NPTEL ONLINE CERTIFICATION COURSES

EARTHQUAKE SEISMOLOGY

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Module 06 : Seismic waves in a spherical earth, Body wave travel time studies
Lecture 04: Core Phases: Reflected, Refracted, and Diffracted

CONCEPTS COVERED

- ➢ **Recap**
- ➢ **Core Phases**
  - ➔ **Reflected**
  - ➔ **Refracted**
  - ➔ **Diffracted**
- ➢ **Additional Core Phases**
- ➢ **Summary**

Recap

- Travel time data are generated by combining data from numerous earthquake at different epicentral distances.
- Jeffreys-Bullen(JB) earth model treat the earth as a series of shells, characterized by the behaviour of velocity with depth.
- JB model did not resolve shear velocities in the inner core, whereas recent model have finite S velocity in the inner core, which implies that it is solid.
- The seismogram shows the arrivals of different phases, correspondent to body waves.
- Surface reflections PP and SS are maximum-time phases in contrast to phases reflection phases like ScS, which are minimum phases.

Core Phases

- **The liquid core, which has lower velocity than the mantle above, is ideally adapted to seismological study of various core phases due to the differences in the solid mantle and the liquid core.**

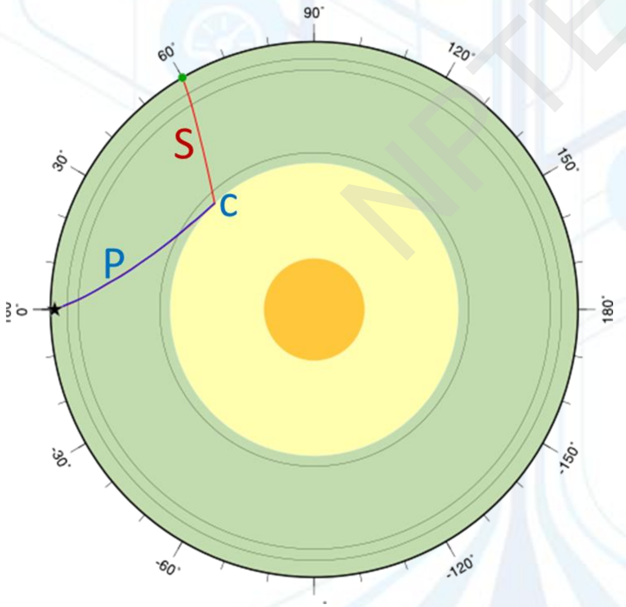
- **Because the core-mantle boundary (CMB) is a solid-liquid interface and a powerful reflector for shear waves.**

- **The travel times and amplitudes of core phases are also used to study structure near and within the core.**

Core Phases: Reflected

- Reflections off the CMB are denoted by a lower-case "c," so ScS is an S-wave reflection and PcP is a P-wave reflection.

- Conversions at the CMB also occur. For example, ScP and PcS.



- **Some phases undergo multiple reflections at both the core and the surface known as multiple ScS; Like, ScSScS (or ScS_2) bounces twice at the CMB and once at the surface.**

