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Lateral variations in D″ below the Caribbean

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Abstract. Broad-band data from the Canadian National Seismograph Network (CNSN) shows evidence for a laterally-varying *S*-wave discontinuity in the lowermost mantle beneath the Caribbean. The magnitude of the velocity contrast across this *D″* discontinuity varies inversely with its distance from the core-mantle boundary (CMB). Clear evidence for a 2.75% increase in shear velocity 250 km above the CMB is observed in a region 10°N and 60 – 85°W; a thicker *D″* layer (290 km) with a less pronounced topside discontinuity (2.45%) is interpreted in the region 80° – 90°W and 20°N; and there is no evidence for a *D″* discontinuity in the region 65° – 80°W and 25°N. Considerable 3D structure within the *D″* region is suggested by travel-time scatter in *ScS* arrivals and *S* arrivals which turn within *D″*. Transverse-component *SKS* signals due to upper-mantle anisotropy can be confused with *D″* signals; however, we show that false interpretations of *D″* structure can be mitigated through the careful analysis of travel-time moveout and low-pass filtering.

Introduction

Over a decade ago *Lay and Helmberger* [1983] presented compelling evidence for the existence of a seismic discontinuity at the top of the lowermost mantle layer known as *D″*. The emerging picture from subsequent studies of both regional and global data sets is that there are significant lateral variations in the structure of the region [*Weber and Davis*, 1990; *Wysession et al.*, 1992; *Garnero et al.*, 1993; *Nataf and Houard*, 1993; *Kendall and Shearer*, 1994] and that this seismic reflector is not necessarily a global feature [*Weber*, 1993]. It has been suggested that this layer may serve as a "graveyard" for ancient subducted material [*Christensen*, 1989] and that it is the site of mantle plume generation [*Yuen and Peltier*, 1980]. It is not yet clear to what degree the observed seismic structure can be explained by the existence of a thermal boundary layer versus a chemically distinct layer, or some combination of the two.

In this paper we analyze recent shear-wave data from the newly refurbished broad-band Canadian National Seismograph Network (CNSN) (Figure 1) for evidence of a *D″* reflector beneath Central America and the Caribbean. Tomographic models of the lowermost-mantle show this to be a high-velocity region [*Woodward et al.*, 1993; *Grand*, 1994]. Our study area is similar to one of those examined by *Lay and Helmberger* [1983], but extends farther north. *Weber and Körnig* [1992] (*P*-waves) and *Kendall and Shearer* [1994] (*S*-waves) found considerable lateral variability in *D″* thickness in parts this region. We use travel-time analyses and waveform modeling to constrain new models of the lowermost-mantle shear-velocity structure in this area.

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Travel-time analyses

In a one year period (1994) we found 5 impulsive deep-focus (> 570 km) events which are suitable for analysis of a *D″* reflector (Table 1). Events 1-3 are in roughly the same location as those examined in *Lay and Helmberger* [1983], while events 4 and 5 are farther north. The broad-band shear-wave arrivals are rotated to isolate the *SH* arrivals. A composite record-section for the southernmost events (1-3) clearly shows *ScSH* precursors (*SdS*) between 70° and 77° (Figure 2a). A sharp increase in velocity a few 100 kms above the CMB will produce a travel-time triplication that can explain the observed precursors.

We determine a new lower-mantle shear-velocity model for the southern part of the study area which refines the previous *Lay and Helmberger* [1983] model SLHA (Figure 3a). SKNA1 is similar to SLHA in the thickness of *D″* (250 km) and the magnitude of the discontinuity (2.75%), but it differs in velocity gradients above and below the discontinuity. Travel-times for SKNA1 match the observed travel-times quite well (Figure 3b), especially those for rays which turn above *D″* (*Sab*). Observed travel-times for rays on the second forward branch (those which turn within *D″* (*Scd*)) and the *ScS* picks show considerably more scatter; however, the overall fit of the model is quite good. The results also agree with those of *Kendall and Shearer* [1994] for this region.

