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# Evidence for a sharp discontinuity at the top of D" from short-period PcP precursors

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## Abstract

We report on a precursor to PcP observed at the short-period Washington Regional Seismic Network (WRSN) at an epicentral distance of about 24°. The precursor appears clearly on the vespagram of an alaskan intermediate earthquake about 40 seconds before PcP, and with a slowness relative to PcP of about $0.7s/°$. It is well explained as a reflection from the top of D", some 300 km above the core-mantle boundary (CMB). The amplitude of this PdP wave reaches 20% of PcP at a period of about 2.5 second. This is consistent with a 3% increase in both P-velocity and density at the top of D". Our observation is the first of this kind and is important because it implies that the discontinuity is very sharp (less than 8km-thick), at least locally. This places an important constraint on the nature of the still mysterious D" discontinuity.

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## Introduction

The D" region at the base of the mantle is known to play a key role in the dynamics of both the core and the mantle. Seismology has revealed a very heterogeneous and complex structure, not unlike what one would expect for a thermal boundary layer (see reviews by *Doornbos* [1983]; *Lay* [1989]; *Loper and Lay* [1995]. More unexpected was the discovery of a reflector some 250-300 km above the CMB [*Lay and Helmberger,* 1983]. This reflector has now been detected in many different regions for both P- and S-waves [e.g., *Young and Lay,* 1990; *Weber and Davis,* 1990; *Houard and Nataf,* 1993; *Kendall and Shearer,* 1994], and might well be a global seismic discontinuity [*Nataf and Houard,* 1993]. The origin of this discontinuity is still unknown. It could mark the top of a chemically distinct layer [*Lay,* 1989], a phase transition [*Nataf and Houard,* 1993], or chemical lamellae remaining from the subduction of oceanic crust [*Weber,* 1994]. The observational constraints are still sparse. There is good evidence that the depth of the reflector varies by more than 100 km [*Young and Lay,* 1990; *Vidale and Benz,* 1993; *Kendall and Shearer,* 1994; *Weber and Körnig,* 1992]. The velocity jump is of the order of 3% [*Weber and Davis,* 1990]. But because most observations so far are in the critical distance range ($70° - 80°$), the thickness of the discontinuity is poorly constrained. Here we report on a precursor to PcP observed at small epicentral distance ($\Delta \simeq 24°$) on the short-period Washington Regional Seismic Network (WRSN). This observation implies that, at least locally, the seismic transition is very sharp (less than about 8 km). Although our study relies on one single earthquake, a recent investigation on ScS precursors at broad-band stations [*Schimmel and Paulssen,* 1995] also points to a sharp discontinuity at the top of D".

## Data and Geometry

The Washington Regional Seismic Network consists in over 120 short-period telemetered digital seismographs, and operates since 1980 [*VanDecar and Crosson,* 1990]. Intermediate depth earthquakes in the alaskan subduction zone are within $21° - 26°$ from the network. In this distance range, PdP waves (P-waves reflected at the top of D") would arrive some 40 seconds before PcP. Assuming a P-velocity jump of 3%, as in the PWDK model of *Weber and Davis* [1990], the same jump for density, and a 2% jump in S-velocity, the PdP/PcP ratio is computed to be about 16% for $\Delta = 24°$. Therefore, if the discontinuity is very sharp, PdP should appear as a detectable precursor to PcP on the WRSN network. We looked for suitable events recorded at WRSN. However, because the network records for 100 seconds before trigger and 300 after, we found only two events large enough to provide a suitable continuous record before PcP. These two events are listed in Table 1. Typical ray paths are drawn in Figure 1. The 13 best PcP records for the first event are shown in Figure 2. Note that the PcP waveform is fairly complex, because of source duration, but quite stable across the network.