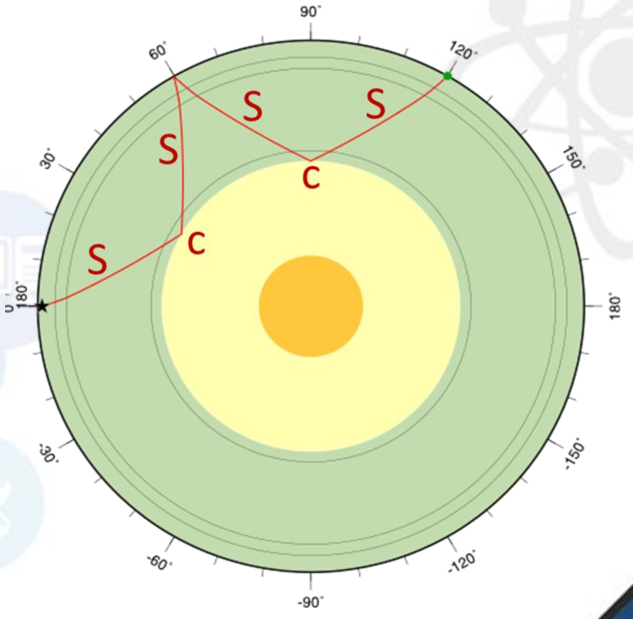
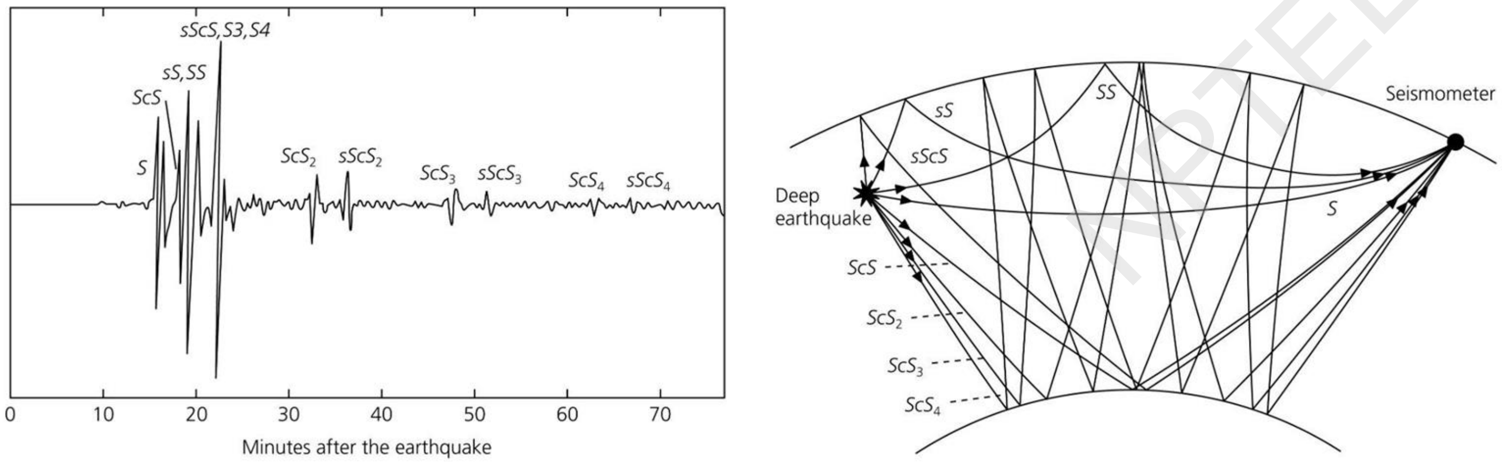


Figure 1.1-4: Seismogram and ray paths for multiple core reflections.



Core Phases: Reflected

- ScS is a more prominent on the seismogram than PcP, because the liquid core does not transmit shear waves.

- The SH part of the motion in the incident ScS cannot convert to P waves at the CMB, so is totally reflected.

