Auxiliary Material

Below we show all the seismograms we used in this study (Figs. S1-S4). For each doublet, records at the same from the two events are overlaid to show the similarity of the waveforms. The earlier and the later events of the doublet are indicated by dotted and solid lines, respectively. The two traces are often not distinguishable because of the high similarity of the waveforms. Background noise is intentionally shown to indicate the signal strength relative to the noise. The mantle and core phases are marked with relative travel times predicted from a 1D reference model (AK135). Labeled also are station codes, epicentral distances, and azimuths. Note the inner core phase PKP(DF) (not marked), which precedes PKP(BC), is barely visible in these records.

Fig. S1. Core and mantle phases for doublet 9804 from South Sandwich Islands (i.e., 1998 and 2004 events). The data are from IRIS DMC. Separated traces in the front at stations LPAZ and VNDA are background traces before the earthquakes, scaled relative to the PcP arrivals. The source depth (h) and the magnitude (mb) are the averaged values of the two events (see Table 1).
9303 SSI IRIS h=33km mb=5.55

Fig. S2A. Mantle phases for doublet 9303 in South Sandwich Islands (i.e., 1993 and 2003 events). All the data are from IRIS DMC.
Fig. S2B. Core phases for doublet 9303 in South Sandwich Islands. Most records are from Alaska Seismic Network and a few are from IRIS DMC.
**Fig. S3A.** Mantle phases for doublet 0004 in Tonga (i.e. 2000 and 2004 events). The data are from IRIS DMC. The secondary phase in the top four stations is identified as pP for the dtt measurements. However, PcP arrives at similar times. Thus, PcP energy and P coda energy make contribute to the secondary phase. Another depth phase sP is also labeled for reference.
Fig. S3B. More mantle phases for doublet 0004 in Tonga. The data are from Southern California Earthquake Data Center and Northern California Earthquake Data Center. The secondary phase is identified as pP for the dtt measurements. However, the PcP phase arrives at similar time. Thus, the PcP energy and P coda energy make contribute to the secondary phase. Another depth phase sP is also labeled for reference.
Fig. S3C. Core phases for doublet 0004 in Tonga. The data are from German Regional Seismic Network (GRSN).
**Fig. S4A.** Mantle phases for doublet 9002 in Fiji (i.e., 1990 and 2002 events). The data are from IRIS DMC. These are deep-focus events. The depth phases (outside the time window) are too weak to be identifiable.

**Fig. S4B.** Core phases for doublet 9002 in Fiji. The data are from German Regional Seismic Network (GRSN).