NPTEL ONLINE CERTIFICATION COURSES

EARTHQUAKE SEISMOLOGY

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Module 08 : Composition of the mantle and core
Lecture 03: Composition of the Mantle and the D” layer

CONCEPTS COVERED

- **Composition of the Mantle (Continued..)**
- **Composition of the D’’ layer**
- **Summary**

Summary

- The geotherm depends on the sources of heat and modes by which the heat is transferred upward in the earth.

- An average thermal gradient is 13°C/km upto depth of 100 km while a low gradient of only about 0.6°C/km upto the base of the mantle.

- Higher temperatures reduce seismic velocity and strength, but increase attenuation. Conversely, higher pressures increase the velocity and strength, but reduce attenuation.

- Temperatures increase rapidly in D”, causing velocities slower than expected from the lower mantle velocity gradient.

- The high temperatures in the core keep the outer core liquid, but the rapid increase in pressure due to the weight of the outer core makes the inner core freeze into a denser solid.

Summary

- A key result from experiments is that the bulk sound speed and the density for a material are approximately linearly related for a given mean atomic weight.
- Dunite, a rock containing 92% olivine, which in turn is 90% forsterite, fits the mantle data.
- Crust is predominantly basaltic or granitic depending on the continents or ocean.
- Upper mantle mainly composed of peridotite: depending upon the pressure peridotite may be in the forms such as olivine, clinopyroxene, orthopyroxene, garnet spinel, or plagioclase.
- The transition zone corresponds to a series of solid state phase changes.

Summary

- Transition zone has 2-3 discontinuities where Olivine changes to its various polymorphs depending upon temperature.

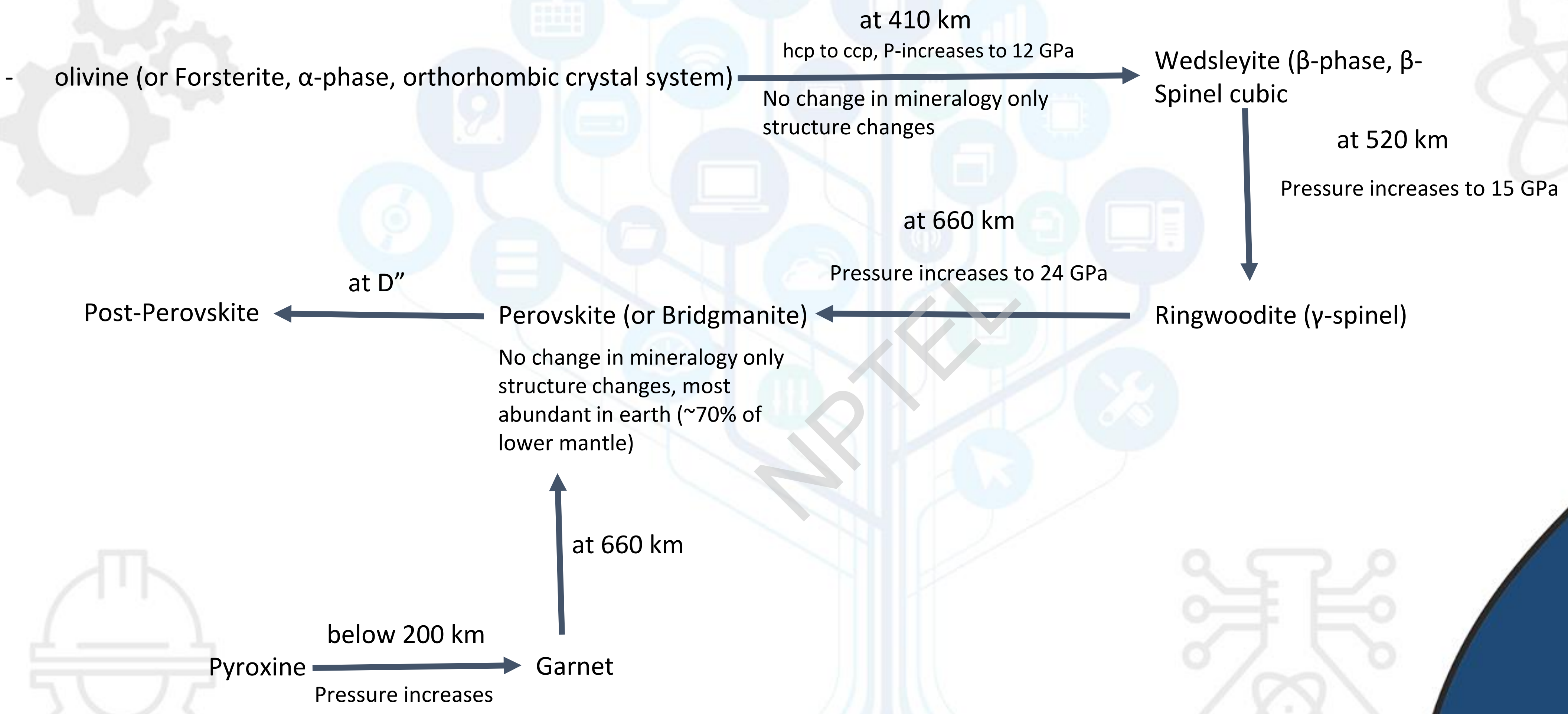
  At 410 km discontinuity – Olivine changes to wadsleyite.

