amphibole
- Plagioclase Pyrolite → olivine + Al poor pyroxene + plagioclase
- Pyroxene Pyrolite → olivine + Al rich pyroxene + spinel
- Garnet pyrolite → olivine + Al poor pyroxene + garnet

The Upper Mantle

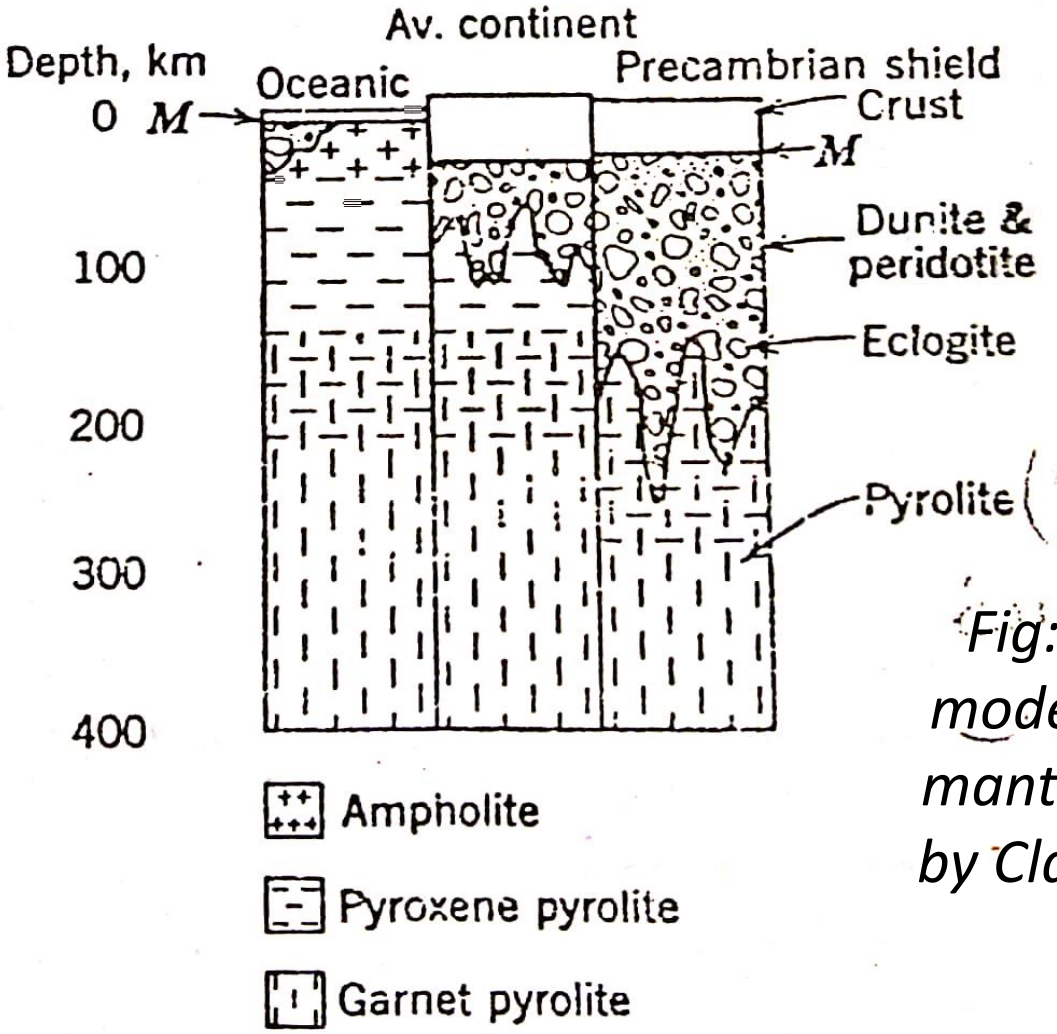
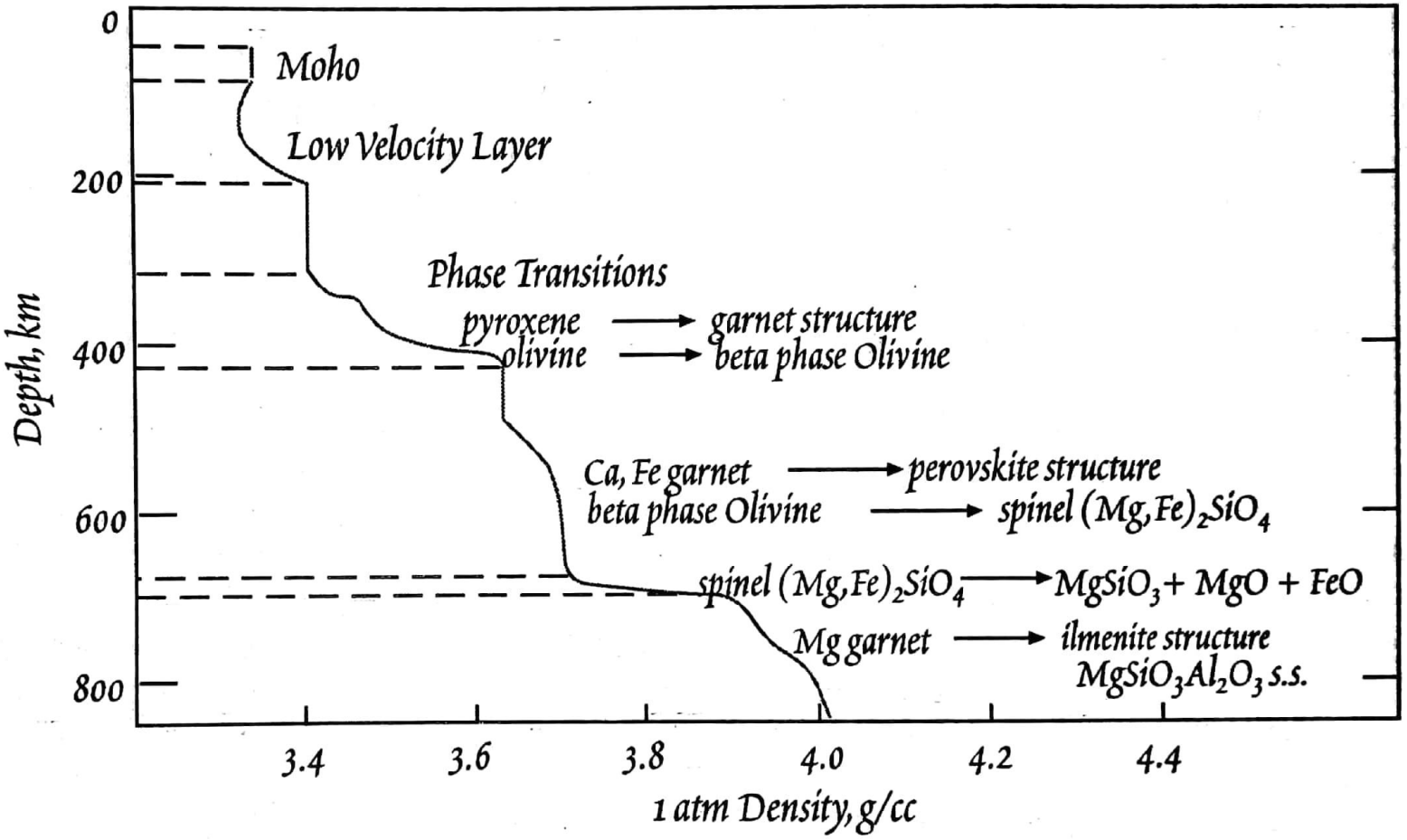