## PcP precursors

In order to detect possible PcP precursors, we follow a now classical scheme : we first align the PcP signals, using multi-channel cross-correlation [*VanDecar and Crosson,* 1990], we keep the records that look most alike, we normalize the traces to the maximum PcP amplitude, we shift the normalized traces by time $t_i$, according to $t_i = p \times (\Delta_i - \Delta_{ref})$ where $\Delta_i$ is the epicentral distance, $\Delta_{ref}$ that of the reference station, and $p$ a relative slowness. For various values of $p$, we stack the records, and contour the absolute value of the stack as a function of relative time and slowness. Figure 3a shows the result obtained for the 13 best records of the 90/05/01 earthquake. PcP appears as a zone of high amplitudes around $p = 0$ and $t = 0$. A clear precursor is observed at $t \simeq -40s$, for $p \simeq 0.7s/°$. Figure 3b shows the stack that corresponds to this value of the relative slowness. The large negative pulse at $t \simeq -40s$ reaches 20% of the PcP maximum amplitude.

## Discussion

The precursor to PcP observed at $-40s$ for the 90/05/01 event is the largest signal in the considered time window. Its arrival time and slowness relative to PcP are in good agreement with the predictions for PdP in a model such as PWDK, which features a discontinuity some 300 km above the CMB. The amplitude of the precursor reaches 20% of the PcP amplitude. This is what is expected if the P-velocity and density jumps at the discontinuity are both 3%. However, since the precursor we observe has a dominant period of $2.5s$, it implies that the discontinuity is very sharp (thickness less than $\lambda/4 = 8km$ [*Richards,* 1972]). Note that the dominant period of PcP is more like $1s$, so that the precursor is clearly at lower frequency. This, in turn, makes the comparison of the two waveforms difficult, especially since the instrument frequency response is rather narrow. Clearly, the amplitude of the precursor could be enhanced by focusing [see *Schimmel and Paulssen,* 1995], but it would still be difficult to escape the conclusion that the discontinuity at the top of D" is very sharp indeed.

The bounce points for PdP, plotted in Figure 1, are in the region where *Young and Lay* [1990] found evidence for a velocity increase 240 km above the CMB, from long-period S-waves. It is to the north of a region where *Vidale and Benz* [1992] found no evidence for any discontinuity from short-period ScP records. It is thus likely that the discontinuity is laterally very variable, as already observed at near-critical incidence [e.g., *Weber and Davis,* 1990; *Gaherty and Lay,* 1992; *Houard and Nataf,* 1993]. Indeed the analysis of our second event (93/05/23) shows no clear precursor. The stack is more noisy, and there is only a weak indication for a signal at $t \simeq -50s$ and $p \simeq 0.5s/°$.

## Conclusion

We find evidence for a precursor to PcP at an epicentral distance of about 24°. The arrival time ($-40s$) and slowness ($0.7s/°$) of the precursor with respect to PcP are well explained if the precursor is a PdP wave, reflected at the top of D", about 300 km above the CMB. At a period of about $2.5s$, the amplitude of PdP is about 20% the PcP amplitude. This ratio is the expected one for a P-velocity jump of 3% and a similar density jump. Our observation implies that the thickness of the transition is very small (of the order of 8 km). This places new and important constraints on the nature and origin of the seismic discontinuity at the top of D". The main weakness of our analysis is that it relies on one single event. Recent observations of ScS precursors [*Schimmel and Paulssen,* 1995] also imply a rather sharp transition in other regions of the world.

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**Figure 1.** a) Geographical set-up of our study. The two alaskan earthquakes discussed in the text are indicated by crosses. Great circles from the 90/05/01 and 93/05/25 events to 13 stations of the WRSN network are drawn. The grey patch gives the zone at the top of D" which are probed. b) Schematic rays at these distances for PcP and PdP (P-wave reflected at the top of D").

**Figure 2.** Record section of the 13 most alike looking short-period seismograms of WRSN for the 90/05/01 event, near the arrival time of PcP. The records are arranged according to epicentral distance $\Delta$, and are normalized to the PcP amplitude. They have been aligned in time by multi-channel cross-correlation. The stack is shown at the bottom. Note the good stability of the PcP waveform across the network. The station names are from top to bottom : GL2, SAW, CBS, STD, RVW, FMW, LMW, GSM, BOW, GMW, SMW, OBH, and OOW.

**Figure 3.** a) Contours of the absolute amplitude of the stack as a function of relative slowness $p$ and time $t$ with respect to PcP for the 13 records of Figure 2. The reference distance is 23.57° (station BOW). b) Stacked seismogram for $p \simeq 0.7s/°$. A precursor at $t \simeq -40s$ is clearly visible, with a dominant period of about $2.5s$. Its amplitude reaches about 20% of the PcP amplitude.

