Near-field observation of slow earthquakes in a subduction zone

Yoshihiro Ito[1] and Koichiro Obana[2]

1: Graduate School of Science, Tohoku University, 6-6, Aramaki-Aza-Aoba, Sendai 980-8578, Japan

E-mail: yito@aob.gp.tohoku.ac.jp

2: Institute for Research on Earth Evolution, Yokohama Institute for Earth Sciences, Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan

Abstract

Recently, small and moderate slow earthquakes have been detected by using an ocean-bottom-seismograph network, although the signals of these earthquakes have never been detected by the landward seismic network along the Nankai Trough. This suggests that slow earthquakes related to megathrust earthquakes occur at the updip portion of an asperity as well as at the downdip portion that corresponds to a transition zone from a coupled zone to an aseismic slip zone. It is important to understand the stress accumulation-release process in the seismogenic zone of a megathrust earthquake to understand the entire deformation process not only in a seismogenic zone but also in a slow-seismogenic zone, using seismological, geodetic, geological, and hydrological observations. We propose the development of a highly dense borehole observatory network for seismological, geodetic, and hydrological observations in the near-field of a seismogenic zone within the accretionary prism along the Nankai Trough.

Recently, various types of slow earthquakes such as non-volcanic tremors [*Obara*, 2002; *Rogers and Dragert*, 2003], very-low-frequency (VLF) earthquakes [*Obara and Ito*, 2005; *Ito et al.*, 2007], and short-term slow slips [*Dragert et al.*, 2001; *Obara and Hirose*, 2004] have been detected worldwide. High fluid pore pressure around both the updip and downdip portions of “slow-seismogenic zones” is estimated by seismic velocity tomography or by a seismic reflection survey.

VLF earthquakes have been extensively observed in the Nankai subduction zone using a highly dense landward broadband seismic network with horizontal intervals of 20–50 km. Shallow VLF earthquakes in the accretionary wedge are distributed at a depth of ~10 km above the upper surface of the subducting Philippine Sea Plate. The focal mechanism of VLF earthquakes indicates reverse faulting. Shallow

VLF earthquakes possibly occur due to the dynamic deformation of out-of-sequence thrusts or megasplay faults in an accretionary prism. In addition, shallow low-frequency (LF) earthquakes have been detected in the records obtained from an ocean-bottom-seismograph (OBS) network [*Sakai et al.*, 2007, *Obana*, 2008], although the signals of these earthquakes have never been detected by the landward seismic network. The hypocenters of these LF earthquakes, as calculated from the OBS network, are clearly distributed above the plate boundary [*Obana*, 2008] in the same manner as those of VLF earthquakes. These results suggest that it is important to permanently deploy highly dense OBS networks immediately above the source region, that is, in the near-field, in order to observe shallow LF earthquakes within the accretionary prism.

Megasplay faults generate a reverse-polarity reflection on seismic reflection profiles [*Park et al.*, 2002]; this may indicate the existence of an elevated fluid process in the fault zones [*Shipley et al.*, 1994]. Hydrotectonic phenomena corresponding to some LF seismic signals detected by ocean-bottom seismometers were first reported by *Brown et al.* (2005) using osmotically driven fluid flow meters (CAT meters); these meters were used to detect temporal changes in the rate of cold seepage of a shallow subduction system in the region of the Costa Rica subduction zone. These results suggest a possible model of slow earthquake generation related to fluid existence or fluid migration.

These slow earthquakes occur at both the downdip and updip portions of the asperity of megathrust earthquakes in the Nankai subduction zone. It is important to understand the stress accumulation-release process in the seismogenic zone of a megathrust earthquake to understand the entire deformation process not only in a seismogenic zone but also in a slow-seismogenic zone, using seismological, geodetic, geological, and hydrological observations.

Currently, the Pacific plate is subducting beneath Tohoku, northeast (NE) Japan, along the Japan Trench; the seismicity along this plate boundary is the highest in the world. An aseismic slip as a post-seismic slip has been observed after the occurrence of large earthquakes. Cold seeps near the trench are also distributed along the lineament of the thrust fault, which branches from plate boundary; this geometry is similar to that of the megasplay faults in the Nankai subduction zone. However, we had observed no non-volcanic tremors, VLF earthquakes, and short-term slow slips in NE Japan; this can be attributed to the low detectability of slow earthquakes above their source regions, although tsunami earthquakes, a type of slow earthquake, have also occurred near this trench. Recently, weak VLF signals have been detected using the landward seismic network; their sources were estimated to be off Tokachi near the Kuril-Japan Trench, although their depths and focal mechanisms were not estimated well because of both large hypocentral distances and low signal-to-noise ratio [*Asano et al.*, 2008]. These results suggest that we should make an allowance for the configuration of the seismic and geodetic network if we consider the existence of any type of slow earthquake.

Considering the previous results mentioned above, we propose the development of a highly dense borehole observatory network for seismological, geodetic, and hydrological observations by employing broadband seismometers, tiltmeters, strain meters, pressure gauges, fluid flow meters, etc., in the near-field of the slow-seismogenic zone within the accretionary prism, which is the source region of shallow LF and VLF earthquakes along the Nankai Trough. This may enable slow slip events to be observed because these events occur at the downdip portion of megathrust earthquakes along with LF and VLF earthquakes.

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