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[1] The three-dimensional *S*-wave velocity structure beneath the South Pacific Superswell is obtained from joint broadband seismic experiments on the ocean floor and islands. We collected only approximately 800 relative times of long-period teleseismic *SH*-waves by using a waveform cross-correlation from 76 events occurring from January 2003 to May 2005. We conducted relative time tomography to obtain a 3D structure to depths of 1600 km. In the resultant image, we find a characteristic distribution of low-velocity regions. The most prominent features are a large doughnut-shaped low-velocity region at 800 km depth, and an elongated large low-velocity region beneath the Society to Pitcairn hotspots at 1200 km depth. Our model suggests that a large low shear velocity province rooted in the D'' extends upwards and culminates near the top of the lower mantle beneath the central part of the South Pacific Superswell although its perfect continuity is not still confirmed. **Citation:** Tanaka, S., D. Suetsugu, H. Shiobara, H. Sugioka, T. Kanazawa, Y. Fukao, G. Barruol, and D. Reymond (2009), On the vertical extent of the large low shear velocity province beneath the South Pacific Superswell, *Geophys. Res. Lett.*, *36*, L07305, doi:10.1029/2009GL037568.

1. Introduction

[2] The seismic structure of the two large low shear velocity provinces (LLSVPs) in the lowermost mantle identified beneath Africa and the Pacific Ocean is important for understanding the thermo-chemical nature in the deep Earth [*Lay*, 2007]. So far, passive seismic experiments in Africa have provided strong evidence that the African LLSVP extends approximately 1500 km upward from the core-mantle boundary (CMB) [*Ritsema et al.*, 1998; *Ni et al.*, 1999; *Wang and Wen*, 2007]. A velocity reduction of the African LLSVP estimated by the regional studies is about 3%, which is much larger than that found in global tomographic results [*Liu and Dziewonski*, 1998; *Ritsema et al.*, 1999; *Masters et al.*, 2000; *Megnin and Romanowicz*, 2000]. On the other hand, the vertical extent of the Pacific LLSVP is recently thought to be less than approximately 500 km from the CMB [*Takeuchi*, 2007; *Garnero and McNamara*, 2008], although some previous studies discussed an upward extension of more than 1000 km toward the Samoa hotspot [*Bréger and Romanowicz*, 1998; *Garnero*, 2000; *Bréger et al.*, 2001].

[3] For detailed regional studies, combinations of hypocenter regions and existing seismic networks or arrays have been used, but this may constrain structures beneath only limited areas of the rim of the Pacific LLSVP. For example, deep earthquakes that occurred in the southwestern Pacific combined with seismic networks in eastern Asia are used to study its northwestern rim [*He et al.*, 2006]. Similarly, the southwestern Pacific events recorded by seismic arrays in southeastern Asia sample its western rim [*Takeuchi et al.*, 2008], whereas Tonga-Fiji deep events recorded by the California arrays are used to study its northeastern rim [*Lay et al.*, 2006]. In the most recent study, a 2D cross-section image passing through the western rim to the southern rim of the Pacific LLSVP is proposed as a result of forward modeling [*He and Wen*, 2009]. In this model, two separated low-velocity regions at the base of the mantle are detected. One is located beneath the Fiji and Kermadec islands, of which the vertical extent is at least 340 km from the CMB. The other is evidenced beneath the Solomon Islands, with a vertical extent of at least 740 km from the CMB.

[4] As discussed above, previous studies have not detected a significant vertically extending LLSVP beneath the Pacific Ocean. However, poorly instrumented and unexplored regions are still extensive. Considering the African LLSVP, its vertical extension has been precisely investigated by passive seismic experiments that are conducted in the region just above the detected anomaly. Therefore, to address the issues of the Pacific LLSVP, the lack of seismic observation in the oceanic area should be balanced. Recently, two passive seismic experiments were conducted in French Polynesia [*Barruol et al.*, 2002; *Suetsugu et al.*, 2005]. These projects have provided seismic studies on the upper mantle [*Isse et al.*, 2006; *Maggi et al.*, 2006a, 2006b; *Fontaine et al.*, 2007], the transition zone [*Suetsugu et al.*, 2007], and the three-dimensional *P*-wave velocity structure in the mantle [*Tanaka et al.*, 2009], which give important constraints on dynamics of the South Pacific Superswell. In this paper, we analyze teleseismic shear waves recorded in French Polynesia to examine the structure of the mantle beneath the South Pacific area and to constrain the lateral and upward extent of a possible Pacific LLSVP beneath this area.