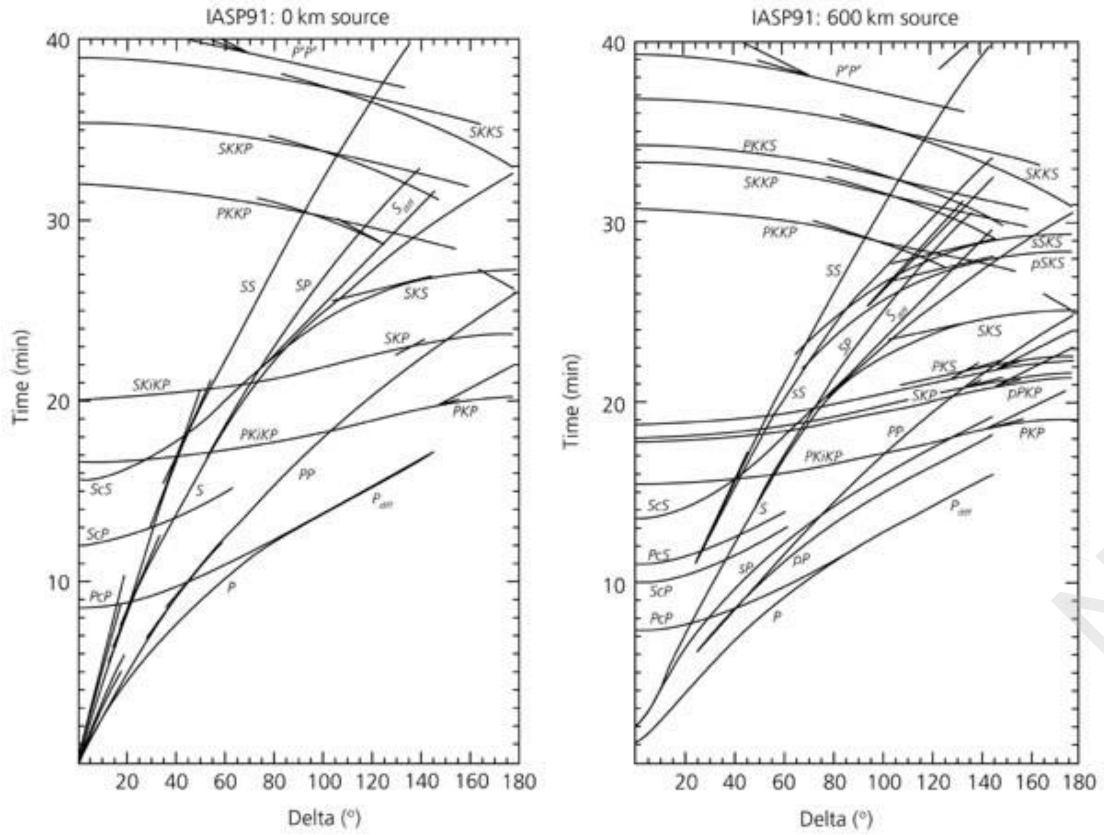
- ScS are sensitive to vertical average velocity for the mantle.

Core Phases: Reflected

- The impedance contrast is small at the CMB results in the transmission of the P-wave and hence, reflected P-wave are not distinct on the record

- The small impedance contrast (about 5%) arises because the P-wave velocity decrease going from the mantle to the core (about 13.7 km/s to 8.1 km/s) is offset by the density increase (about 5.5 g /cm^3 to 9.9 g/cm^3).

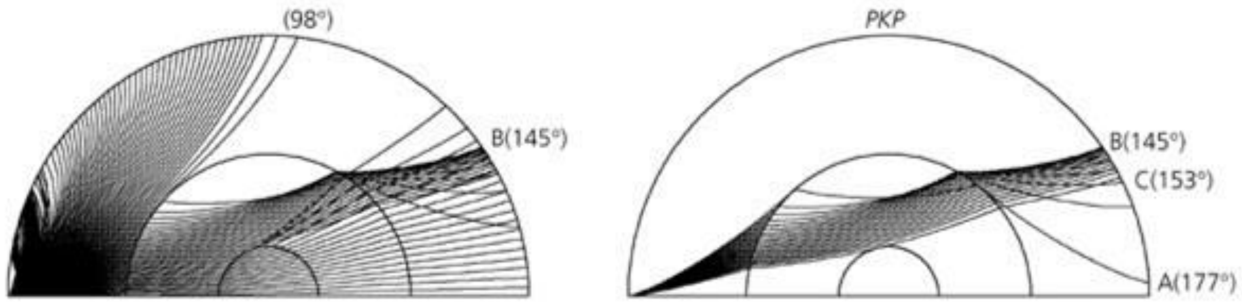
Figure 3.5-4: IASP91 travel time curves for a surface and deep source.



- **Rays leaving the source at progressively smaller angles of incidence (closer to the vertical) bottom deeper in the mantle and so reach greater distances.**
- **As the bottoming depth approaches the core–mantle boundary, the travel times of P and PcP converge (concave upward).**
- **And at certain angle of incidence, P grazes the core – mantle boundary, and P and PcP are identical.**

Core Phases: Reflected

Figure 3.5-7: Ray paths and travel times for major core phases.



- P-wave enters the outer core, travels through it, refracts into the mantle (PKP).

- For an angle of incidence slightly below grazing, PKP reaches the surface at point A at a distance close to 180°.

