Earth and Planetary Sciences (ES1101)

(Minerals: Building Blocks of Rocks)

(Autumn 2021 by Gaurav Shukla)

Book: 1) Understanding Earth by Grotzinger & Jordan (Text Book)
2) Earth: An introduction to Physical Geology by Tarbuck & Lutgens
3) The Solid Earth: An introduction to global geophysics by Fowler

Exploring Earth's Interior using Seismic Waves

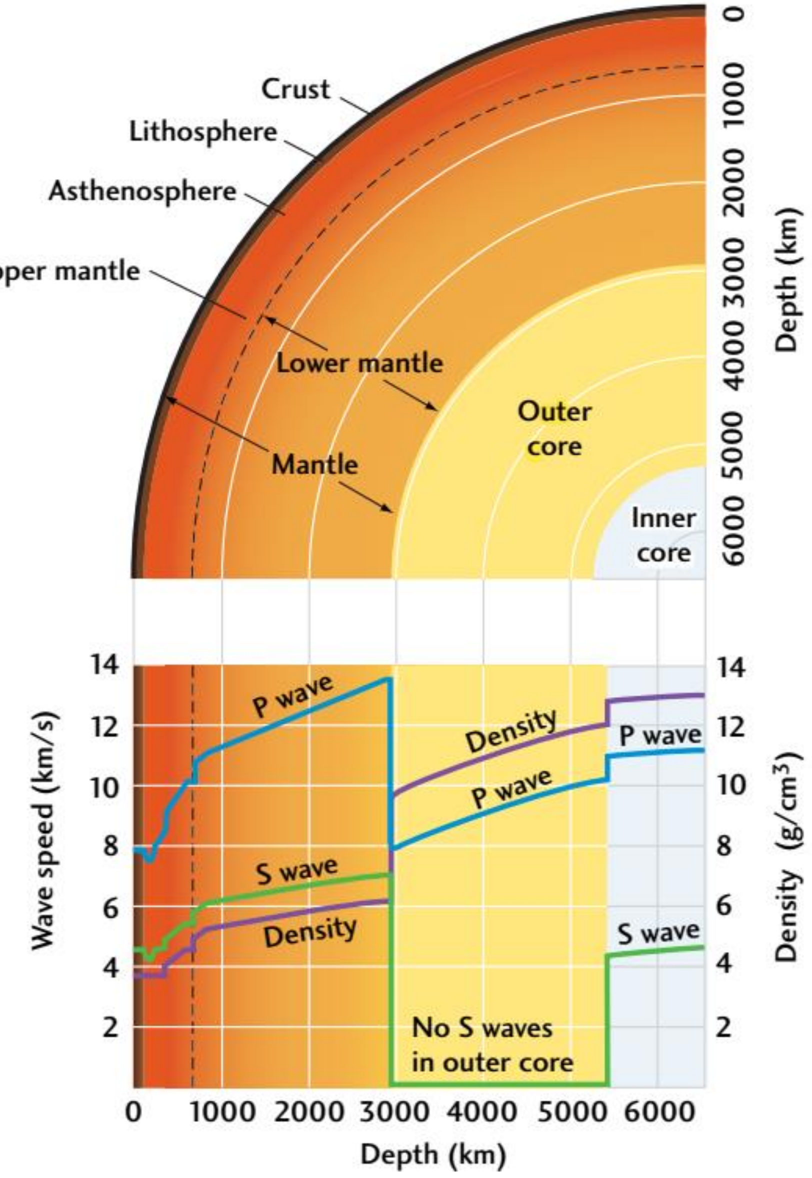


FIGURE 14.7 ■ Earth's layering as revealed by seismology. The lower diagram shows changes in P-wave and S-wave velocities and rock densities with depth. The upper diagram is a cross section through Earth on the same depth scale, showing how those changes are related to the major layers (see also Figure 1.12).