  At 520 km discontinuity– wadsleyite changes to ringwoodite.

  At 660 km discontinuity – ringwoodite turns to perovskite + magnesiowustite.
  This produces the lower mantle minerals.

- Lower mantle's main constituent is perovskite which is known as bridgemanite (MgSiO3) + magnesiowustite/ferropericlase (Mg,Fe)O.
- Outer Core mainly composed of Liquid iron-alloy. It lies at 2891-5100km.
- Inner Core mainly composed of Solid iron. It lies at 5100-6400 km.

Composition of the mantle



- olivine (or Forsterite, α-phase, orthorhombic crystal system)

at 410 km

hcp to ccp, P-increases to 12 GPa

No change in mineralogy only structure changes

Wedsleyite (β-phase, β-Spinel cubic

at 520 km

Pressure increases to 15 GPa

Ringwoodite (γ-spinel)

at 660 km

Pressure increases to 24 GPa

Perovskite (or Bridgmanite)

No change in mineralogy only structure changes, most abundant in earth (~70% of lower mantle)

at D”

Post-Perovskite

Pyroxine

below 200 km

Pressure increases

Garnet

at 660 km

Composition of the mantle

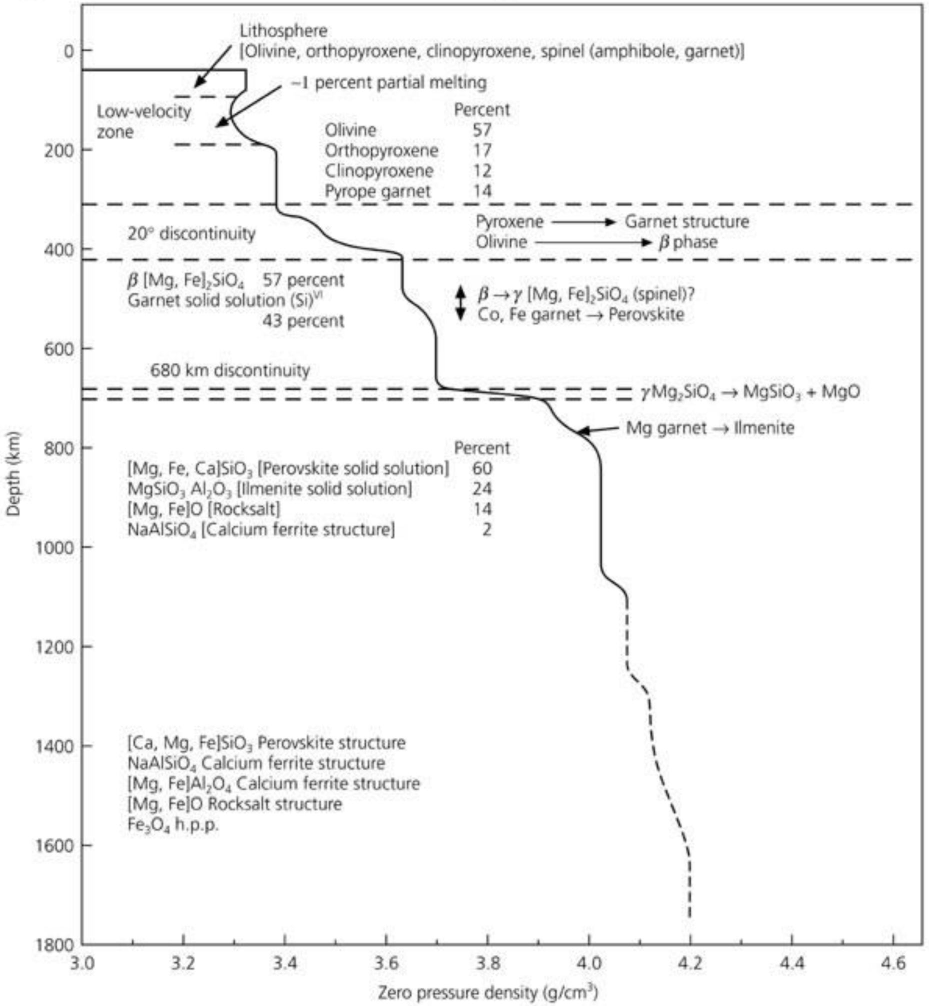


Figure 3.8-8: Predicted mineral assemblages for the mantle.

- **Upper mantle comprises of olivine and its goes into a series of phase changes at transition zone.The α-phase transforms to β-spinel spinel known as Wedsleyite at a pressure of ~12 GPa at 410 km discontinuity.**

- **The β phase transforms to a γ, or spinel, structure known as ringwoodite at a pressure of ~15 GPa, corresponding to the less dramatic seismic discontinuity at 520 km.**

- **At pressures above about 24 GPa, corresponding to the 660 km discontinuity, γ spinel breaks down to a perovskite structure and (Mg, Fe)O magnesiowustite.**

- **The (Mg,Fe)SiO$_3$ pyroxene component also undergoes changes, beginning with a transformation to garnet below about 200 km**
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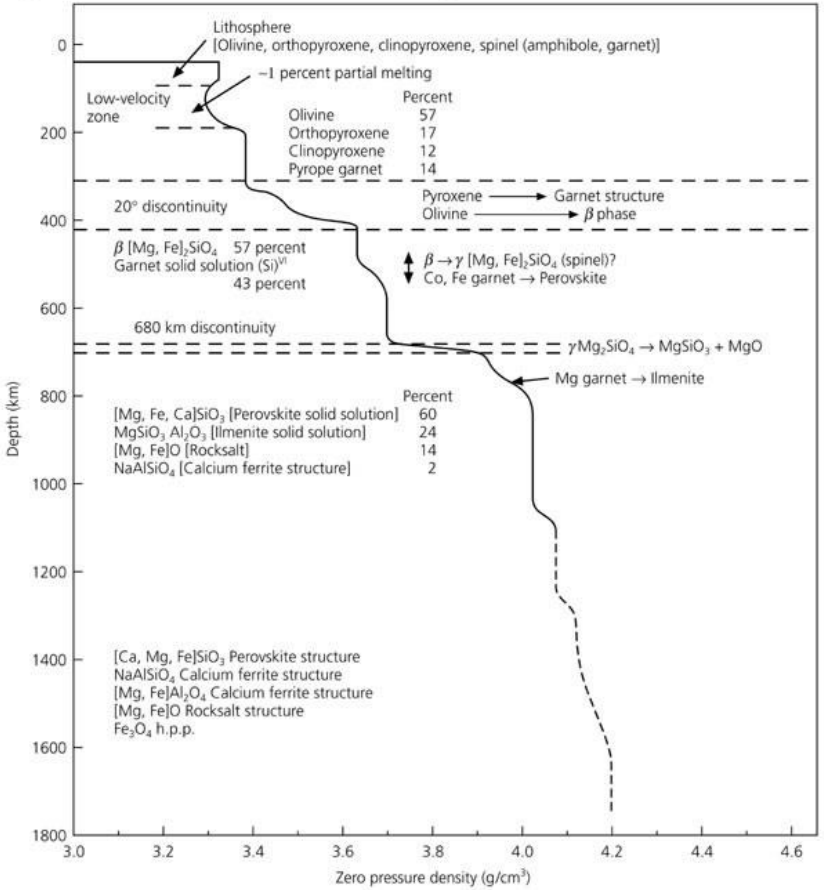
Composition of the mantle