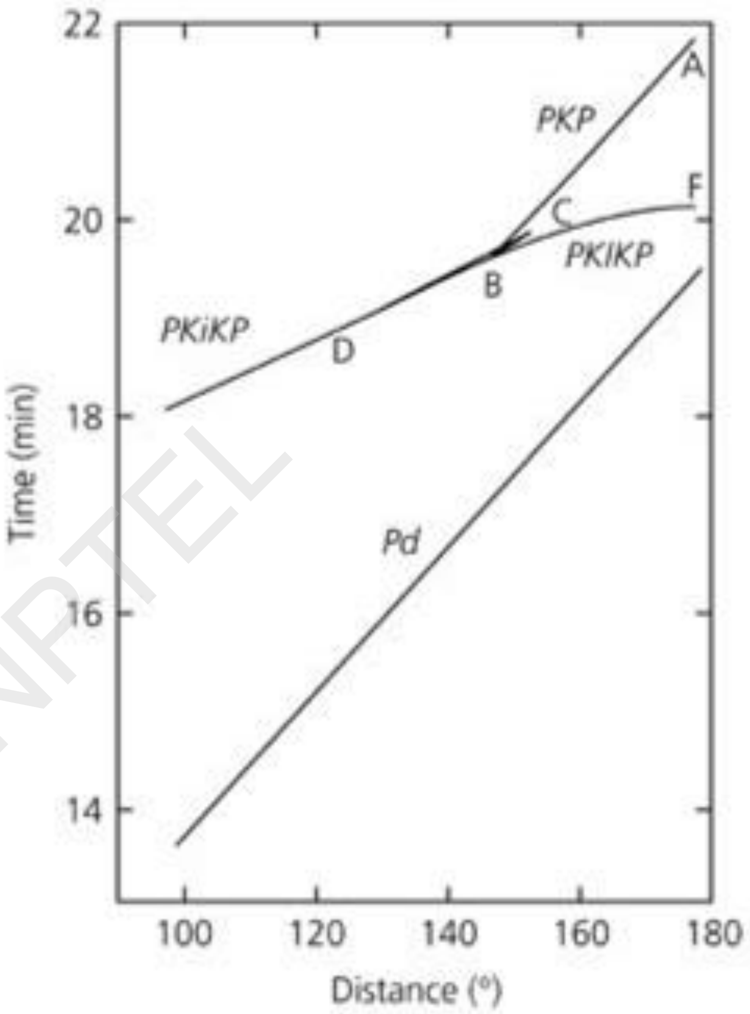
- Rays that have smaller angles of incidence enter the core further, arriving at distances that are progressively closer to 180° until they reach roughly 145° (point B, retrograde motion).

- At point B, the pattern reverses, because rays with smaller angles of incidence arrive at successively greater distances (prograde motion). This goes on for rays reaching distances up to point C (~153°), corresponding to the ray that grazes the inner core–outer core boundary.

- For the core, the shadow zone occurs for distances between ~98° to ~145° for the P-wave.

- The AB branch (sometimes labeled PKP2) is the back branch, on which rays with smaller angles of incidence appear at smaller distances.

- The BC branch is the forward branch on which rays with smaller angles of incidence appear at larger distances.