Exploring Earth’s Interior using Seismic Waves

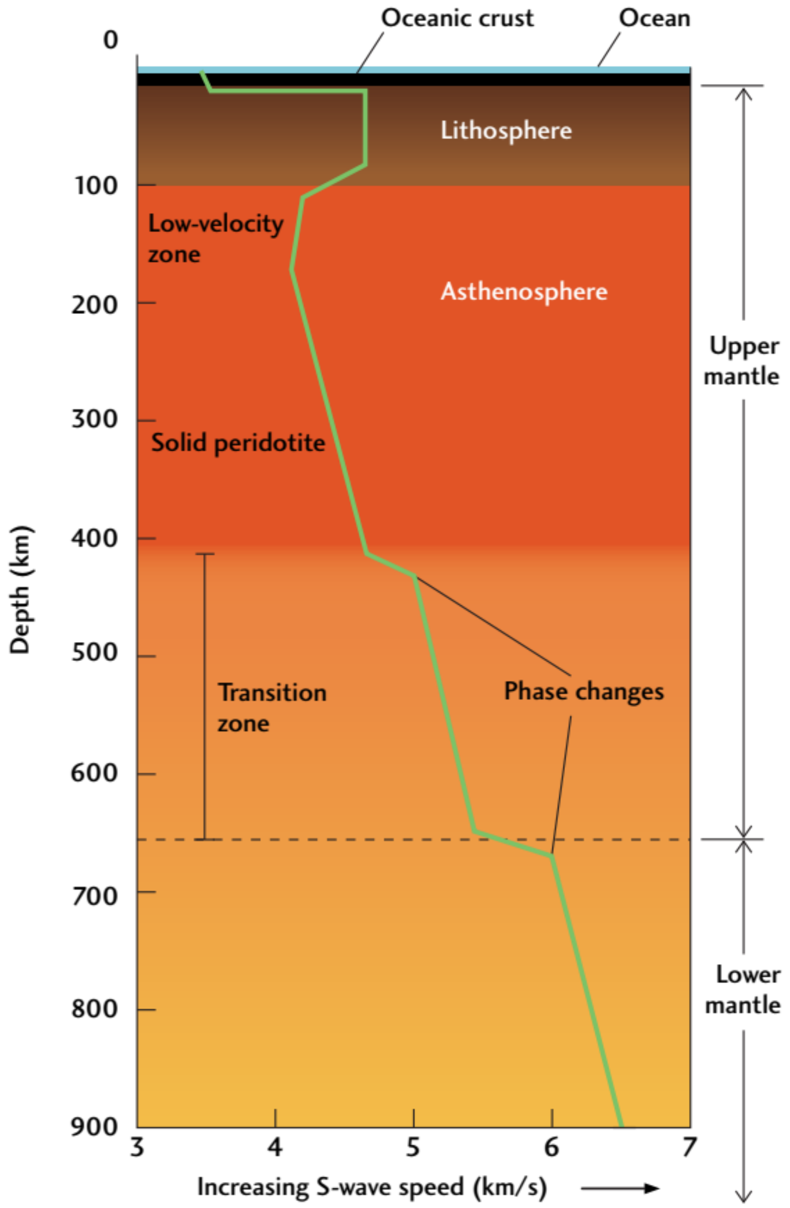


FIGURE 14.8 ■ The structure of the mantle beneath old oceanic lithosphere, showing S-wave velocities to a depth of 900 km. Changes in S-wave velocity mark the strong, brittle lithosphere, the weak, ductile asthenosphere, and a transition zone, in which increasing pressure forces rearrangements of atoms into denser and more compact crystal structures (phase changes).