The results for events 4 and 5 can be grouped into two regions (Figure 1): a western region which shows evidence for a thick *D″* layer with a relatively weak topside discontinuity and an eastern region which shows no evidence of a *D″* discontinuity. Travel-times for the western region (Figure 3c) are fit with a model that has a 290 km thick *D″* layer and a 2.45% velocity contrast at the discontinuity (SKNA2 – Figure 3a). There are fewer travel-time picks for these events and our confidence in these picks is less than it is for events 1-3. Nevertheless, it is clear that the *D″* region thickens and its topside

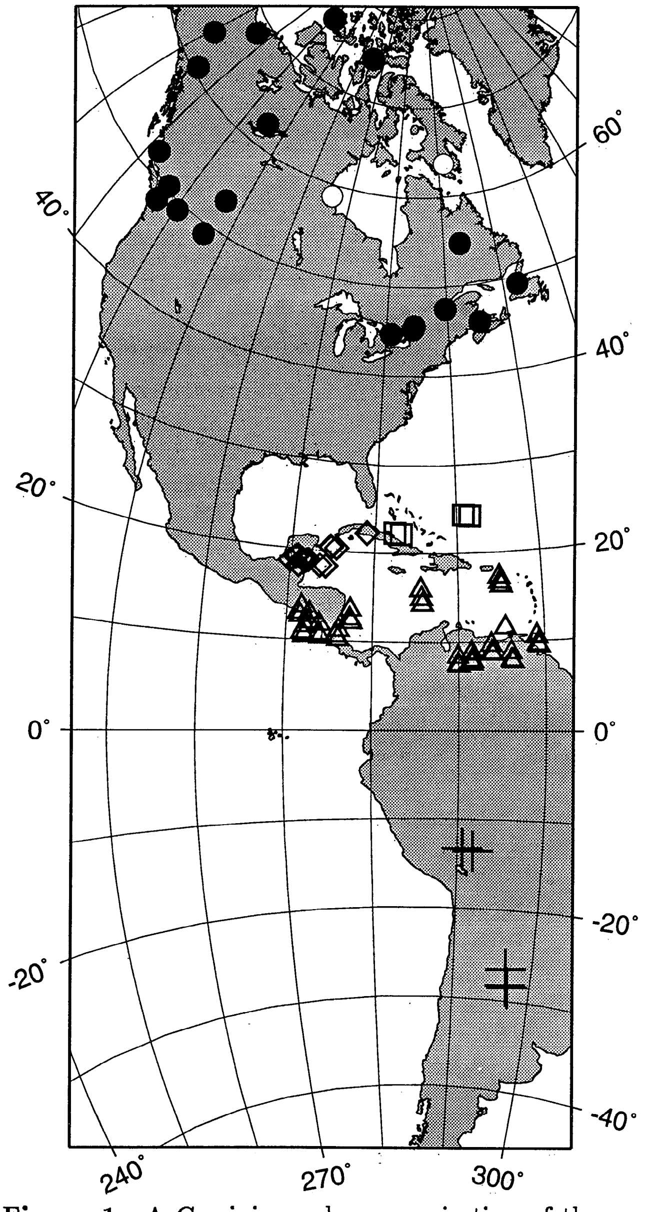

Figure 1. A Cassini equal-area projection of the region of study. Circles show the sites of CNSN stations, crosses show the epicentres of the earthquakes studied, triangles show surface projected bounce points of ScS phases for events 1-3 and diamonds and squares show bounce points for events 4 and 5. Squares indicate the region with no evidence of a D'' discontinuity, diamonds show the region where the lower-mantle S-wave model SKNA2 best fits the data and triangles show the region where the model SKNA1 best fits the data. The CNSN stations marked with open circles are FCC and FRB.

velocity discontinuity diminishes in the north-westerly region. The north-easterly region is imaged with stations FCC and FRB (Figure 1). No obvious D'' signal was observed at these stations, suggesting the discontinuity fades away in the northeast region.