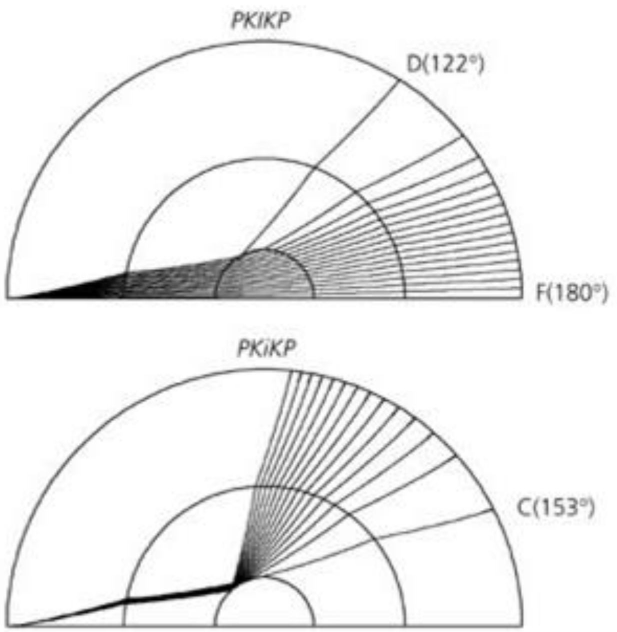
Core Phases

- In reality, body waves are observed in the shadow zone. Much of the body wave energy arrives as surface-reflected (PP, PPP, SS, etc.) or multiply core-reflected (ScS2, etc.) arrivals.

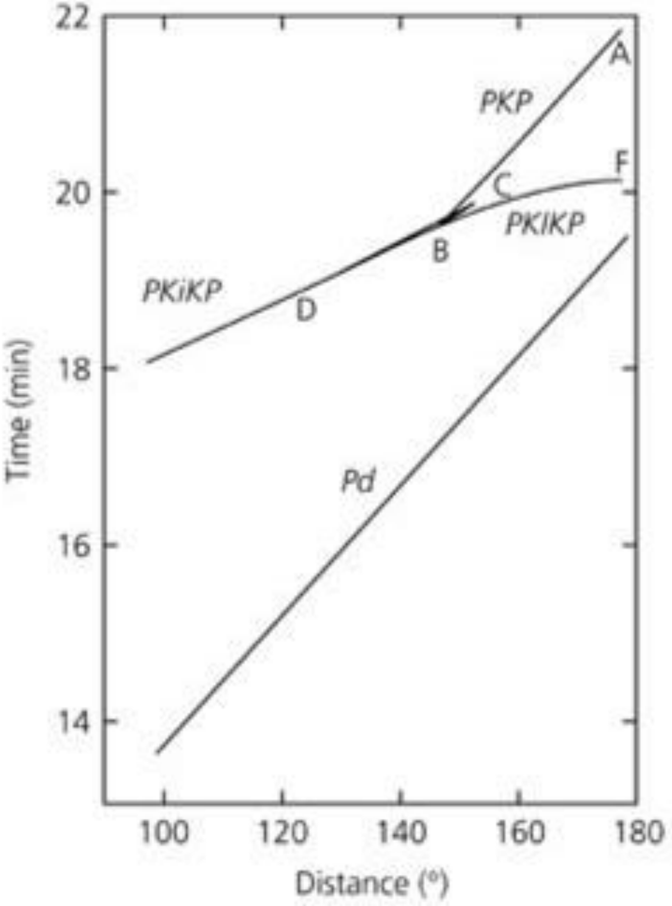
- Since the inner core has higher P-wave velocity, other arrivals are of P waves that encounter the inner core also appear in the shadow zone.

- These phases are known as **PKIKP**, because P waves in the inner core are denoted by "I."

- In addition, waves reflect at the boundary between the inner and outer cores, giving the phase **PKiKP** (The lowercase "i" is analogous to the lowercase "c" in PcP.)



Core Phases



- The travel time curve thus has a PKIKP branch DF, where D is the distance at which PKIKP is first observed (122^0), and a back branch for PKiKP.

- Because the reflection occurs at vertical incidence, the back branch starts at C, where PKiKP and PKP are equal, and extends via D back to zero distance.

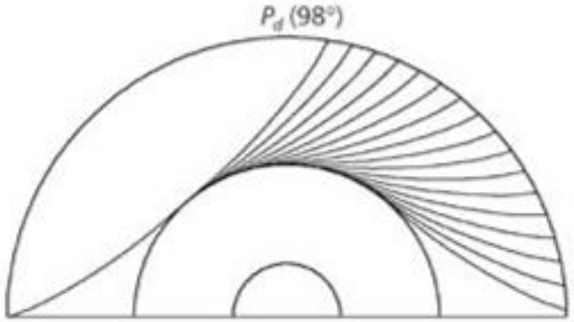
- Hence the portion of the travel time curve containing CD and DF is due to the rapid increase of velocity at the inner core–outer core boundary, and is analogous to a triplication.

