Probing South Pacific mantle plumes with Broadband OBS

BY

D. SUETSUGU, H. SHIOBARA, H. SUGIOKA, G. BARRUOL. F. SCHINDELE, D. REYMOND,

A. BONNEVILLE, E. DEBAYLE, T. ISSE, T. KANAZAWA, AND Y. FUKAO

We conducted broadband ocean bottom seismic observations on the French Polynesian seafloor from 2003 to 2005 to image the mantle structure beneath the South Pacific superswell. A preliminary analysis of the recovered seismic data indicated slow velocity anomalies in the upper mantle beneath the superswell, which appear to be related to hot spots at surface.

Seismic structure beneath this region had not previously been well explored in spite of its significance for mantle dynamics. The region is characterized by a topographic high of more than 680 m [*Adam and Bonneville*, 2005], a concentration of hotspot chains (*e.g.*, Society, Cook-Austral, Marquesas, and Pitcairn) whose volcanic rocks have isotopic characteristics suggesting deep mantle origin, and a broad low velocity anomaly in the lower mantle revealed by seismic tomography. These previous observations suggest the presence of a large-scale mantle flow from the bottom of the mantle beneath the region, which is called a ‘superplume’ [*McNutt*, 1998].

However, the seismic structure has been only poorly resolved so far and the maximum depth of anomalous material beneath the hotspots has not yet been determined, mainly because permanent seismic stations in the region have heretofore been deployed only on a few oceanic islands and not on the sea floor. Recently ten broadband stations have been temporally installed on oceanic islands of French Polynesia as part of the PLUME project since 2001 [*Barruol et al*., 2002]. The PLUME network improved seismic coverage in the region substantially, while a large gap of seismic observation on seafloor had remained.

Polynesia BBOBS array

To improve the seismic coverage provided by the permanent and temporary land-based stations, we deployed ten broadband ocean bottom seismographs (hereafter abbreviated BBOBS) in the French Polynesia area as the Polynesia BBOBS array. The project was conducted as a Japan-France cooperative project of which the participating institutions are found in the Authors list below. In contrast to land-based stations, which are restricted to oceanic islands and clustered in a non-uniform manner, the BBOBS observations have the advantage of flexibility in selecting station sites. Figure 1 shows the station distribution of the Polynesia BBOBS array as well as the PLUME and the permanent CEA stations. The 10 BBOBS (FP1-FP8; S1; S2) were located to supplement the existing stations on oceanic islands so that the overall station distribution would be as uniform as possible. The observation period of the BBOBS project overlapped with that of the PLUME observations for nearly two years.

The BBOBS system has been developed by Earthquake Research Institute of University of Tokyo since the 1990s [*Kanazawa et al.*, 2001]. The BBOBS is a self pop-up type ocean bottom seismograph, which is designed to rise from the seafloor upon receipt of an acoustic command sent from a ship. It is equipped with the Guralp CMG-3T broadband sensor that can record ground motions at periods from 0.02 to 360 s. All the seismic instrumentation (sensor, data logger, hard disks, transponder, and batteries) is packed in a Titanium sphere whose diameter is 65 cm. The system can operate for as long as 400 days and is suitable for long-term observations of earthquakes. It is easy to install and recover and has been deployed successfully around Japan, in the Philippine Sea and in the northwestern Pacific since 1999.

Deployment of BBOBS

We deployed 8 BBOBS (FP1-FP8) in January, 2003, over the entire Superswell region and 2 BBOBS (S1, S2) in August, 2004, near the Society hotspot, on the seafloor at depths of 4000-5000 meters with the research vessel “YOKOSUKA” of Japan Agency for Marine-Earth Science and Technology (JAMSTEC). The recovery cruises were conducted in August-September, 2004, with “YOKOSUKA” and in June, 2005, with a Tahitian fishing boat “Fetu Tea II”. We recovered the BBOBS with the self pop-up method at 5 of the 10 stations, but failed at the other 5 stations due to a failure of the release mechanism of the anchor. The BBOBS left on the seafloor were then recovered with the submersible “SHINKAI-6500” of JAMSTEC, from which we could confirm that the BBOBS were sitting level on the seafloor (Figure 2). Nine of the ten BBOBS stations successfully recorded 10-12 months of data as planned.