Figure 3.8-8: Predicted mineral assemblages for the mantle.

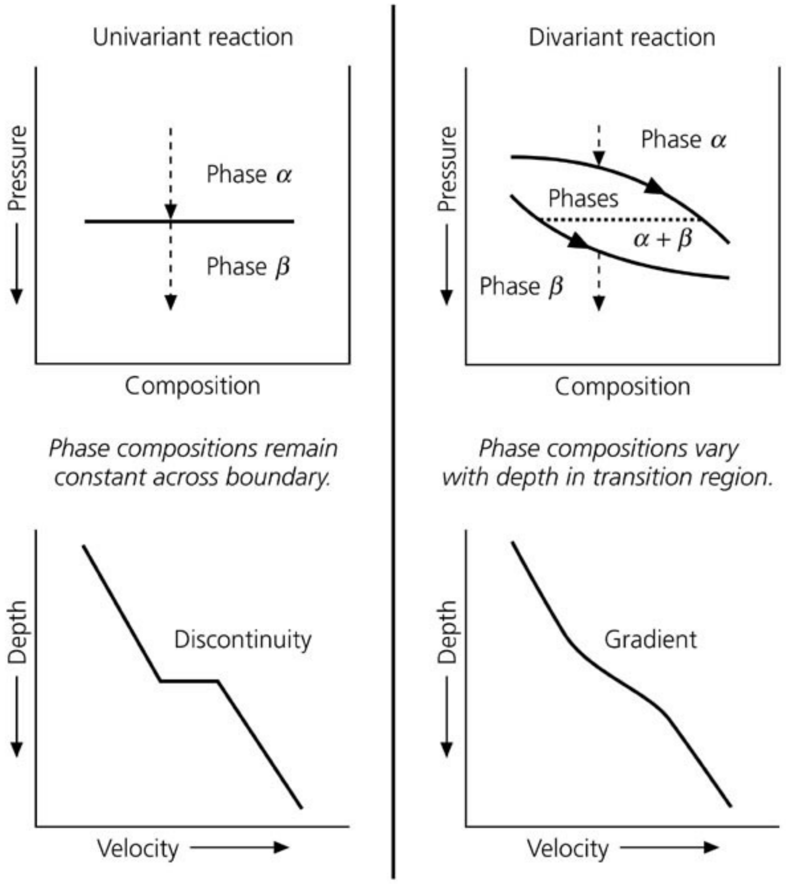


- **Below 600 km, some of the Mg-bearing garnet, majorite, transforms to a structure called ilmenite.**
- **Beneath about 660 km, the majorite/ilmenite transforms to perovskite.**
- **Some of the majorite probably survives into the lower mantle as stishovite, a high-pressure phase of quartz, and an Al_2O_3 -rich phase.**
- **The pyroxene and garnet transformations occur gradually and contribute to a high velocity gradient through the transition zone down to about 770 km.**

Composition of the mantle

Velocity structure at the transition zone may still be benefitted from seismological studies to understand its composition. There may be two possibilities for phase changes.

Figure 3.8-11: Effect of phase changes on velocity structure.