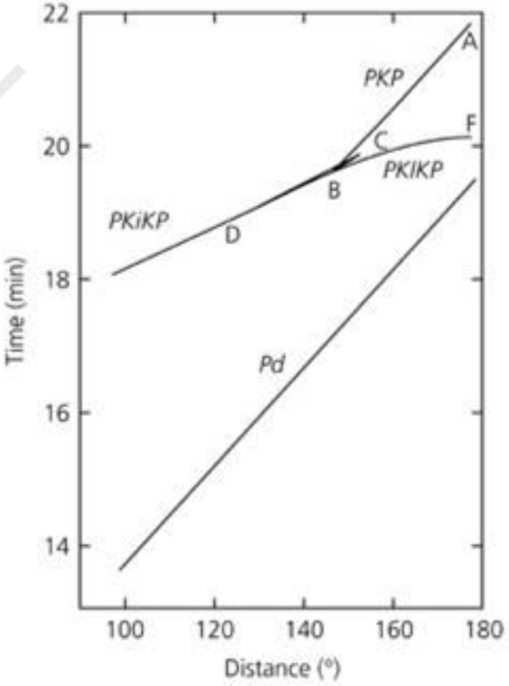
Core Phases: Diffracted

Note: Seismic energy also enters the shadow zone via P and S waves that diffract around the core.

- The ray paths for the diffracted P waves is denoted by P_d or P_{diff}. They start to diffract at a distance of around 100°.

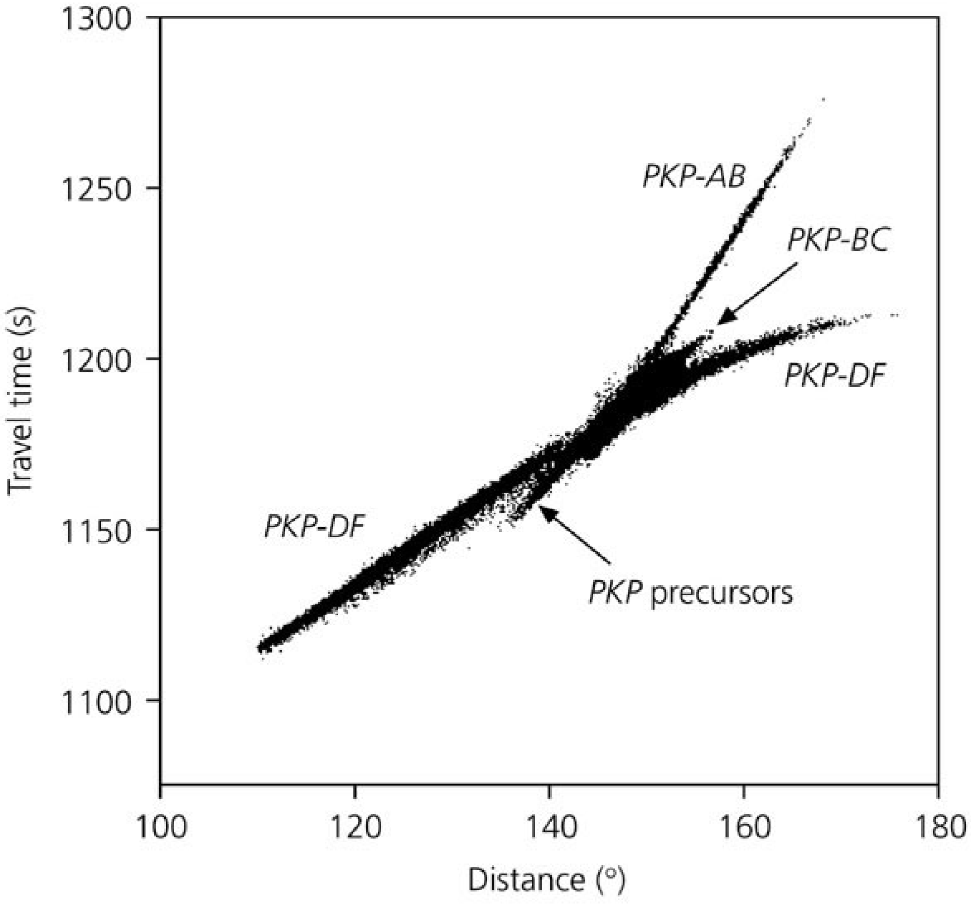
- Travel time curve becomes linear because all the diffracted waves bottom at the CMB, and so have the same ray parameter and hence apparent velocity.