Exploring Earth's Interior using Seismic Waves

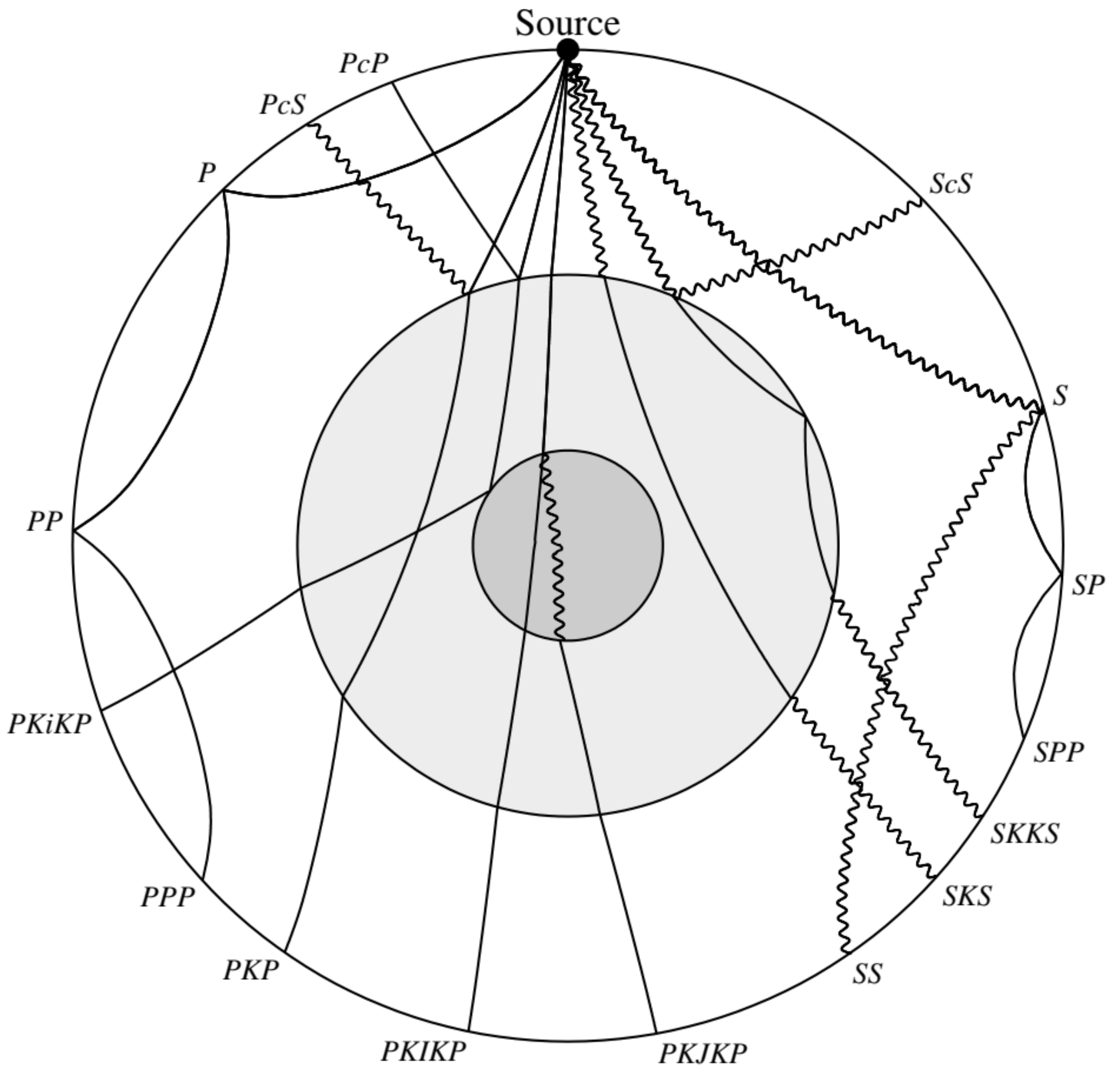
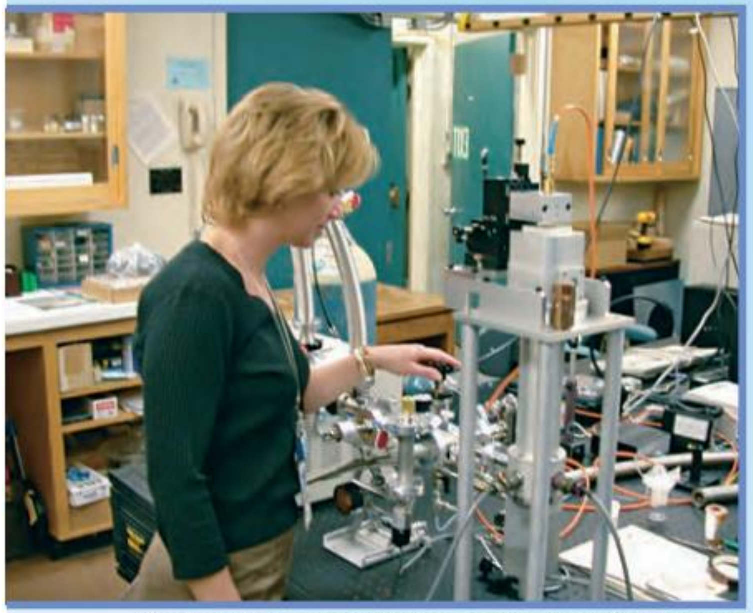


Figure 4.15 Global seismic ray paths and phase names, computed for the PREM velocity model. *P* waves are shown as solid lines, *S* waves as wiggly lines. The different shades indicate the inner core, the outer core, and the mantle.

GEO GRAPHICS 12.1 Recreating the Deep Earth

Seismology alone cannot determine the nature of the materials deep in Earth's interior. Additional information must be obtained by other techniques. Mineral physics experiments can measure physical properties of rocks and minerals such as stiffness, compressibility, and density while simulating the extreme conditions of the mantle and core.