2. Travel Time Residual

[5] The criteria for the earthquake selection and the basic processing of seismograms are almost the same as in the

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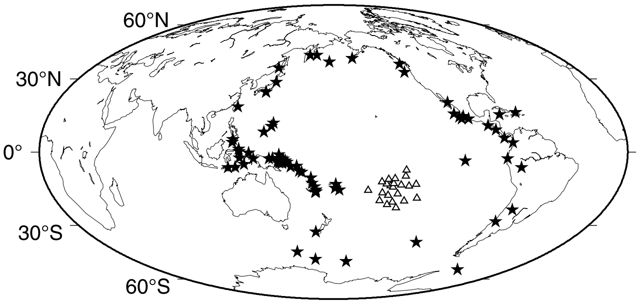

Figure 1. Geographical distribution of the 76 epicenters (solid circles) and the 22 seismic stations (open triangles) that are used in this study.

previous *P*-wave tomographic analysis [*Tanaka et al.*, 2009]. We mainly used broadband seismograms recorded by two passive experiments: One is the French Polynesia broadband ocean bottom seismic project (referred as FP-BBOBS) conducted between 2003 and 2005 [*Suetsugu et al.*, 2005], the other is the Polynesian Lithosphere and Upper Mantle Experiment (PLUME) conducted between 2001 and 2005 [*Barruol et al.*, 2002]. In addition, seismograms from the adjacent permanent stations of IRIS and GEOSCOPE were included. We rotated the two horizontal components to obtain a transverse (*SH*) component. Even though we analyzed a period range between 13 and 33 s in which the ambient noise was relatively low, the noise level of the horizontal components was significantly higher than that of the vertical component. We surveyed earthquakes with magnitude greater than 5.5 in two periods, January 2003 to January 2004 and August 2004 to June 2005, when the data from FP-BBOBS was available. Finally, we used 76 earthquakes and 22 stations in total, as shown in Figure 1.

[6] Relative times were measured by the following procedure. Seismograms were aligned on the *S*-wave arrival predicted from PREM [*Dziewonski and Anderson*, 1981] with the correction of physical dispersion for a period of 13 s (Figures S1 and S2).[1] The reference pulse was an *SH*-wave recorded at PPT with a window length of 10 to 30 s, if not available, those at RAR or PTCN were used. The data that had a correlation coefficient larger than or equal to 0.7 and passed a visual check of waveforms were retained for further analysis. Then, we obtained the time fluctuations around the theoretical arrival times. After the ellipticity correction [*Kennett and Gudmundsson*, 1996], we subtracted a median value from the time fluctuations for each event, and finally we obtained 823 residuals. To grasp the characteristics of the residuals, we simply plot the ray distribution of which colors are classified by their magnitudes of the residuals after subtracting the average residual at each station (Figure 2). Many ray paths with large positive residuals crossed each other in the lower mantle below depths of about 1000 km beneath the central part of the survey area, whereas those with small and/or negative residuals mainly sample the periphery. This suggests that a low-velocity region exists in the lower mantle beneath the central part of the South Pacific Superswell.

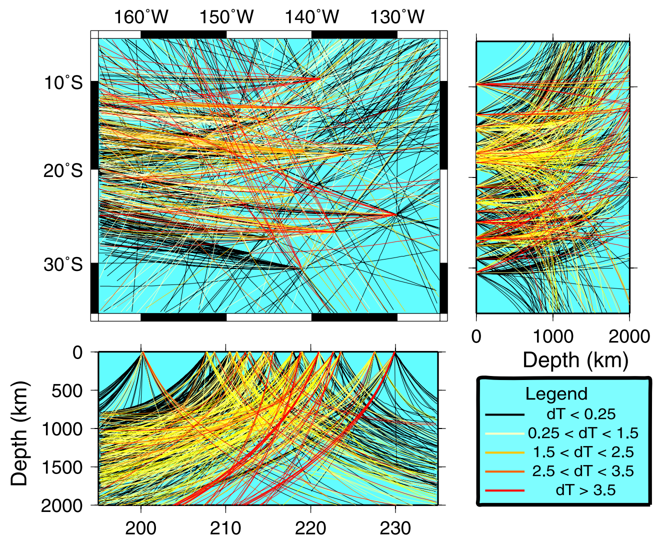

Figure 2. Geometry of the seismic rays, projected on the horizontal map, and along north-south and east-west cross sections. Colors indicate the magnitude of residuals as shown in legend.