Waveform Analysis

Waveforms for the models SKNA1 and SKNA2 are calculated using a WKBJ approach [*Kendall et al.*, 1992] and the D'' discontinuity is represented as a sharp change in velocity gradient across a 10 km region. Estimates of the source wavelet are made by fitting a point source synthetic to the observed S-phases for each event and we neglect attenuation effects as the events are deep and the rays travel along paths of weak attenuation to the Canadian stations. A comparison of the data with predicted waveforms for the model SKNA1 at epicentral distances between 70° and 100° shows clear evidence of D'' signals (Figure 2).

Inspection of selected observed and synthetic waveforms shows the high resolution of the broad-band data (Figure 4). Figures 4a and 4b show very clear ScS precursors in data from different events recorded at the same station (DRLN - Dear Lake, Newfoundland), thus

Table 1. Time, location, and body-wave magnitude for earthquakes used in this study.

	Date - Time	Lat	Long	Depth	Mb
(1)	1994-04-29 07-11-30	28.30S	63.17W	572	6.9
(2)	1994-05-10 06-36-27	28.50S	62.90W	599	6.2
(3)	1994-08-19 10-02-53	26.52S	63.27W	576	5.8
(4)	1994-01-10 15-53-49	13.31S	69.39W	589	6.4
(5)	1994-08-08 07-55-39	13.60S	68.20W	600	5.3

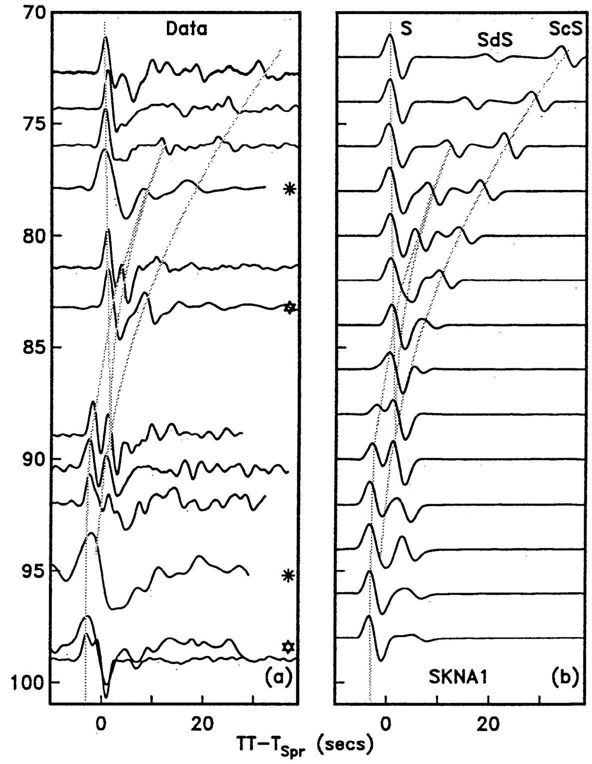

Figure 2. Record sections of the observed SH-waveforms for events 1-3 (a) and WKBJ SH-waveforms for the model SKNA1 (b). Travel-times are reduced by the S-wave travel-times for PREM. The synthetics are calculated for a source depth of 576 km. In the composite record section of the unfiltered depth-corrected data (a), event-1 traces are marked by an asterisk, event-2 traces are marked by a star and event-3 traces are unmarked. The travel-time curve for the model SKNA1 is shown in grey.