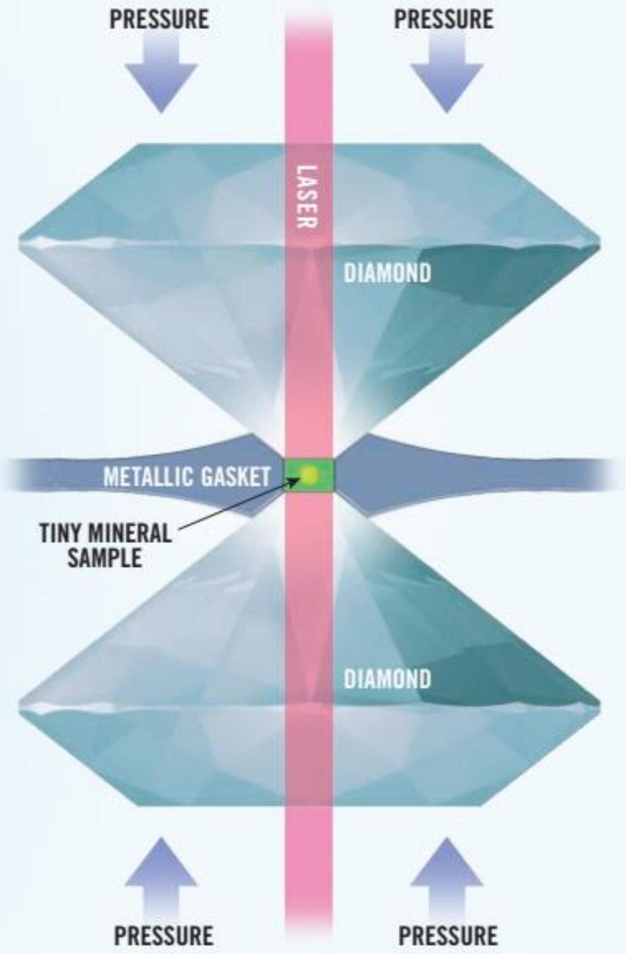


C.Arache, D. Jackson and S.T. Weir/Lawrence Livermore National Laboratory

One experiment examines the temperatures and pressures at which one mineral phase will become unstable and convert into a new "high-pressure" phase. These experiments are useful because they help identify where phase changes take place within Earth.

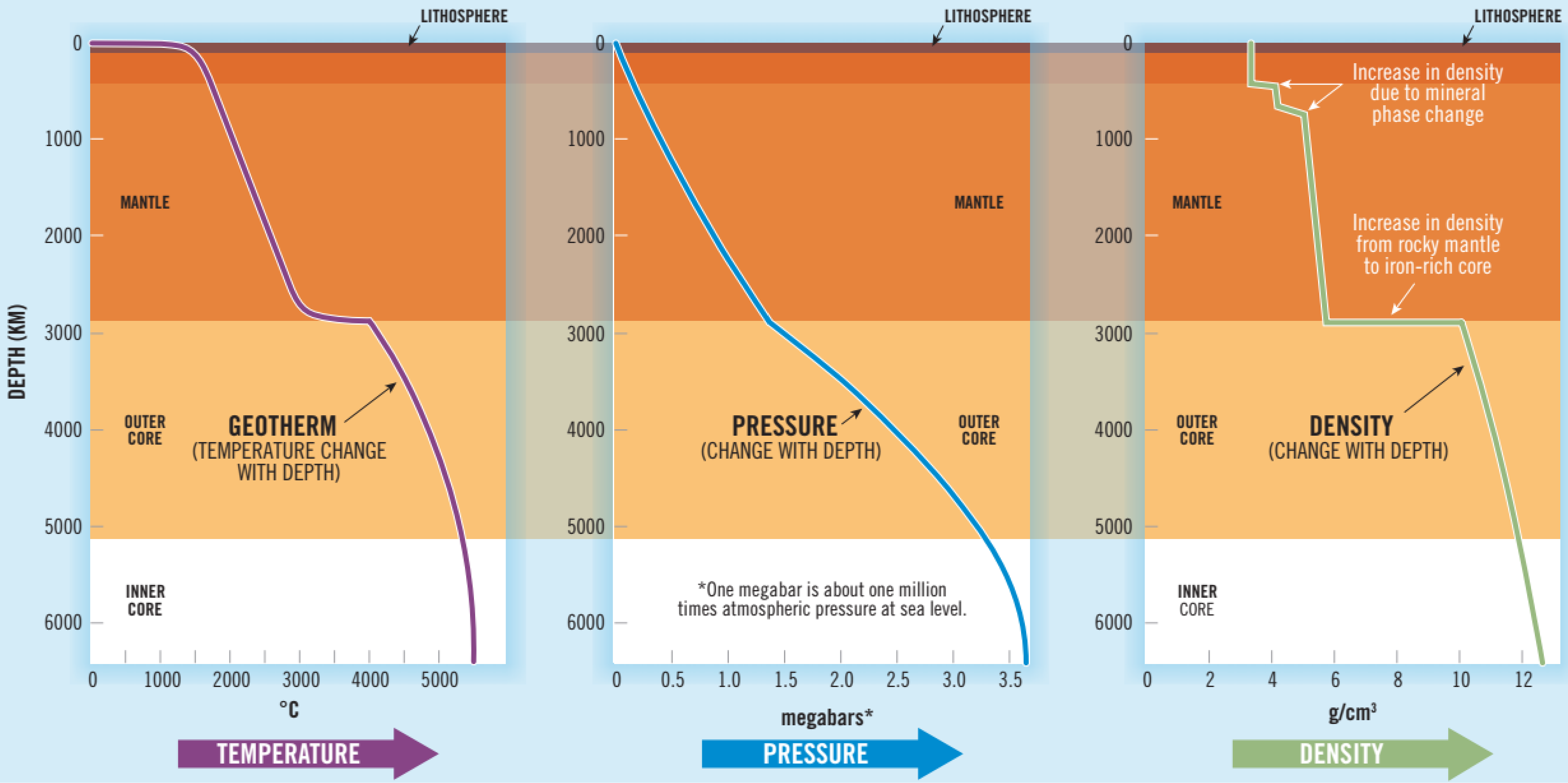
Most mineral physics experiments are conducted using diamond-anvil presses like the one shown here. These take advantage of two important properties of diamonds—hardness and transparency. The tips of two diamonds are cut off, and a small mineral sample is placed between them. By squeezing two diamonds together, pressures as high as our planet's interior have been simulated. High temperatures are achieved by firing a laser beam through the diamond and into the mineral sample.