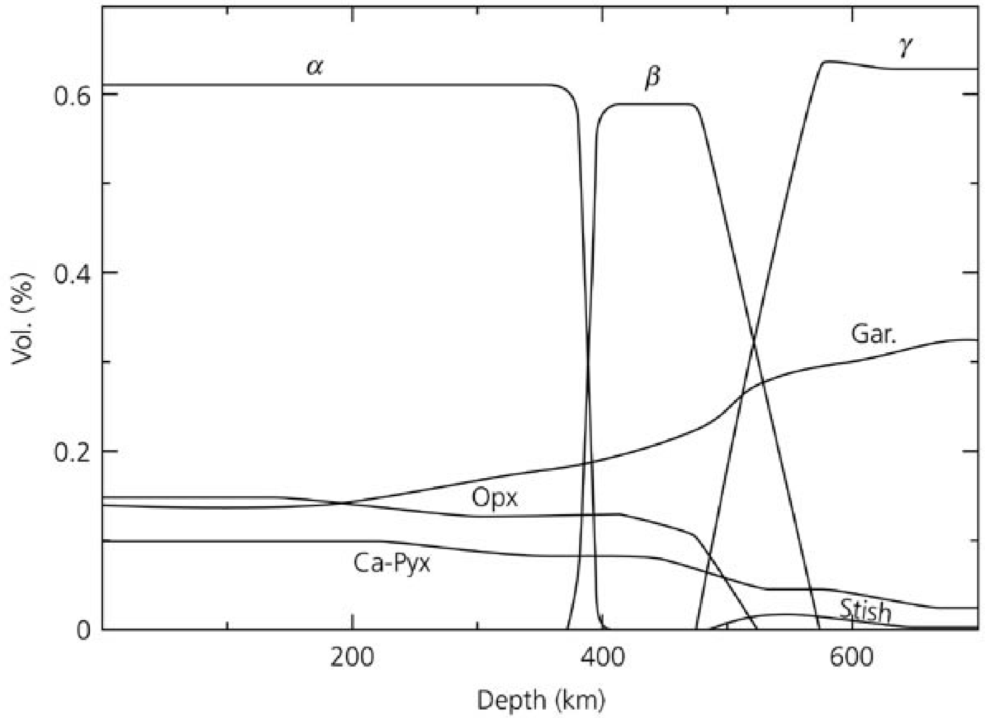


Case 1. A simple univariant phase change, in which material of a single composition changes completely from one phase to another as pressure increases, causes a sharp discontinuity in velocity.

Case 2. A more complicated multivariant phase change involving a system of variable compositions causes two or more phases to coexist over a broad region of pressure, and so produces a velocity gradient.

Composition of the mantle: Prediction Vs. Observation

Figure 3.8-9: Relative proportions of mineral phases in the upper mantle.



- **Pyroxine to garnet transformation occur gradually and contribute to a high velocity gradient through the transition zone.**

- **The olivine α-to-β reaction should occur over a narrow depth range. It is exothermic and occur at lower pressures in subducting slabs due to the colder temperatures at 410 km discontinuity.**

- **β-to-γ transformation should occur over a broader depth range at 520 km discontinuity.**

- **The γ-spinel to perovskite and magnesiowustite transition should occur over a narrow depth range, consistent with the observed sharpness of the 660 km seismic discontinuity.**

Composition of the mantle: Upper Mantle Vs Lower Mantle

- An unresolved question is whether the lower mantle is chemically distinct from the upper mantle, which has important implications for how the two have mixed during the earth's evolution.

- The velocity data do not appear to require phase changes in the lower mantle. However, the lower mantle may be denser than expected for pyrolite, and hence perhaps enriched in iron and silica.

- The observation that some subducting lithosphere penetrates the 660 km discontinuity indicates that mixing occurs.

- However, even if all slabs reach the lower mantle, the earth may not be old enough for the lower and upper mantles to be well mixed.

- Another possibility is that the early earth had distinct upper and lower mantle convection systems, and whole mantle convection began later.

Composition of D”

- Seismic observations give a picture of the D” region that includes lateral velocity variations, vertical layering, and anisotropy.

- Hence processes there may be as complex as in the lithosphere, the other major thermal boundary layer.

