Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

SSS019-04 Room: 303 Time: May 23 16:15-16:30

Vertial seismic profiling at an ocean bottom riser hole in the rupture area of the 1944 Tonankai Earthquake, Japan

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A series of scientific drilling expeditions is in operation in the Nankai Trough to reveal the faulting mechanism of the magathrust earthquakes, through clarifying composition, fine structure, mechanical behavior, and environmental variables of the seismogenic faults. In the studied area, extensive seismic surveys for site characterization have been made to image detailed geometry of the fault complex in the accretionary prism as well as Vp distribution around the faults. Although these previous surveys provided invaluable information for understanding seismotectonic processes in this subduction zone, more complete knowledge is needed to be acquired to predict dynamic behavior of the faults, such as geometrical irregularities in short wavelength, Vs and seismic attenuation which are sensitive to fluid distribution in and around fault zones. It is expected that estimation of these parameters would be improved considerably by a seismic exploration using a vertical array of seismographs installed in a deep borehole (VSP: vertical seismic profiling). In July 2009, we made a VSP at one of the drilling sites located just above the rupture area of the 1994 Tonankai Earthquake (M 8.1), during the IODP Exp.319.

The well site of our VSP was made by the riser drilling of D/V Chikyu. The seismic array, lowered from Chikyu into the hole, was composed of a three-component accelerometer and vertical separation of the array elements was 15.12 m. The VSP was composed of offset VSP and zero-offset VSP. In the offset VSP, a tuned airgun array towed by R/V Kairei was shot along one straight line (walk-away VSP) and another circular line (walk-around VSP) and seismic signals were recorded by an array consisting of 16 elements installed from 907 to 1,135 m in depth from seafloor.

The object of the walk-away VSP is to obtain fine image of the faults using reflection arrivals with less attenuation. It is also expected to obtain spatial variation of Vs from arrival time tomography of refracted S waves. For this purpose, we preferred extraordinarily longer (~ 30 km) offset shooting than usual industrial VSPs. Shot spacing was 60 m along the same line as the previous 3 D reflection and OBS wide angle surveys. The radius of circle of the walk-around VSP was 3.5 km to detect azimuthal anisotropy of downgoing P and S waves, correlated to stress state around the site. In zero-offset VSP, shots just above the hole were recorded by the 8 element array moving from 0 to 1,135 mbsf along the hole so that seismic structure with comparable vertical resolution as core-log information would be obtained.

In the records of the walk-away VSP, clear first arrivals as well as several evident later arrivals were clearly identified. The travel times of the first arrivals can be well explained by the Vp structure model derived from the previous seismic surveys. After applying deconvolution and multiple suppression, the waveform records were prestack migrated using the velocity model to obtain the reflection image beneath the drill site. The VSP data contains frequency component up to ~ 40 Hz, giving us much finer images of the mega-splay fault and the top of the subducting oceanic basement. In the horizontal (radial) component records, there appear evident later arrivals with lower apparent velocity than those of reflected or refracted P phases. Assuming Vs model based on the Vp model with Vp/Vs of 1.73, the travel times of the phases can be explained as those of SS reflections from the mega-splay fault. The walk-around VSP also provided us with high S/N records. Travel time analysis of the first arrivals indicates that the basin sedimentary layer, surrounding the drill hole, shows significant azimuthal anisotropy of Vp. The amount of the anisotropy is estimated to be about 2 % and the fastest direction of P-wave propagation matched well with the direction of maximum horizontal stress derived from the borehole break out at the drill site.