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Probing South Pacific Mantle Plumes With Ocean Bottom Seismographs

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The seismic structure beneath the South Pacific superswell has not 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 hot spot island 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 that has been revealed by seismic tomography.

These 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].

The seismic structure of this region has been only poorly resolved so far, and the maximum depth of anomalous material beneath the hot spots has not yet been determined, mainly because permanent seismic stations in the region have been deployed only on a few oceanic islands and not on the seafloor.

From 2001 to 2005, 10 broadband stations have been temporarily installed on the hot spot island chains in French Polynesia as part of the PLUME (Polynesian Lithosphere and Upper Mantle Experiment) project to image the upper mantle structure beneath French Polynesia [*Barruol et al.*, 2002]. The PLUME network has improved seismic coverage in the region substantially, but a large gap of seismic observation on the seafloor had remained.

To improve the seismic coverage provided by the permanent and temporary land-based stations, a Japan-France cooperative project deployed 10 broadband ocean bottom seismographs (BBOBS) in the French Polynesia area from 2003 to 2005 as the Polynesia BBOBS array. A preliminary analysis of the recovered seismic data has indicated slow velocity anomalies in the upper mantle beneath the superswell, which appear to be related to hot spots at the surface of the Earth.

By D. Suetsugu, H. Shiobara, H. Sugioka, G. Barruol, F. Schindele, D. Reymond, A. Bonneville, E. Debayle, T. Isse, T. Kanazawa, and Y. Fukao

Polynesia BBOBS Array

In contrast to land-based stations, which are restricted to oceanic islands and clustered in a non-uniform manner, the BBOBS observations provide an advantage due to flexibility in the selection of station sites.

Figure 1 shows the station distribution of the Polynesia BBOBS array as well as the PLUME and the permanent CEA (Commissariat à l'Energie Atomic) and IRIS (Incorporated Research Institutions for Seismology) stations. The 10 BBOBS [FP (French Polynesia) 1–FP8, and S (Society) 1, and S2] were located to supplement the existing island stations so that the overall station spatial distribution would be as uniform as possible. The observation periods of the BBOBS and PLUME projects overlapped for 22 months during two separate time periods between January 2003 and June 2005.

The Earthquake Research Institute of the University of Tokyo has been developing the BBOBS system since the 1990s [*Kanazawa et al.*, 2001]. A BBOBS unit is a self-pop-up type ocean bottom seismograph that 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 seconds.

All of the seismic instrumentation (sensor, data logger, hard disks, transponder, and batteries) is packed into a 65-cm diameter titanium sphere. 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 to recover and has been deployed successfully around Japan, in the Philippine Sea, and in the northwestern Pacific since 1999.

Deployment of BBOBS

With the research vessel *Yokosuka* of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the project deployed eight BBOBS (FP1–FP8) in January 2003 over the entire superswell region and two BBOBS (S1 and S2) in August 2004 near the Society hot spot, all on the seafloor at depths of 4000–5000 m. The cruises to recover the BBOBS were conducted in August–September 2004 with *Yokosuka*, and in June 2005 with a Tahitian fishing boat, *Fetu Tea II*.

The BBOBS were recovered at five of the 10 stations with the self-pop-up method, but the method failed at the other five stations due to a failure of the release mechanism of the anchor. The five BBOBS left on the seafloor were recovered with the JAMSTEC submersible SHINKAI-6500, from which it was confirmed that the BBOBS were sitting level on the seafloor, which is important for recording ground motion precisely (Figure 2). Nine of the 10 BBOBS stations successfully recorded the planned 10–12 month collection of data.

Preliminary Data Analysis

Ambient noise level on the seafloor was estimated using the retrieved data. The vertical component of the seafloor noise has amplitudes close to an average noise level observed at land stations at periods longer than one second. This indicates that vertical-component BBOBS records are suitable for analyzing Rayleigh waves (which are sensitive to the upper mantle structure) and teleseismic *P*-waves (which are sensitive to the deeper mantle structure), both of 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 but higher at longer periods.

Hot mantle plumes should be detectable as low seismic velocity anomalies. Because of the low noise level on the vertical component of the BBOBS records, Rayleigh waves on vertical-component records are the best method of detecting such velocity anomalies.

Pairs of stations that were nearly aligned on the great circles (i.e., the shortest path between two points on a sphere) from earthquakes were selected, and the phase differences of the fundamental mode Rayleigh waves as a function of frequency were measured 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 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 of the mantle, which suggests that the upper mantle beneath the superswell is slower (i.e., that the upper mantle is hotter) than the area surrounding the superswell.

