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Fig. 7. 70 second time window around *PP* arrival times for stacked. Shown are waveforms of the 2003 (blue) and 1993 (red) events. Note the similarity of the waveforms and, in particular, of the *PP* coda. for a 30 sec interval after the main energy arrival.

Fig. 8. Time windows around *PP* arrival times for stacked waveforms of the 2003 (blue) and 1993 (red) events in different frequency ranges. In the frequency range of 0.5–1.0 Hz, *PP* phases dominate and waveforms are highly similar, with a cross-correlation coefficient of 0.98. In the frequency range of 1.0–2.0 Hz, amplitudes of the doublet waveforms are smaller by a factor of 3.3 and background noise starts to be visible, but waveforms are still very similar, with a cross-correlation coefficient of 0.90. In the frequency range of 2.0–5.0 Hz, amplitudes of the doublet waveforms are 200-times smaller than in the frequency range of 0.5–1.0 Hz. The background noise is relatively strong. This presents other evidence that the 2003 event and 1993 event are a real doublet, at least in the frequency range of 0.5–2 Hz.

Fig. 9. Reflection coefficients of *PKiKP* at the ICB. The black dashed line is computed for the PREM model, the blue and red lines are corresponding to "liquid" and "solid" patchy models, respectively, suggested by Krasnoshchekov *et al.* (13). In our epicentral distance range (138°), for all three models, *PKiKP* is postcritically reflected at the ICB. The reflection coefficients are close to 1. In comparison with the subcritical reflected *PKiKP* (13), the amplitude of the postcritically reflected *PKiKP* is not significantly influenced by strong perturbations of density, V_p, or V_s contrasts at the ICB. In other words, lateral variations of seismic structures (except topography) at the ICB do not significantly change the amplitude of *PKiKP* in our study.

Fig. 10. Spectra of *PKiKP* phases for 2003 (blue) and 1993 (red) events. In the relatively wide frequency range from 0.4 to 4.3 Hz, *PKiKP* amplitudes for the 2003 event are consistently larger than those for the 1993 event. Shapes of the two amplitude spectra are basically similar except from 1.0 to 2.0 Hz. Therefore, in the anomalous 1993 *PKiKP* waveform, there are not scattered waves due to small-scale heterogeneities near the source.

Fig. 11. Vespagrams of *PKIKP* (*Left*) and *PKiKP* (*Right*) for the doublet in the slowness and back-azimuth domain. Solid white lines denote the theoretical back-azimuth (126.5°). Grey circles denote the scale of slowness with an interval of 1.0 s/deg. In yellow brackets are estimates of slowness (s/deg)

and back-azimuth (deg), respectively. The theoretical slowness of *PKIKP* and *PKiKP* are 1.86 s/deg and 2.04 s/deg, respectively. The uncertainties of our estimates of slowness and back-azimuth are ≈0.3 s/deg and ≈5.0°, respectively, based on the sampling rate (0.05 second) and the aperture (25 km) of YK seismic array. Therefore, these results confirm that PKIKP and PKiKP paths do not deviate significantly from the great circle path between the sources and the array.

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Wavelet Analysis for the 1993/2003 doublet. We applied the continuous wavelet transform (1, 2) in an attempt to detect potentially unpredicted seismic phases in the seismograms of the 1993 and 2003 earthquakes (e.g., depth phases and scattered phases). A short time series around the *PKIKP* and *PKiKP* theoretical arrival time have been analyzed. The wavelet transform, which was partly developed in work on seismic signals (3, 4), is a very reliable tool for the analysis of nonstationary signals, such as seismic signals. As the wavelet transform of a signal may be represented in terms of both time and frequency, it is subject to the uncertainty principle (2). This principle states that increasing the time resolution implies a loss in the frequency resolution and conversely. For example, choosing an analyzing wavelet (often called the "mother wavelet"), which has a compact time support is useful to track very impulsive signals but at the cost of a poor frequency resolution. To overcome this limitation, we computed the wavelet transform three times using different mother wavelets. The analyzing wavelets we used range from high temporal and low-frequency resolutions to low temporal and high-frequency resolutions. Varying the resolutions in time and frequency allows to check for a large class of seismic phases (i.e., both very impulsive and highly oscillating seismic phases).

The results of the wavelet analysis are presented in Fig. 4. First, we analyzed the seismograms by using a Paul (5) wavelet with the parameter m set to 4 (see ref. 5 for a definition of the parameter m). This wavelet offers a very compact time support and is sensitive to instantaneous changes in the signals. For both time series, the amplitude spectrum shows two well separated amplitude peaks corresponding the seismic phases *PKIKP* and *PKiKP*. Moreover, the spatial distributions of the amplitudes in the time-frequency plane (shown as time and period here) are very similar. Still, the amplitudes levels differs. Comparing the phases of the two time series shows a strong correlation between the two records. Indeed the phases computed from the two seismograms match almost perfectly, both versus time and frequency. To track a possible seismic phase that would have a more oscillatory behavior, we used two morlet (5) wavelets. The first one, for which the parameter w_0 have been set to 5, has an intermediate resolution in time and frequency (see ref. 5 for a definition of w_0), while the second one ($w_0 = 7$) has a higher frequency resolution. Here again the *PKIKP* and *PKiKP* appear as two distinct areas with higher amplitudes. The slight overlapping observed when $w_0 = 7$ is due to the low temporal resolution of this particular wavelet. The plots showing the zero isophases emphasize the quasi-perfect phase match between the two seismograms.

None of the three wavelet transforms shows the presence (i.e., an anomalous amplitude peak) of an external seismic phase that would be observed in one seismogram and not in the other. Moreover, the perfect match in the phases of the two seismograms is a strong evidence that the hypothesis of having either a depth phase or some scattered phase interfering with the two core phases *PKIKP* and *PKiKP* can be rejected.

1. Daubechies I (1992) in *CBMS-NSF Regional Conference Series in Applied Mathematics* (Soc Industrial and Appl Math, Philadelphia), Vol 61, pp ???.[1]

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3. Goupillaud P, Grossmann A, Morlet J (1984) *Geoexploration* 23:85102.

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5. Torrence C, Compo GP (1998) *Bull Am Meteorol Soc* 79:61–78.

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[1] ?/Au: Please give the page range that you used for ref. 1 (not the total number of pages in the book). Otherwise, you can cite the entire book by removing "in" from before the title.

to appear Date; dd/mm/yy | Time | Latitude; ° | Longitude; ° | Depth; km | m_b | Δ; °

1c

Table 1. Seismic Parameters of Doublets

Date (dd/mm/yy)	Time	Latitude (°)	Longitude (°)	Depth (km)	m_b	Δ (°)
01/12/93	00:59:01.2	-57.475	-25.685	33 (45)	5.5	137.8
06/09/03	15:46:59.9	-57.419	-25.639	33 (44)	5.6	137.8
30/12/93	17:45:00.3	-58.956	-25.356	10	5.0	139.0
29/01/01	09:14:29.8	-58.909	-25.473	33	4.8	138.9
04/04/97	02:35:44.8	-57.893	-25.599	33	4.8	138.1
14/05/99	05:05:08.2	-57.943	-25.452	33	4.7	138.2

*Event parameters are based on PDE catalog (depths in ~~brackets~~ are from Harvard CMT).

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