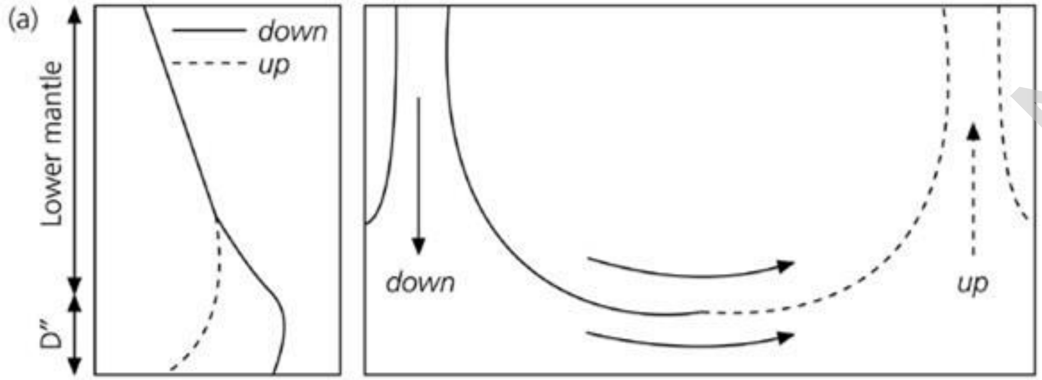
- This complexity may reflect factors including subducted lithosphere, the generation of mantle plumes, and interactions between the core and the mantle.

Composition of D" : **Model I**

- **Figure shows a simple convection model, with cold material sinking to the CMB, heating up from contact with the core, and then rising again.**

- **The left side of the figure shows the resulting vertical velocity profiles in regions of downwelling (solid line) and upwelling (dashed line).**

Figure 3.8.12: Cartoon of possible processes at work at the base of the mantle.



- **Thus the large (> ±5%) lateral seismic variations at the base of the mantle would be caused by temperature variations.**

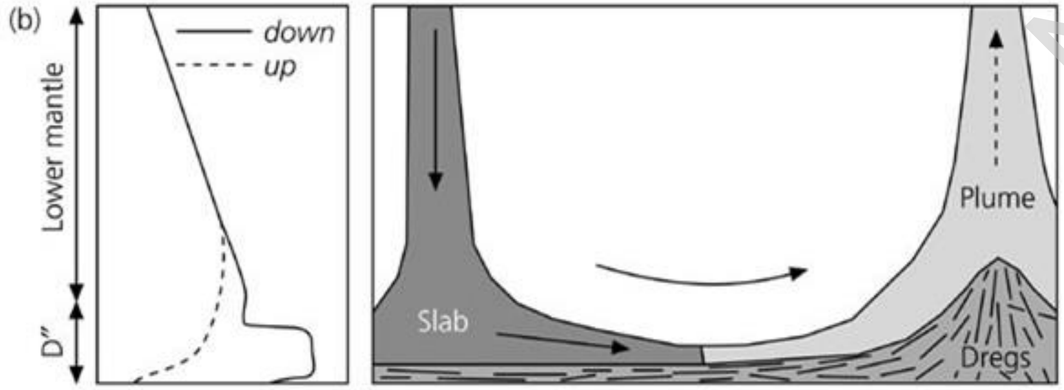
- **However, given the complex seismic structures observed, this model component seems necessary but insufficient.**

Composition of D”: **Model II**

- **Another possibility is that, the subducted slabs do not reach the top of the core, but remain separated by a chemically distinct layer.**

- **This layer may result from early planetary differentiation, or may have grown by chemical reactions between the mantle and the core.**

- **High-pressure experiments imply that perovskite and magnesiowustite would react with iron. These mantle dregs might be thinned in regions of mantle downwelling, and thickened beneath upwellings.**