We estimated the ambient noise level on the seafloor using the retrieved data. The vertical component of the seafloor noise is well below the level at high noise land stations at periods longer than 1 s, indicating that vertical-component BBOBS records are suitable for analyzing Rayleigh waves and teleseismic P-waves, which have large long-period vertical motions. The noise level of the two horizontal components is lower than or comparable to the level at high noise land stations at periods between 1 and 30 seconds and higher at the longer periods.

Preliminary data analysis

Hot mantle plumes should be detectable as low seismic velocity anomalies. Rayleigh waves on vertical component records are most suitable to detect such velocity anomalies, because of the low noise level on the vertical component of the BBOBS records. We selected pairs of stations aligned nearly on the great circles from earthquakes and measured the phase differences of the fundamental mode Rayleigh waves as a function of frequency to obtain the average phase velocities between the two stations. Figure 3 presents examples of such pairs of vertical-component records at the BBOBS and IRIS (Incorporated Research Institutions for Seismology) stations, showing that the signal to noise ratios of the BBOBS and land stations are comparable. The phase velocities in the superswell region are slower than those outside the region at frequencies of 0.007-0.03 Hz. Phase velocities of the fundamental mode Rayleigh wave in this frequency range mainly reflect shear wave velocities in the upper 200 km, suggesting that the upper mantle beneath the superswell is slower (i.e., that the upper mantle is hotter) than the surrounding area. We are now conducting an analysis of all of the data for a three-dimensional shear wave velocity model to identify presumed mantle plumes. In order to study a thermal structure in the mantle transition zone, a depth range from 400 km to 700 km, we will map a topography on the mantle discontinuity using the BBOBS data, which should help us determine whether the origin of hotspots in the region are located in the upper mantle, transition zone, or in the lower mantle.

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Authors

D. Suetsugu, H. Sugioka, T. Isse, and Y. Fukao, Institute for Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology, Yokosuka, Kanagawa, Japan; H. Shiobara and T. Kanazawa, Earthquake Research Institute, the University of Tokyo, Tokyo, Japan; G. Barruol, Laboratoire de Tectonophysique, CNRS, Université Montpellier II, Montpellier, France; and Laboratoire Terre-Océan, Université de Polynésie Française, Tahiti, French Polynesia; F. Schindelé Département Analyse Surveillance Environnement, CEA, Bruyères-le-Châtel, France; D. Reymond, Laboratoire de Géophysique, CEA, Tahiti, French Polynesia; A. Bonneville, Laboratoire de Géosciences Marines, Institut de Physique du Globe de Paris, CNRS, Paris, France; E. Debayle, Ecole et Observatoire des Sciences de la Terre, CNRS, Université Louis Pasteur, Strasbourg, France.

References

Adam, C., and A. Bonneville, The extent of the South Pacific Superswell, *J. Geophys. Res.*, 2005, in press.

Barruol, G., D. Bosch, V. Clouard, E. Debayle, M. P. Doin, F. Fontaine, M. Godard, F. Masson, D. Reymond, A. Tommasi, and C. Thoraval, PLUME investigates the South Pacific Superswell, *Eos*, 83, 511-514, 2002.

Jordahl, K., M. K. Caress, K. McNutt, and A. Bonneville, Seafloor morphology of the South Pacific Superswell region *in R. Hekinian Eds., Oceanic Hot Spots, Springer Verlag,* 2004.

Kanazawa, T., M. Mochizuki, and H. Shiobara, Broadband seismometer for a long-term observation on the sea floor, Proceedings of the OHP/ION Joint Symposium on Long-term observations in the oceans:current status and perspectives for the future, S11-06, 2001.

McNutt, M.K., Superswells, *Rev. Geophys*., 36, 211-244, 1998.