Douglas L. Peck Photography



Question:
What two properties of diamonds make them ideal for use in a diamond-anvil press?

These experiments have also helped identify where changes in temperature, pressure, and density occur in Earth's interior, as shown in the graphs below.



Heat Sources in the Earth

- **Heat from the early accretion and differentiation of Earth:**
  - **Kinetic energy released by impacts with the planetesimals heated its outer regions.**
  - **Gravitational energy released by differentiation of the core heated its deep interior.**

- **Heat released by the radioactive decay of unstable nuclei.**

Heat transfer

- **Radiation**
- **Conduction**
- **Convection**

Geothermal Gradient

- **Heat is transported in the lithosphere by <u>conduction mainly</u>.**

- **Measurement of heat flow shows that continental areas have lower heat flows than ocean basins.**

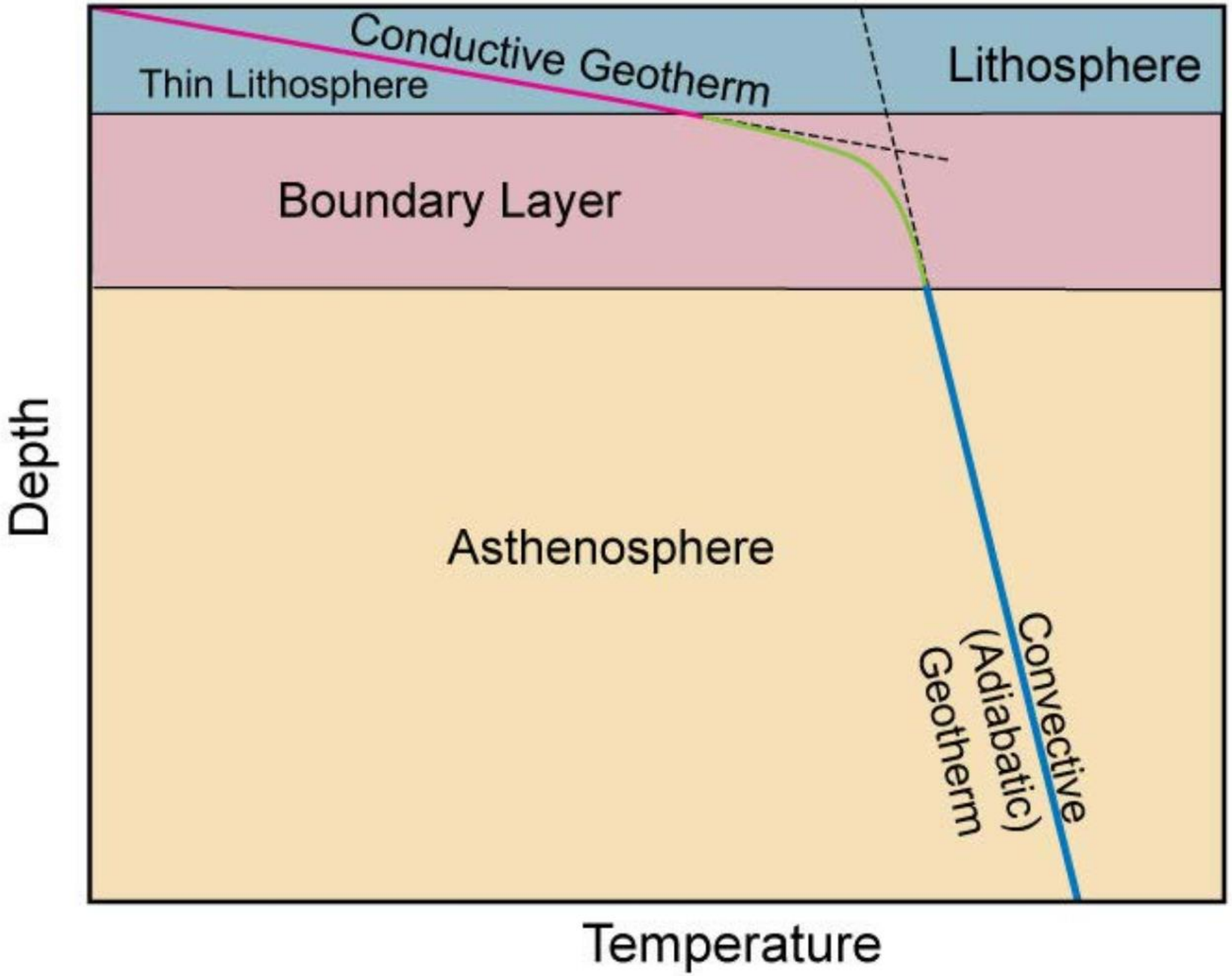
- **Consequently, the continental geotherm is located at relatively lower temperature side of the oceanic geotherm in the lithosphere.**