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**Table 1.** Parameters of the alaskan earthquakes used in this study, from USGS National Earthquake Information Center. Also given the time and amplitude of PdP relative to PcP predicted from model PWDK [*Weber and Davis,* 1990] and $\Delta = 25°$.

| Date | Time | Latitude | Longitude | Depth | $m_b$ | PdP-PcP | PdP/PcP |
|---|---|---|---|---|---|---|---|
| 90/05/01 | 16:12:21 | 58.84° | −156.86° | $211km$ | 6.1 | $-37s$ | 0.15 |
| 93/05/25 | 23:16:43 | 55.03° | −160.48° | $33km$ | 6.2 | $-37s$ | 0.14 |

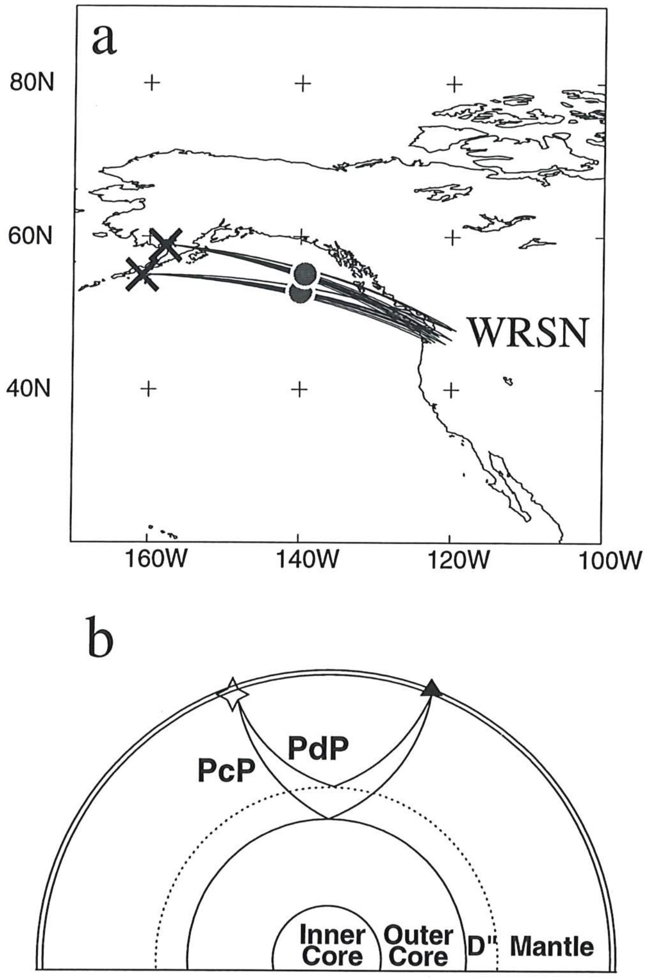
a
80N
60N
40N
WRSN
160W
140W
120W
100W
b
PcP
PdP
Inner Core
Outer Core
D"
Mantle