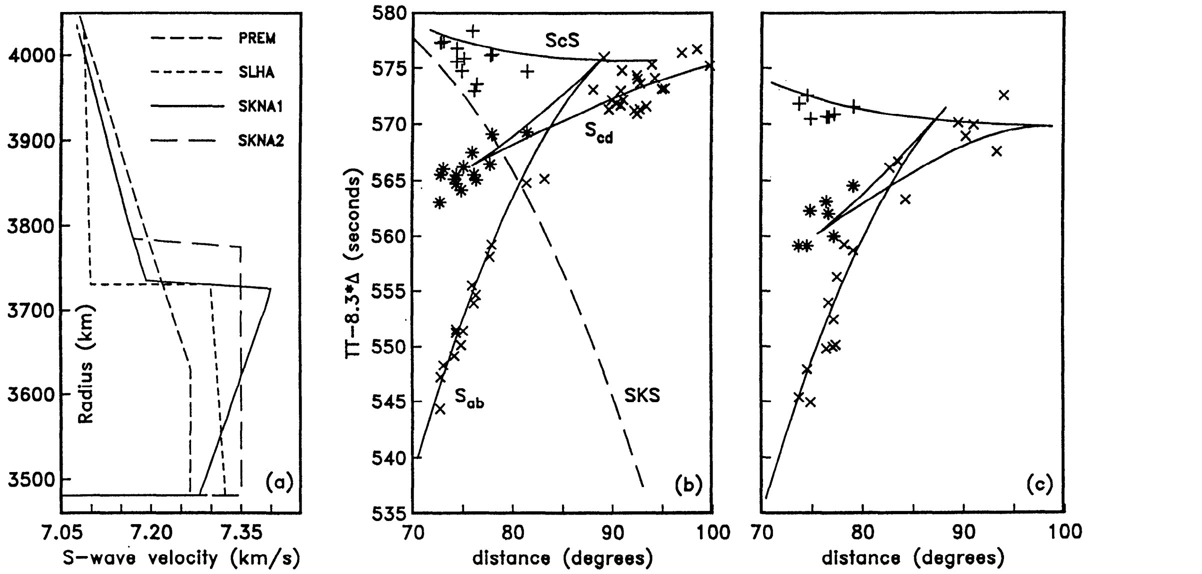

Figure 3. (a) The velocity profiles of the reference Earth model PREM, the 1D models presented in this work (SKNA1 and SKNA2) and the earlier model SLHA [*Lay and Helmberger*, 1983]. (b) Travel-time picks for events 1, 2 and 3 (corrected for a depth of 576 km) and the predicted travel-times for the model SKNA1. Crosses denote S-picks, plus signs denote ScS-picks and asterisks denote D'' signals. The dotted line shows the predicted SKS travel-times. (c) Travel-time picks for events 4 and 5 (corrected for a depth of 589 km) and the predicted travel-times for the model SKNA2.

ruling out explanations of the precursor as a source effect. As pointed out by *Schlittenhardt et al.*, [1985] it is also important to consider waveforms from the more distant side of the triplication. Figure 4c shows the good agreement between the waveform for the model SKNA1 and the observed waveform at 90.9°; longer-period data would not show such detail. Diffractions from the most distant travel-time cusp are observable at the stations even out to 100° (Figure 2a). An example of an observed FRB seismograms where there is no indication of a D'' discontinuity is shown in Figure 4f.

Anisotropy and SKS Contamination

Figure 5 shows a strong transverse-component SKS signal recorded at the station PNT, 92.4° from the source. Receiver side anisotropy will generate S-wave signals on both radial and transverse components, especially in broad-band data (e.g., *Bostock and Cassidy* [1995] show this for the CNSN stations). Comparing predicted SKS arrivals with travel-times for the southern events suggests that only a few D'' picks could be potentially confused with $SKSH$ signals. It is possible that some of the ScS picks between 70° and 74° are being contaminated by the SKS phase. *Lay and Young* [1986] showed that $ScSH$ precursors are unlikely to be associated with SKS signal contamination when assuming an isotropic Earth. Errors in component rotations and signal calibration can cause some transverse-component SKS signal, but it is difficult to explain the strong $ScSH$ precursors with these errors.

False interpretations of D'' signals which are due to anisotropy-induced $SKSH$ signals can be mitigated with low-pass filtering. The travel-time separations of the S-waves and variations between proximal receivers generally constrain the anisotropy to upper-mantle regions which are at a maximum a few hundred kilometers