- **From the asthenosphere downwards in the mantle, <u>heat transport is by convection</u>, which should theoretically homogenize the temperature distribution, and the two geotherms should merge.**

- **There are various estimates of geothermal gradients in the lithosphere, but The continental geotherm is always at lower temperatures than the oceanic geotherm.**

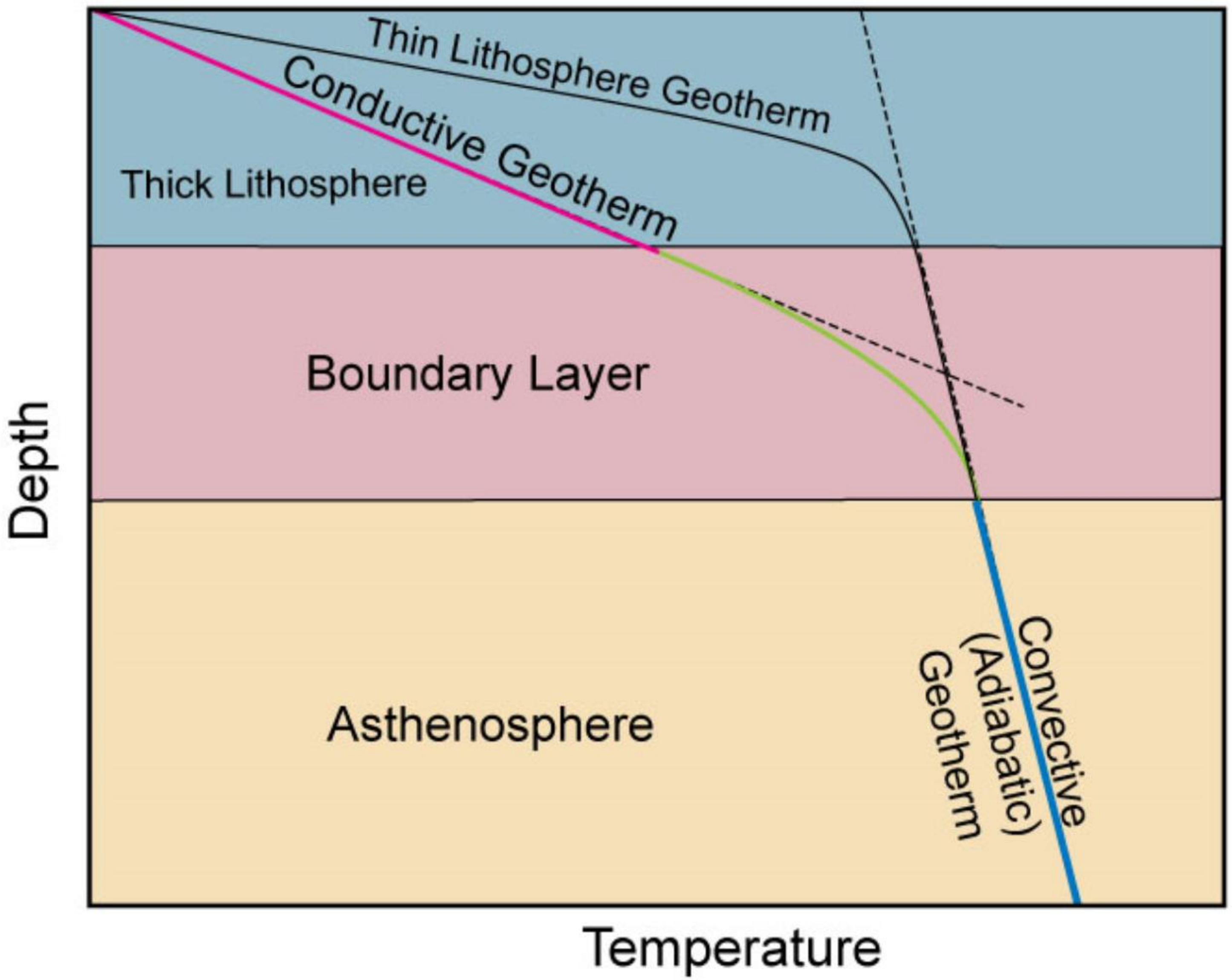
Geothermal Gradient

Figure 1.9 Diagrammatic cross-section through the upper 200-300 km of the Earth showing geothermal gradients reflecting more efficient adiabatic (constant