Fig. 1

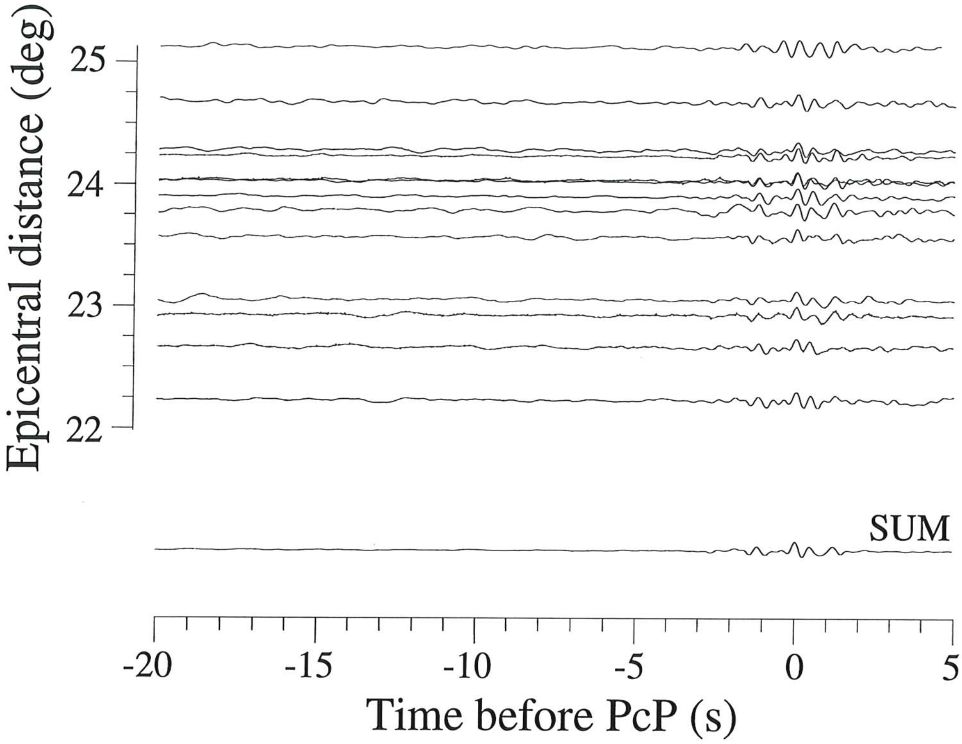
Epicentral distance (deg)
25
24
23
22
SUM
-20
-15
-10
-5
0
5
Time before PcP (s)

Fig. 2

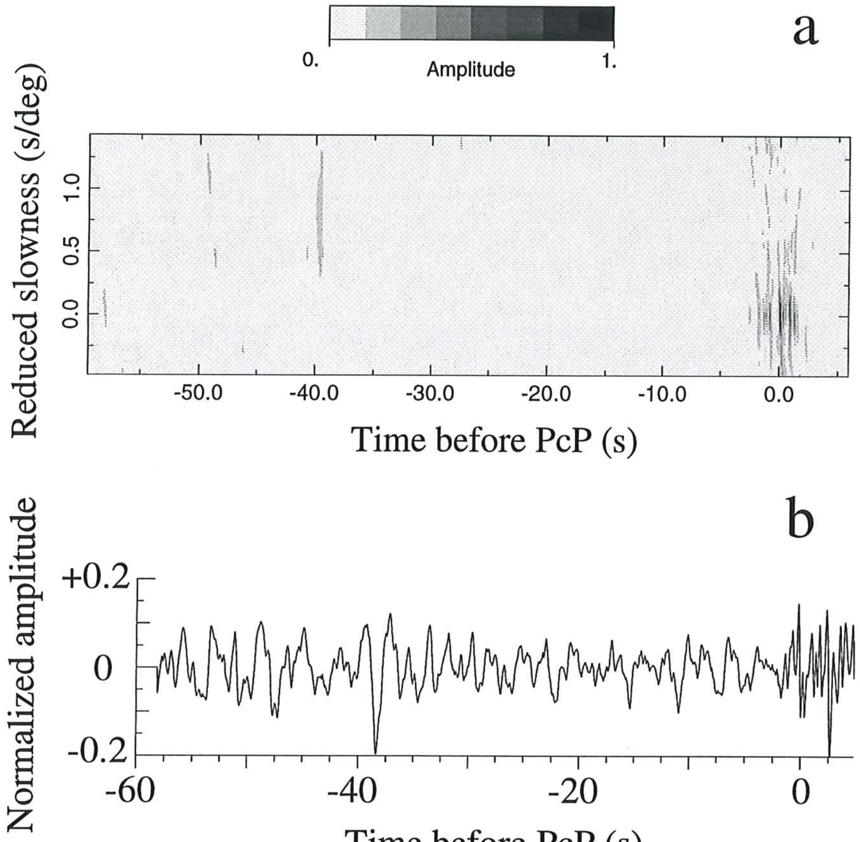
a
0.
Amplitude
1.
Reduced slowness (s/deg)
0.0
0.5
1.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
Time before PcP (s)
b
Normalized amplitude
+0.2
0
-0.2
-60
-40
-20
0
Time before PcP (s)

Fig. 3