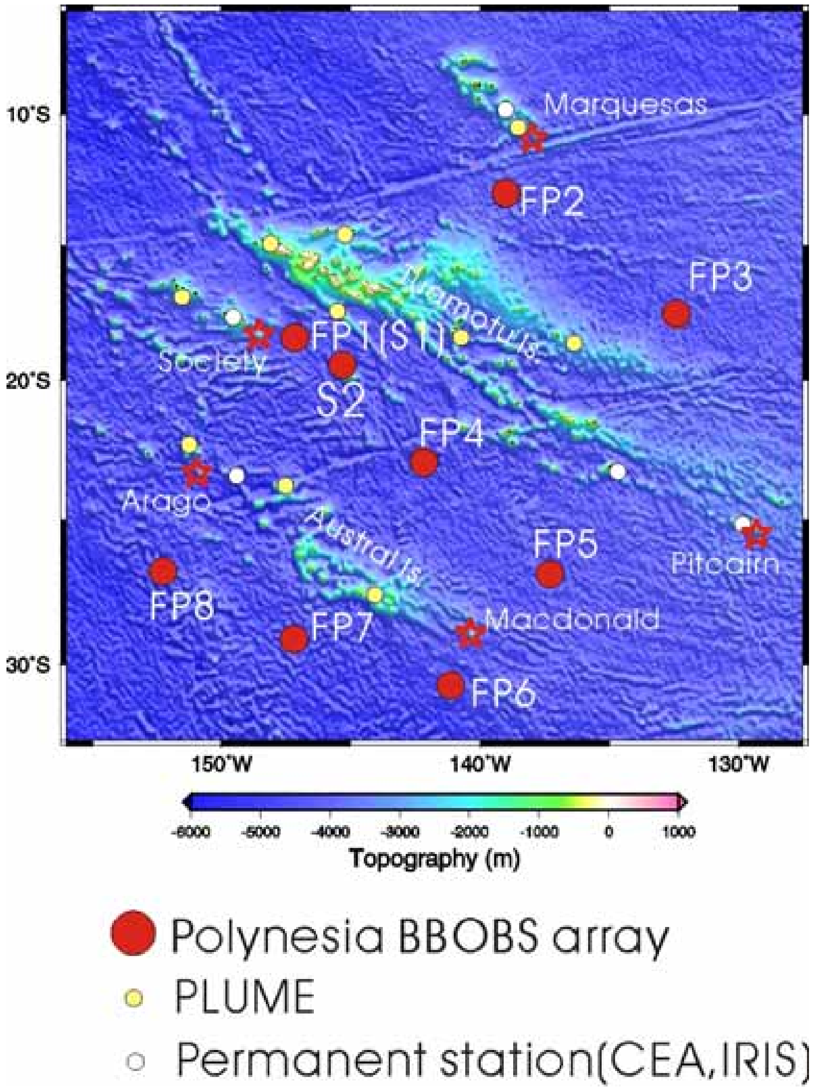

Fig. 1. The BBOBS stations (red circles) on a bathymetric map [Jordahl et al., 2004]. The S1 site is located at the FP1 site with different observation period. The PLUME stations (yellow circles) and the permanent broadband stations of CEA and IRIS (open white circles) are also shown. Red stars denote hotspots in the French Polynesian region.