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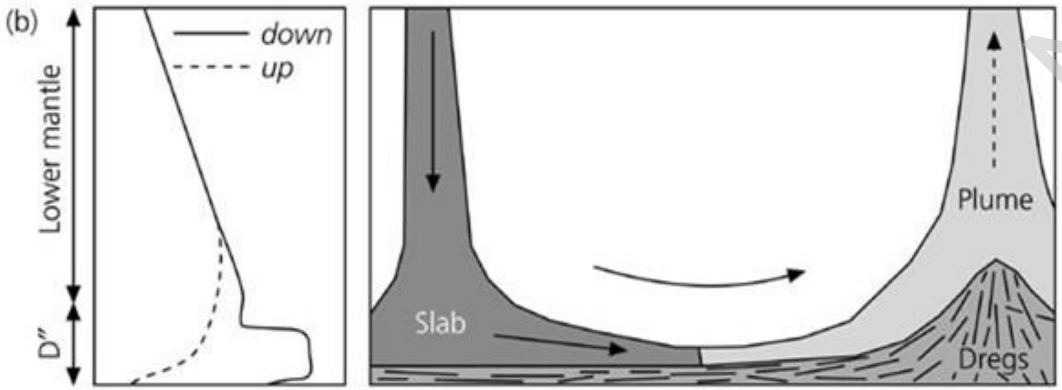
Composition of D”: **Model II**

- **Layering in the dregs may explain observations of transverse isotropy in downwelling regions and azimuthal anisotropy in upwelling regions.**

- **The velocity increase of the D” discontinuity may be partly caused by ponded slab material, which will still be colder and have higher velocity than ambient rock.**

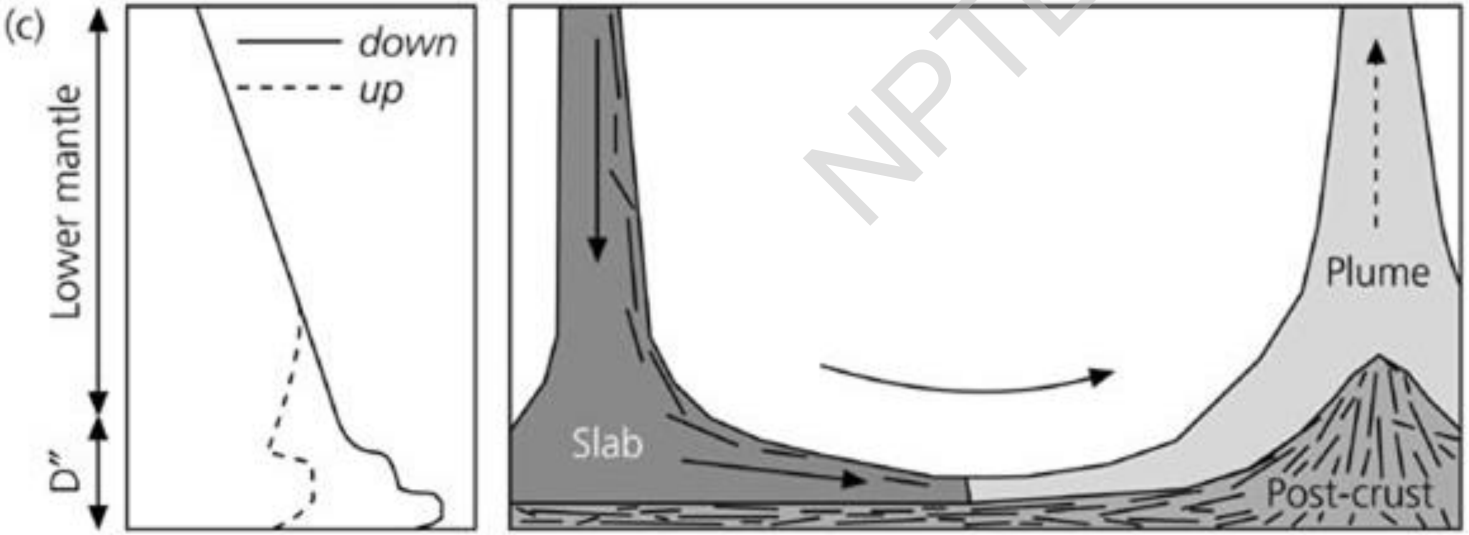
- **This discontinuity may be enhanced by dregs flowing up and over ponded slabs.**



Composition of D”: Model III

- **Another possibility is that the part of the subducted lithosphere that started as basaltic ocean crust and then transformed to eclogite transforms to a material that is seismically faster than the rest of the lower mantle (Fig. 3.8-12c).**