Core Phases: Diffracted

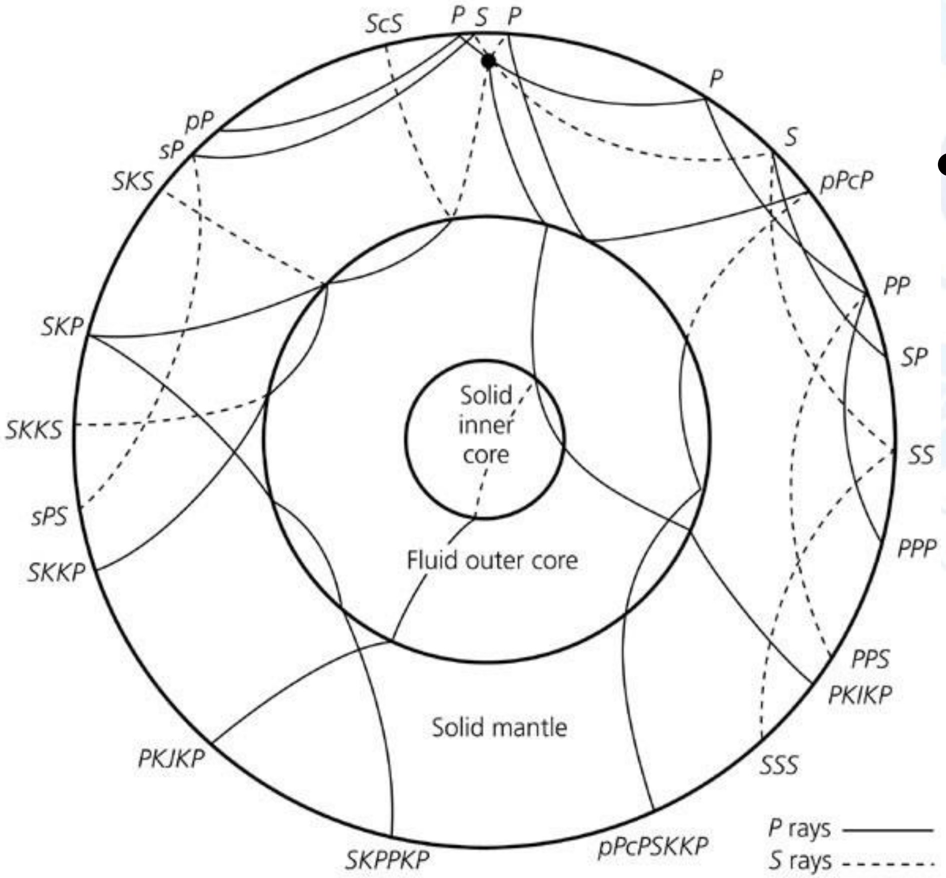
Figure 3.5-8: *PKP* arrival time data, showing *PKP* precursors.



- **Arrival times of PKP waves recorded by the International Seismological Centre during 1964–87. A point is plotted if there are at least 200 arrivals in the catalog for that time and distance.**
- **The PKP-BC branch is observed beyond its geometrical limit (153°) due to diffraction around the inner core.**
- **Precursors to the PKP-DF branch are observed that result from seismic scattering at the CMB and in the mantle.(Courtesy of K. Koper.)**

Additional Core Phases

Figure 3.5-5: Illustration of various body wave phases.