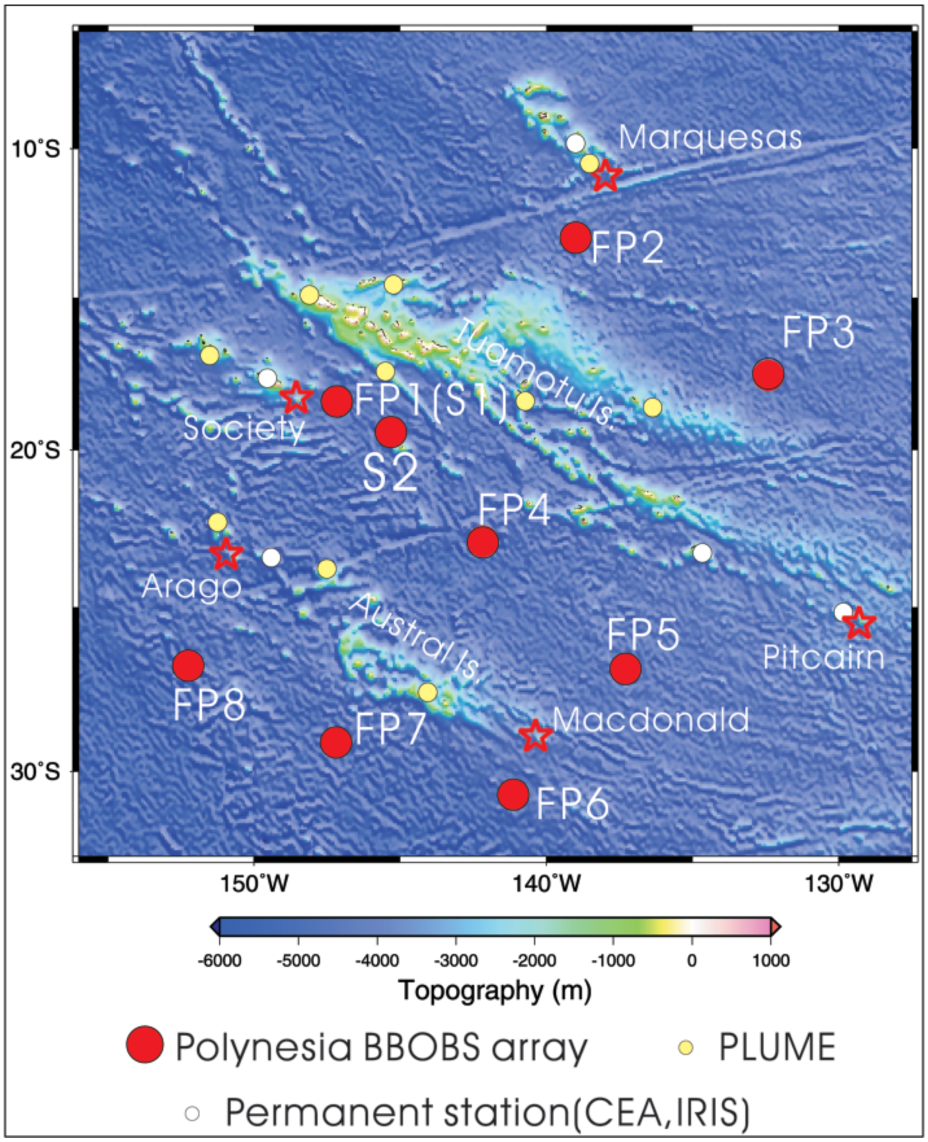

*Fig. 1. The Polynesia BBOBS stations (red circles) on a bathymetric map [*Jordahl et al., *2004]. The S1 site is located at the FP1 site but has a different observation period. The PLUME stations (yellow circles) and the permanent broadband stations of CEA and IRIS (white circles) are also shown. Red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

The project is now conducting an analysis of all of the data to create a three-dimensional shear wave velocity model to identify presumed mantle plumes. To study thermal structure in the mantle transition zone—a depth range from 400 to 700 km—the BBOBS data will be used to map topography on the mantle discontinuity. This should help to determine whether the origins of hot spots in the region are located in the upper mantle, in the transition zone, or in the lower mantle.