heat content) convection of heat in the mobile asthenosphere (steeper gradient in blue)) and less efficient conductive heat transfer through the more rigid lithosphere (shallower gradient in red). The boundary layer is a zone across which the transition in rheology and heat transfer mechanism occurs (in green). The thickness of the boundary layer is exaggerated here for clarity: it is probably less than half the thickness of the lithosphere.



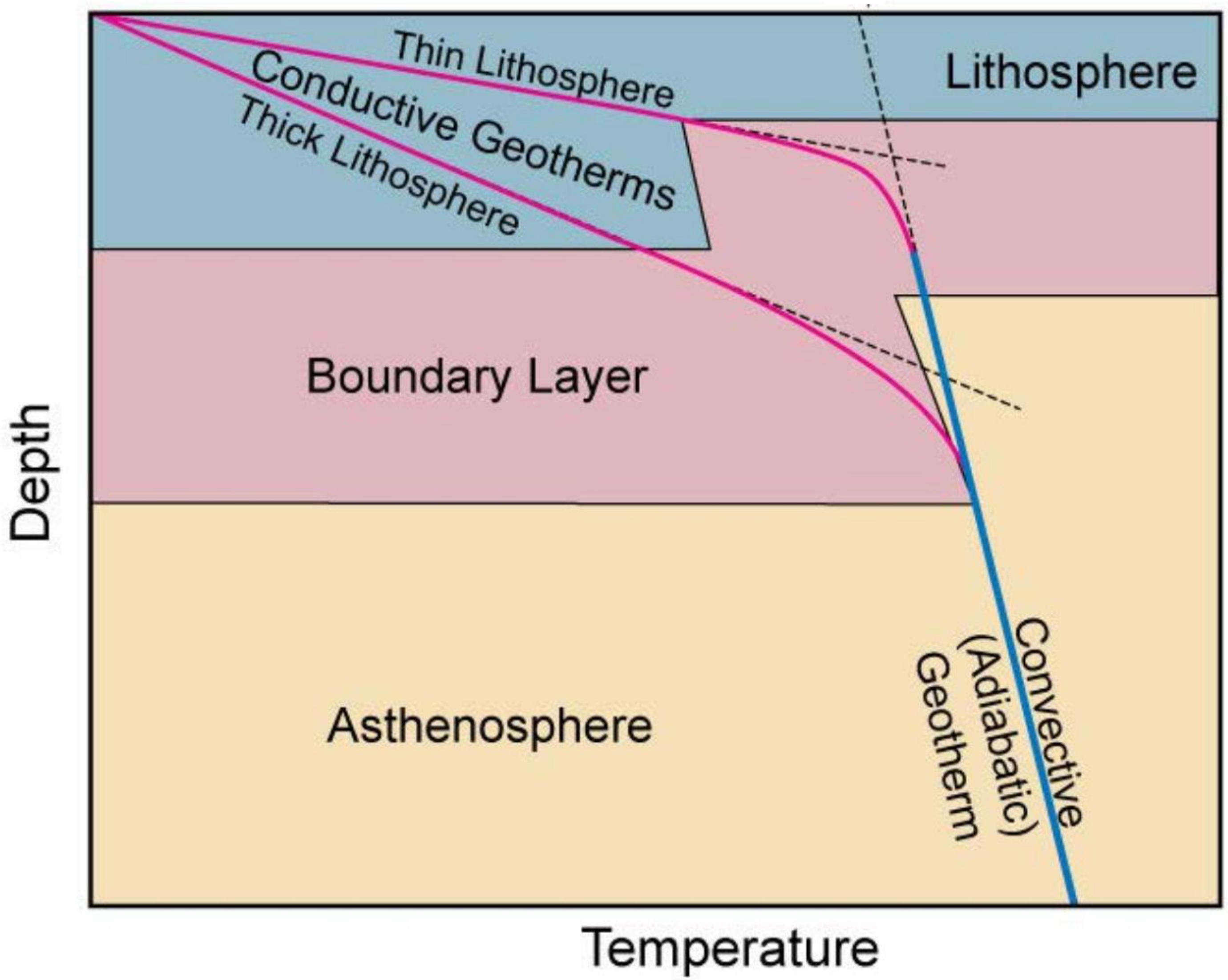
Geothermal Gradient

Figure 1.9 A similar example for **thick** (continental) lithosphere.