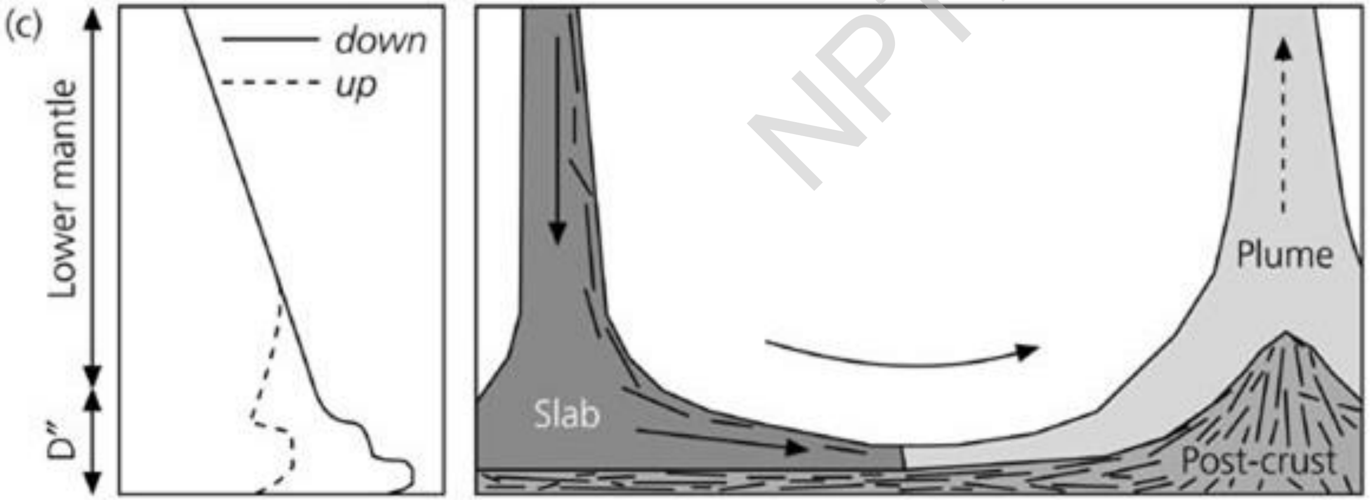
- **This phase could delaminate from the slabs and accumulate, forming a different chemical boundary layer. If it remained solid, it might partially explain the D” discontinuity.**



Composition of D”: **Model III**

- **Alternatively, if it melted, it might explain the ULVZ. Either way, its laminar nature might explain the observed seismic anisotropy.**

- **The lateral variations in velocity would correlate with anisotropy; SH waves would travel fast in downwelling regions because of transverse isotropy, but be slowed by the vertical laminations beneath upwellings.**



Summary

- The β phase transforms to a γ, or spinel, structure known as ringwoodite at a pressure of ~15 GPa, corresponding to the less dramatic seismic discontinuity at 520 km.
- γ spinel breaks down to a perovskite structure and (Mg, Fe)O magnesiowustite at 660 km discontinuity.
- A simple univariant phase change causes a sharp discontinuity in velocity while a complicated multivariant phase change produces a velocity gradient.
- The olivine α-to-β reaction should occur over a narrow depth range and β-to-γ transformation should occur over a broader depth range which aggress well with the lab predictions.
- The γ -spinel to perovskite and magnesiowustite transition should occur over a narrow depth range, consistent with the observed sharpness of the 660 km seismic discontinuity.

Summary

- **For the D“ layer four possible models describe the observed characteristics. First is, a simple convection model, with cold material sinking to the CMB, heating up from contact with the core, and then rising again.**

- **Second model predicts that, the subducted slabs do not reach the top of the core, but remain separated by a chemically distinct layer.**

- **Another possibility is that the part of the subducted lithosphere that started as basaltic ocean crust and then transformed to eclogite transforms to a material that is seismically faster than the rest of the lower mantle**

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- https://geologyscience.com/geology-branches/structural-geology/stress-and-strain/
- Seismology course, Professor Derek Schutt, Colorado State Univ., USA.

THANK YOU !