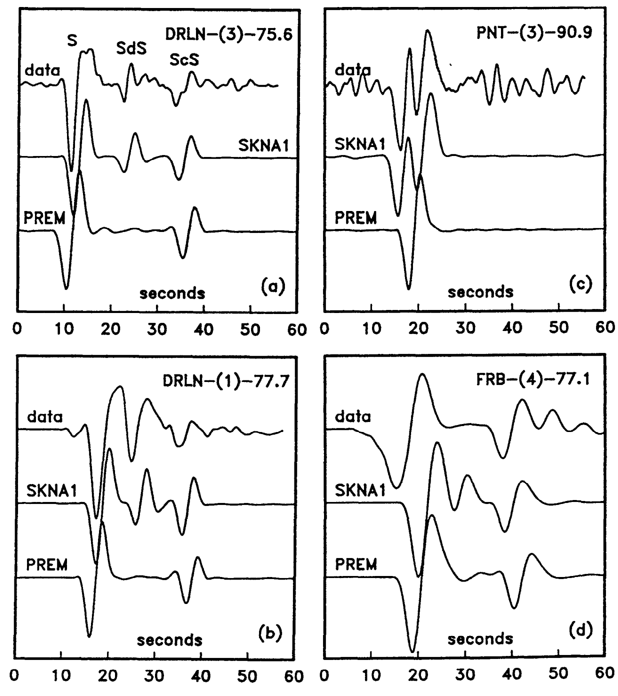

Figure 4. Observed and synthetic waveform comparisons (station, event and epicentral distance are listed in the top right of each panel). The data in (a) through (c) show an ScS precursor, while (d) shows no evidence of D'' signal. The data in (d) are band-pass filtered (0.001Hz-0.1Hz), while (a)-(c) show unfiltered data.

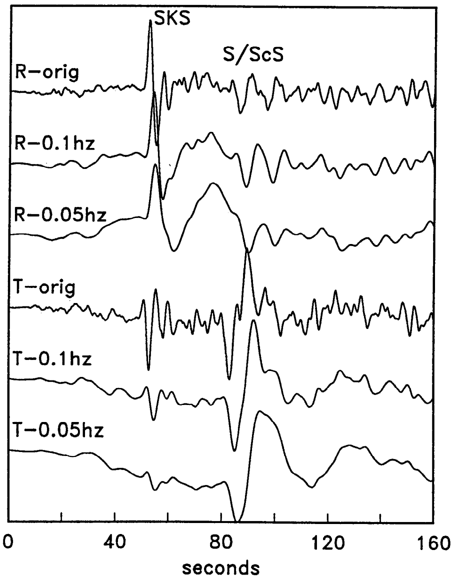

Figure 5. An example of low-pass filtering broad-band data to reduce a transverse-component *SKS* signal which is due to upper-mantle anisotropy. Notice that the transverse-component *SKS* signal diminishes with the reduction in cut-off frequency, while the radial *SKS* signal remains strong. The data are from event 1 recorded at PNT, 92.4° from the epicentre.

thick [e.g. *Silver and Chan*, 1988]. In such cases long-wavelength seismic energy will not be able to resolve the travel-time separations between the fast and slow shear-wave arrivals. Figure 5 shows that the *SKSH* signal diminishes as the high-frequency energy is removed though low-pass filtering. As a cross-check we repicked our travel-times after low-pass filtering the data and found good agreement with the unfiltered-data picks.

Discussion

We have found two areas where there is evidence of a D'' shear-wave discontinuity beneath the Carribean. The magnitude of the discontinuity diminishes in a northerly direction and disappears altogether in the northeast. The suggested weakness of the discontinuity in the northern region is perhaps why *Weber and Kőrnig* [1992] did not find evidence for a D'' signal, but their study analyzed *P*-waves. Although not described herein, we have also found no evidence of a *P*-wave discontinuity in this region.

Broad-band waveforms allow high-resolution analysis of the D'' region. In comparison with longer-period data, separate arrivals of the D'' travel-time triplication are much more easily discerned in the CNSN waveform data, especially at distances beyond 80°. It is clear from the travel-times (Figure 3) that there is more lateral variability within D'' than there is in the overlying mantle. The predicted travel-time anomalies for the Earth model WM13 [*Woodward et al.*, 1993], for the range of azimuthal take-off angles which bracket our region of study, show similar variability [*Kendall et al.*, 1992]. This consistency adds confidence to our assertion that the travel-time scatter is due to 3D structure within the D'' layer and not errors in travel-time picks. The next stage in this work is to explore the 3D velocity variations within the D'' region.

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