Acknowledgments

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Author Information

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, University of Tokyo, Tokyo; G. Barruol, Laboratoire de Tectonophysique, Centre National De La Recherche Scientifique, 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; E. Debayle, Ecole et Observatoire des Sciences de la Terre, CNRS, Université Louis Pasteur, Strasbourg, France.

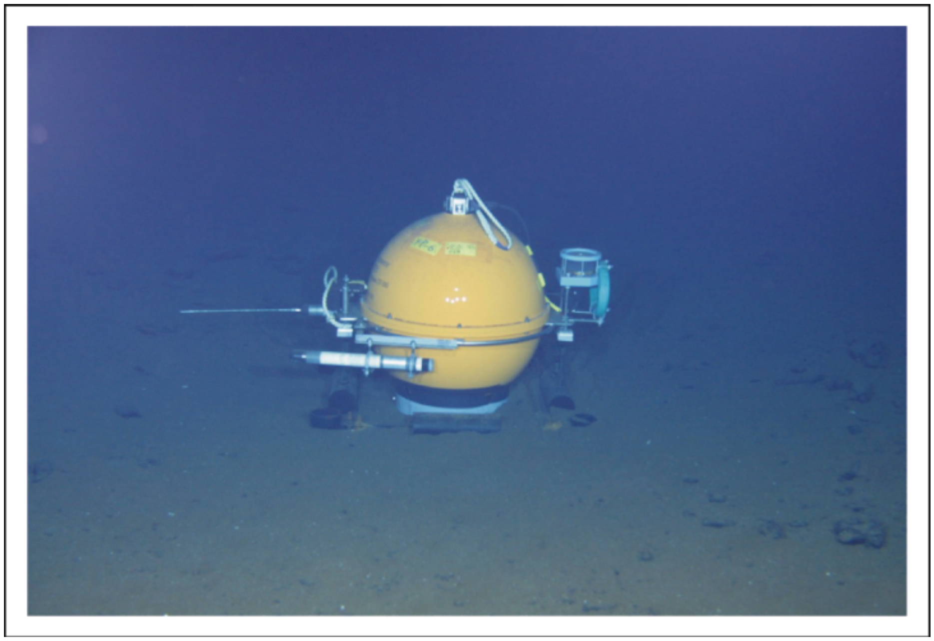

Fig. 2. The BBOBS on the seafloor at the FP6 station, which is 200 km south of the Macdonald hot spot at a depth of 4400 m.

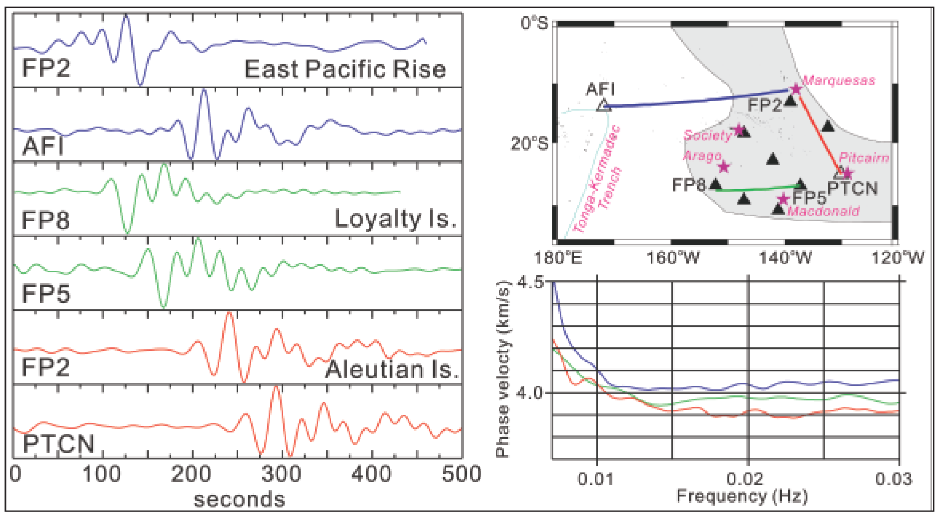

*Fig. 3. Examples of Rayleigh wave phase velocity measurements using the BBOBS data. (left) Three pairs of Rayleigh wave records from three earthquakes whose respective epicentral regions are noted in the figure. The AFI and PTCN stations are IRIS stations on islands. (top right) Rayleigh wave propagation 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. The BBOBS and IRIS stations are denoted by solid and open triangles, respectively, and hot spots are denoted by stars. (bottom right) The measured phase velocities from the three pairs of Rayleigh wave records. The three colors correspond to the three earthquakes throughout this figure.*