3. Seismic Tomography

[7] To determine the features of a low-velocity region, tomographic analysis was applied to this data. We adopted TOMOG3D2 developed by [*Zhao et al.*, 1992]. In this study, we solved station terms and shear velocity perturba-

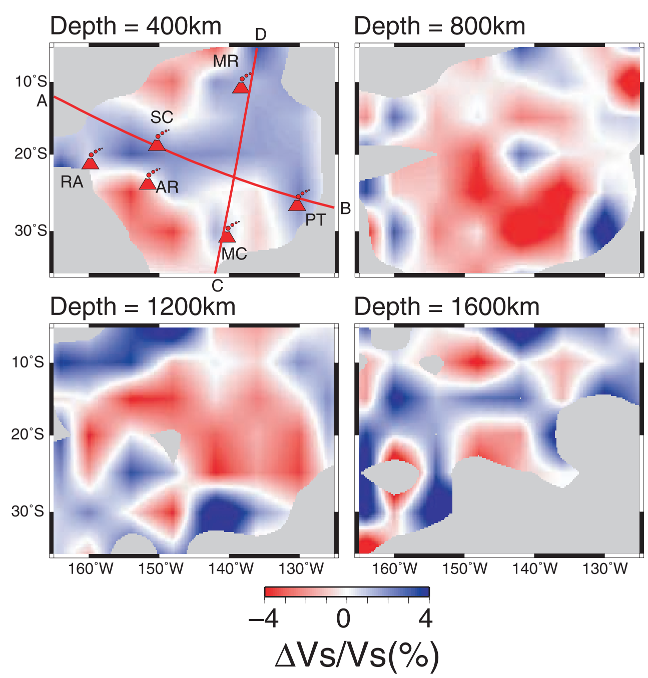

Figure 3. Velocity perturbation projected at depths of 400, 800, 1200, and 1600 km. The six hotspots are plotted as red triangles in the map at 400 km depth. The labels represent hotspot names as follows: SC, Society; PT, Pitcairn; MC, Macdonald; MR, Marquesas; RA, Rarotonga; and AR, Arago.

[1] Auxiliary materials are available in the HTML. doi:10.1029/2009GL037568.

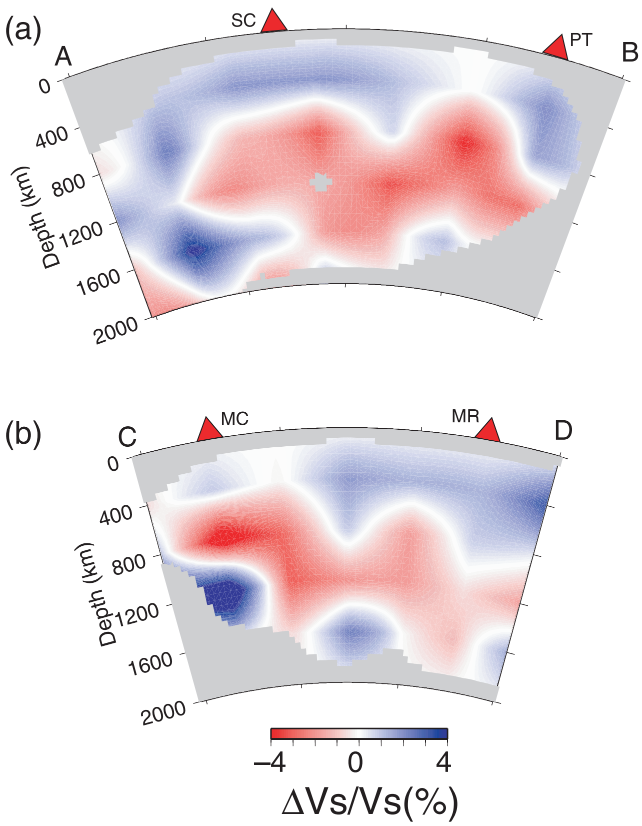

Figure 4. Velocity perturbation plotted along the vertical cross-sections from the surface to 2000 km depth passing (a) through the Society (SC) and Pitcairn (PT) hotspots (the AB cross-section) and (b) through the Marquesas (MR) and Macdonald (MC) hotspots (the CD cross-section). The red triangles show hotspot locations.

tions at the given grid points. Here, we gave horizontal grid intervals of 5° and 6° for latitude and longitude, respectively, and a vertical grid interval of 400 km. We did not use ray perturbation that was originally implemented in this code because the grid spacing was much larger than the expected ray perturbation. To lower the influence of the earthquakes located in the southwestern Pacific, we assigned the weight of 1/10 to the travel time residuals obtained from this area. Absolute residuals larger than 10 s were discarded.