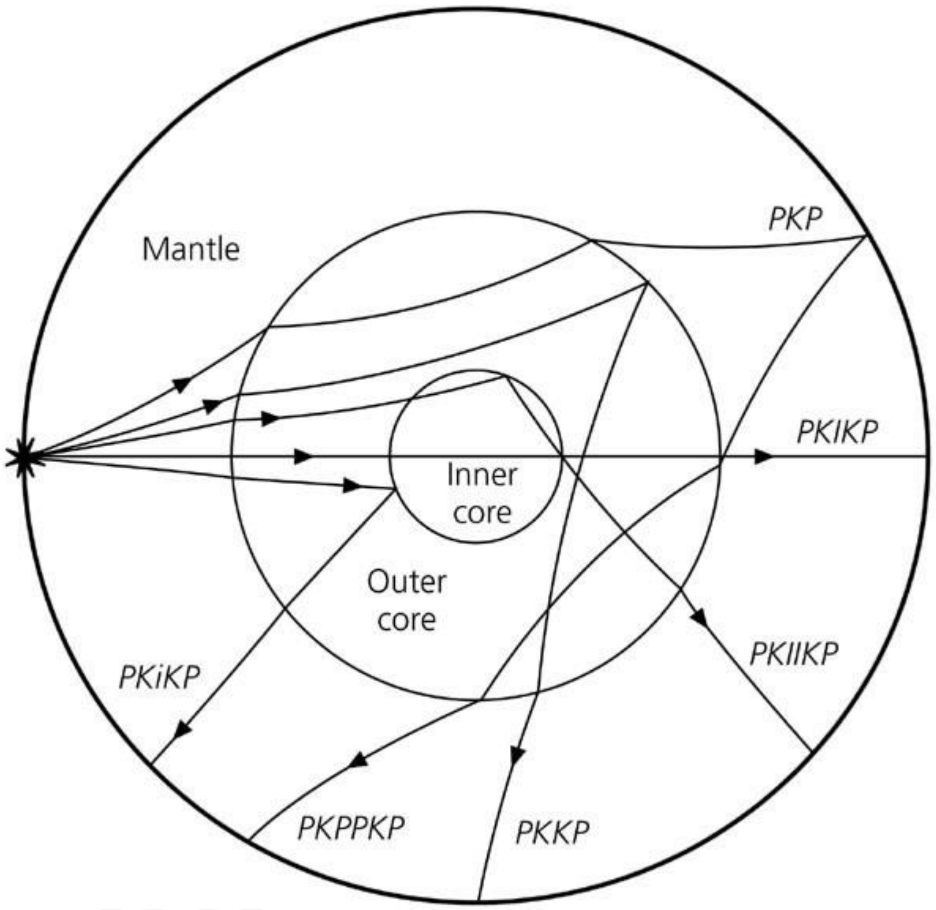
- SKKS is similar to SKS, but also involves an underside reflection at the CMB.

- Because the P velocity of the uppermost core is not much larger than the S velocity of the lowermost mantle, SKS and SKKS waves do not change direction significantly as they cross the CMB.

- SKS, SKKS, SKKKS, etc. are the only waves that bottom near the top of the core and are used to constrain the outer core's velocity structure.

Additional Core Phases

Figure 3.5-10: Ray paths for additional core phases.



- PKKP: a P wave that has undergone under- side reflection at the CMB.
- PKPPKP: a PKP phase reflected at the surface sometimes called P′P′.
- PKIIKP: an underside reflection from the outer core–inner core boundary.
- PKJKP: An especially elusive phase , which, by analogy to PKIKP, travels through the inner core as an S wave. This phase presents a weak peak, which makes it hard to see as it enters late into the seismogram within different phases.

Summary

- Core phases can be challenging to study with travel time data because their travel time curves are complicated and some of the arrivals are small.
- Reflections off the CMB are denoted by a lower-case “c,” so ScS is an S-wave reflection and PcP is a P-wave reflection.
- ScS is a more perceptible on the seismogram arrival than PcP, because the liquid core does not transmit shear waves.
- “K” denotes passage through the outer core like PKP like enters the core, travels through it, refracts into the mantle, and reaches the surface .
- For the core, the shadow zone occurs for distances between ~98° to ~145° fo the P-wave.
- P waves in the inner core are denoted by “I” and waves reflect at the boundary between the inner and outer cores, giving the phase PKiKP
- Seismic energy also enters the shadow zone via P and S waves that diffract around core.
- S wave, going over the mantle and through the core as a P wave like SKKS involves an underside reflection at the CMB.

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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 !