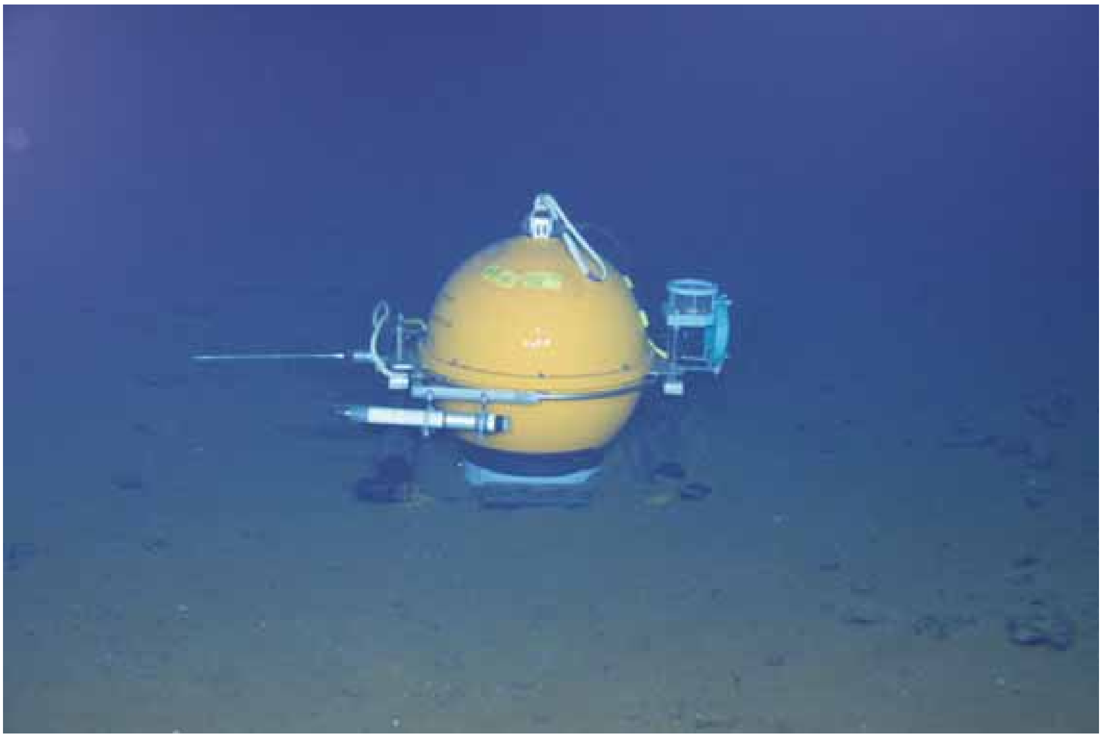

Fig. 2. The BBOBS on the seafloor at the FP6 station, which is 200 km south of the Macdonald hotspot. The depth is 4400 m.

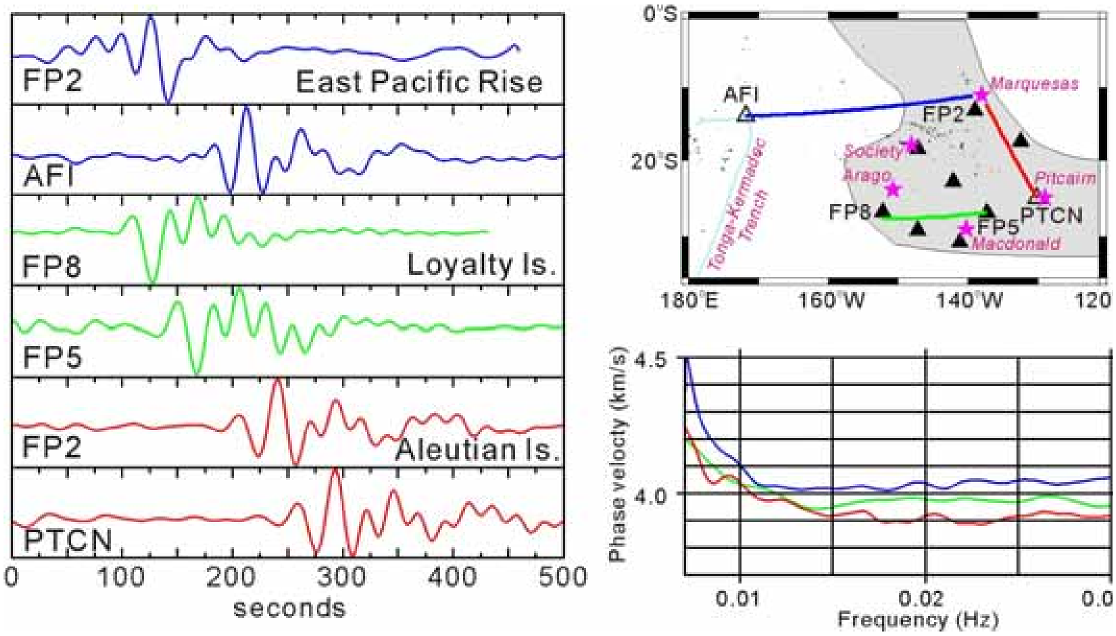

Fig. 3. Examples of Rayleigh wave phase velocity measurements using the BBOBS data. Left panel: three pairs of Rayleigh wave records from three earthquakes whose respective epicentral regions are noted in the figure. AFI and PTCN are IRIS stations on islands. Top right panel: Rayleigh wave propagation path segments to which the phase differences between the two stations of each pair are attributed. An area of the shallow seafloor depth anomaly greater than 300 m [Adam and Bonneville, 2005], is shaded in grey. The BBOBS and IRlS stations are denoted by solid and open triangles, respectively, and hotspots by stars. Lower right panel: The measured phase velocities from the three pairs of Rayleigh wave records. The three colors correspond to the three earthquakes throughout this figure.