[8] The weighted RMS residual of 1.63 s is improved to 0.66 s after performing three iterations. The resultant maps of the velocity perturbations at depths of 400, 800, 1200, and 1600 km are presented in Figure 3. The red and blue colors are saturated at the velocity perturbations of ±4%. We conducted a checkerboard test to estimate a recovery rate at each grid point (Figure S3). Unreliable areas defined as the recovery rate less than 0.2 are masked by a gray color. As we are interested in the relationship with the LLSVP in the D″ beneath the Pacific Ocean, we focus on the pattern of low-velocity regions. At 400 km depth, remarkably low-velocity regions are identified north of the Society hotspot and south of the Arago hotspot. At 800 km depth, a large horizontally lying doughnut-shaped low-velocity region is visible in our tomographic image. The northern arc is located beneath the Society hotspot to the south of the Marquesas hotspot, whereas the southern covers the Arago and the Macdonald hotspots. At 1200 km depth, an elongated large low-velocity region exists beneath the Society to Pitcairn hotspots. At 1600 km depth, we observe several strong low-velocity regions in central and northern French Polynesia. Two vertical cross-sections passing through two of the major hotspots are illustrated in Figure 4. The locations of the cross-sections AB (from Society to Pitcairn hotspots, in almost an east-west direction) and CD (from Macdonald to Marquesas hotspots, in almost a north-south direction) are indicated in the map at 400 km depth in Figure 3. In the AB cross-section, a large low-velocity region occurs in the lower mantle beneath the central part and culminates at the top of the lower mantle (Figure 4a). In the CD cross-section, a low-velocity region seems to be rooted beneath the Marquesas hotspot and extend upward to the south of the Macdonald hotspot (Figure 4b).

4. Discussion and Conclusions

[9] To discuss the relationship between the low velocity regions found in the mid mantle and the LLSVP in the D″, we compare our model with four previous global models of SAW24B16 [*Megnin and Romanowicz*, 2000], S20RTS [*Ritsema et al.*, 1999], S16U6L8 [*Liu and Dziewonski*, 1998], and SB4L16 [*Masters et al.*, 2000]. Figure S4 illustrates the collection of the AB cross-sections extending to the depth of the CMB with the same color scale as in Figure 4. Note that the reference velocity structure of these four models is originally PREM [*Dziewonski and Anderson*, 1981]. Thus we converted to the velocity perturbation with respect to the average perturbation in the region concerned in this study (5°S–35°S, 165°W–125°W) at each depth.

[10] A characteristic feature of heterogeneity in the lower mantle on the AB cross-sections for the global models can be summarized as a weak velocity anomaly. Exceptions are SAW24B16 and S16U6L8, which illustrate a relatively remarkable low-velocity body at the top of the lower mantle and in the lowermost approximately 500 km in the mantle, respectively, beneath the Society hotspot. *Tanaka* [2002] examined the differential travel times of *S–SKS* and *SKKS–SKS* and preferred S16U6L8 for the seismic structure in the lowermost mantle beneath the Superswell. Our model indicates the existence of a clear low-velocity region in the depth of 800–1600 km just above the low velocity region in the D″ seen in S16U6L8. Although our model does not resolve the velocity perturbation in the depth of 2000–2400 km, it is likely that the low-velocity anomaly in the mid mantle connects with that in the lowermost mantle because of their good coincidence of the horizontal locations.

[11] The top of the low-velocity region culminates near the top of the lower mantle at approximately 2000 km from the CMB, of which the feature is qualitatively similar to the result of the previous *P*-wave tomographic study [*Tanaka et al.*, 2009]. Moreover, the magnitude of the *S*-wave velocity perturbation reaches ±4%, which is approximately twice as large as that of the *P*-wave. Such information would be important to elucidate the thermo-chemical nature of the LLSVP in the Pacific. Unfortunately, the quality of *S*-wave data is insufficient to precisely compare with the *P*-wave velocity perturbation. Directly mapping of *Vp/Vs* ratio by using the inversion of *S–P* times may be an alternative way as well as the improvement of the quality of *S*-wave data in a future study. Furthermore, the miss-mapping of anoma-

lous structures outside the volume of interest is not fully considered. Tentatively we corrected the outside anomaly by using S16U6L8 to obtain another tomographic image (Figure S5). We find our main conclusions are not affected by this correction. However, to fully address this issue, our new data should be involved in global tomography.

[12] In conclusion, combining broadband seismic experiments conducted on the ocean floor and islands allows us to reveal the possibility that a large-scale shear velocity low-velocity region in the lowermost mantle extends upward approximately 2000 km from the CMB beneath the South Pacific Superswell.

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