Geothermal Gradient

Figure 1.9 Notice that thinner lithosphere allows convective heat transfer to shallower depths, resulting in a **higher** geothermal gradient across the boundary layer and lithosphere.



Geothermal Gradient: an estimate

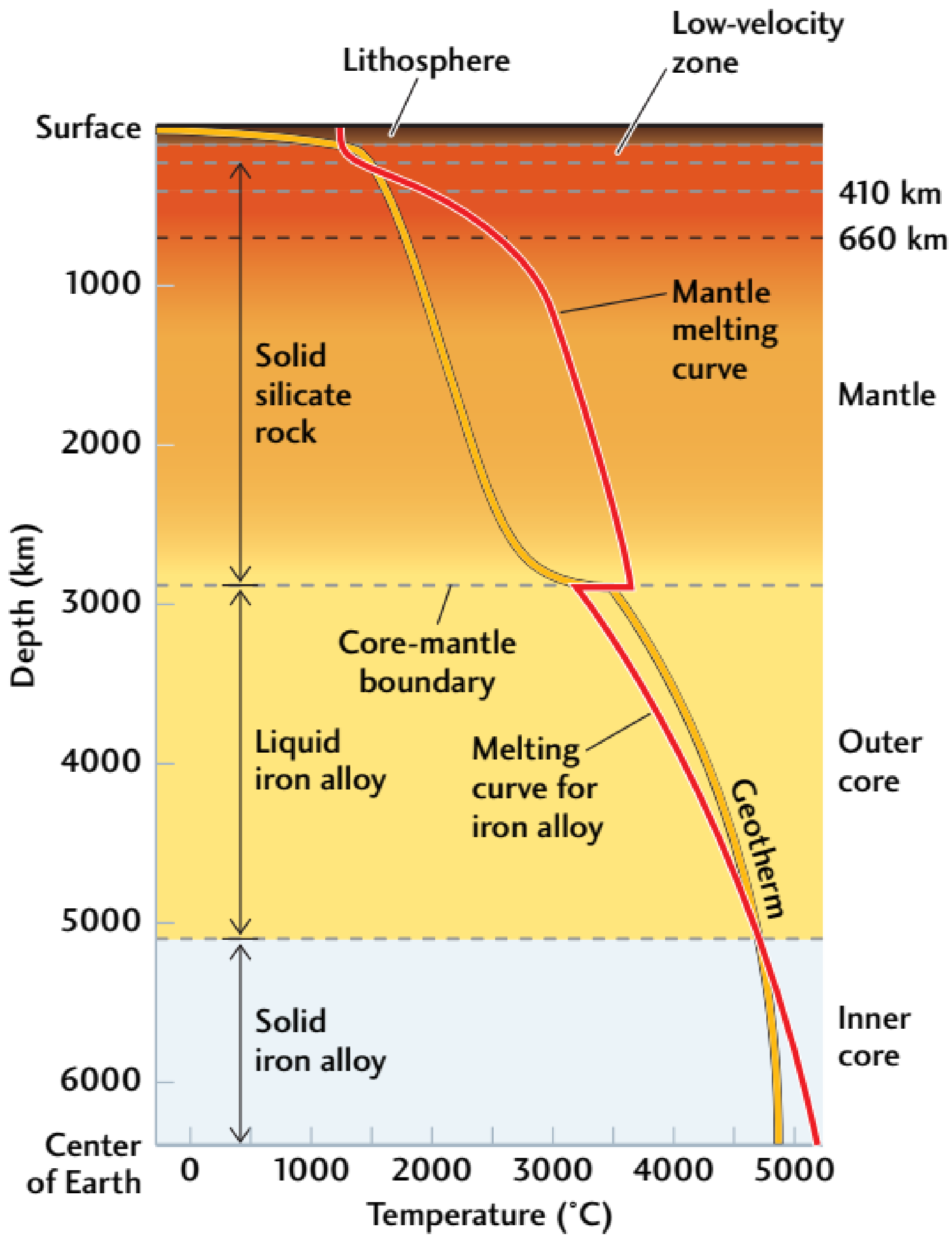


FIGURE 14.10 ■ An estimate of Earth's geotherm, which describes the increase in temperature with depth (yellow line). The geotherm first rises above the melting curve—the temperature at which peridotite begins to melt (red line)—in the upper mantle, forming the partially molten low-velocity zone. It does so again in the outer core, where the iron-nickel alloy is in a liquid state. The geotherm falls below the melting curve throughout most of the mantle and in the solid inner core.