Fig: Petrographic model for the upper mantle as suggested by Clark & Ringwood (1964)

**Figure courtesy Brian Mason: Principle of Geochemistry*

Phase transition in the upper mantle



Phase transition represents the change in high density structure of the mineral phases with depth

**Figure courtesy W.M.White: Geochemistry*

The Lower Mantle

- The lower mantle, the region between the 660 km seismic discontinuity and the core-mantle boundary at 2900 km.

- Density **~ 3.3 g/cm^3 - 5.7 g/cm^3**
- Temperature **~ 3500°C - 3870°C**

- It's composition must be inferred by its seismic properties.

The Lower Mantle

- The lower mantle is grossly similar in compositional to the upper mantle,

  - composed dominantly of SiO_2, MgO, and FeO

  with lesser amounts of CaO, Al_2O_3, TiO_2, etc.

- Perovskite and magnesiowustite appear to remain the principal phases throughout the lower mantle.

**Perovskite constitutes about 80% of the lower mantle, and thus is the most abundant mineral in the Earth.*

The Core

- The core accounts for just about **16 per cent of the earth's volume but 33% of earth's mass**.
- The average density is about "**11.0 g/cm^3**"

  (average density of the earth is 5.51 g/cm^3).

- It is further differentiated as:
  - *Outer core*
  - *Inner core*

The Outer Core

- It lies between **2900 km and 5100 km.**
- Density **~ 9.9 g/cm^3 - 12.2 g/cm^3**.
- Mainly composed of **iron mixed with nickel** (**nife**),
  and trace amounts of lighter elements, such as **S, C, Si**

- The outer core is **not under enough pressure to be solid**, so it is liquid even though it has a composition similar to the inner core.
- Dynamo theory suggests that **convection in the outer core, combined with the Coriolis effect**, gives rise to **Earth's magnetic field**.

The Inner Core

- It extends from the centre of the earth to 5100 km below the earth's surface.
- Density ~ **12.6 g/cm^3 - 13 g/cm^3**.
- Temperature ~ 6000 ℃.
- Since this layer can transmit shear waves (transverse seismic waves), it is solid.

  -*when P-waves strike the outer core – inner core boundary,*

  they give rise to S-waves.

- At 6000°C, this iron core is as hot as the Sun's surface, but the crushing pressure caused by gravity prevents it from becoming liquid.

The Inner Core

- Its composition is more or less similar to the Outer core.

  - primarily of Nickel-Iron complex (**nife),**

    (*iron 80% and some nickel*).

- Earth's inner core rotates slightly faster relative to the rotation of the surface.
- The solid inner core is too hot to hold a permanent magnetic field.

References & for further study

- *Anderson, D. L., 1989. Theory of the Earth. Boston: Blackwell Scientific Publishers*
- *Mason, B., Moore, C. B., Principle of Geochemistry: John Wiley & sons*
- *Ringwood, A.E., 1991. Phase transformation and their bearing on the constitution and dynamics of the mantle, Geochim. Cosmochim. Acta, 55, 2083-2110.*
- *White, W. M., Geochemistry: 2015 John Wiley & Sons, Ltd.*