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Seismic structure off the Kii Peninsula, Japan, deduced from passive- and active-source seismographic data

Yojiro Yamamoto [a,*], Tsutomu Takahashi [a], Yuka Kaiho [a], Koichiro Obana [a], Ayako Nakanishi [a], Shuichi Kodaira [a], Yoshiyuki Kaneda [b]

[a] Japan Agency for Marine-Earth Science and Technology, 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan
[b] Kagawa University, Saiwaicho 1-1, Takamatsu, Kagawa, 760-8521, Japan

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A B S T R A C T

We conduct seismic tomography to model subsurface seismicity between 2010 and 2012 and structural heterogeneity off the Kii Peninsula, southwestern Japan, and to investigate their relationships with segmentation of the Nankai and Tonankai seismogenic zones of the Nankai Trough. In order to constrain both the shallow and deep structure of the offshore seismogenic segments, we use both active- and passive-source data recorded by both ocean-bottom seismometers and land seismic stations. The relocated microearthquakes indicate a lack of seismic activity in the Tonankai seismogenic segment off Kumano, whereas there was active intraslab seismicity in the Kii Channel area of the Nankai seismogenic segment. Based on comparisons among the distribution of seismicity, age, and spreading rate of the subducting Philippine Sea plate, and the slip-deficit distribution, we conclude that seismicity in the subducting slab under the Kii Channel region nucleated from structures in the Philippine Sea slab that pre-date subduction and that fluids released by dehydration are related to decreased interplate coupling of these intraslab earthquakes. Our velocity model clearly shows the areal extent of two key structures reported in previous 2-D active-source surveys: a high-velocity zone beneath Cape Shionomisaki and a subducted seamount off Cape Muroto, both of which are roughly circular and of 15–20 km radius. The epicenters of the 1944 Tonankai and 1946 Nankai earthquakes are near the edge of the high-velocity body beneath Cape Shionomisaki, suggesting that this anomalous structure is related to the nucleation of these two earthquakes. We identify several other high- and low-velocity zones immediately above the plate boundary in the Tonankai and Nankai seismogenic segments. In comparison with the slip-deficit model, some of the low-velocity zones appear to correspond to an area of strong coupling. Our observations suggest that, unlike the Japan Trench subduction zone, in our study area there is not a simple correspondence between areas of large coseismic slip or strong interplate coupling and areas of high velocity in the overriding plate.

1. Introduction

The Nankai Trough subduction zone is well known for repeated M 8 class mega-earthquakes, which have occurred at intervals of 100–150 yr (Ando, 1975). The four major seismogenic segments in this area sometimes rupture simultaneously and sometimes independently. The area off the Kii Peninsula is key to understanding the seismic behavior of these large earthquakes because it includes the boundary between two of the largest seismogenic segments in the subduction zone, the Tonankai and Nankai segments (Fig. 1; Baba and Cummins, 2005). The most recent mega-earthquakes in this region, the 1944 Tonankai (M_w 8.1) and 1946 Nankaido (M_w 8.3) earthquakes, occurred about 70 yr ago.

Subsurface structural heterogeneity might be a controlling factor for the segmentation of rupture zones in this region. Kodaira et al. (2006) inferred that high-velocity, high-density rocks beneath Cape Shionomisaki play an important role in the separation of ruptures in the Tonankai and Nankai seismogenic segments. The velocity anomaly they identified corresponds also to a Bouguer anomaly high identified by Honda and Kono (2005). A subducting seamount off Cape Muroto is also considered to inhibit rupture propagation in this area (Kodaira et al., 2000, 2002). The locations of the structural anomalies determined by these studies (Fig. 1)

* Corresponding author. Fax: +81 45 778 6439.
E-mail addresses: yamamotoy@jamstec.go.jp (Y. Yamamoto), ttaka@jamstec.go.jp (T. Takahashi), kaihoy@jamstec.go.jp (Y. Kaiho), obanak@jamstec.go.jp (K. Obana), ann@jamstec.go.jp (A. Nakanishi), kodaira@jamstec.go.jp (S. Kodaira), kanedaykg@cc.kagawa-u.ac.jp (Y. Kaneda).

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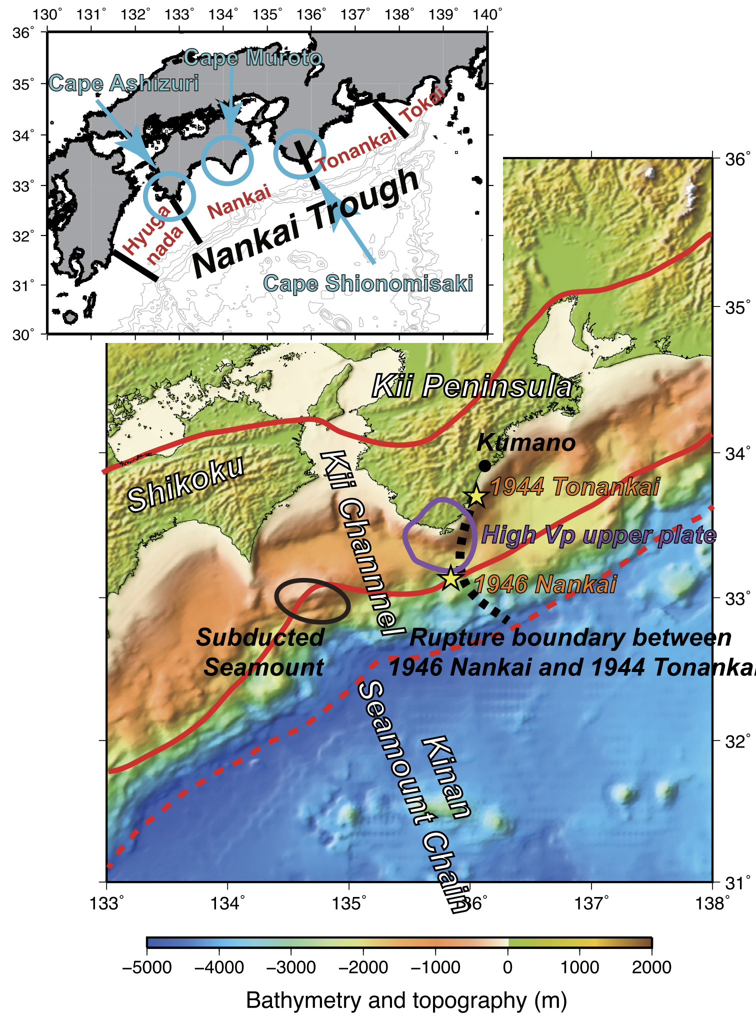

Fig. 1. Maps of study area. Inset regional map shows the seismogenic segments of the Nankai Trough in southwestern Japan. On the main bathymetric/topographic map, the two red lines delimit the Nankai Trough seismogenic zone and the dashed red line bounds the additional seaward area considered by the Japan Headquarters for Earthquake Research Promotion in 2013 to be potentially tsunamigenic. The high-velocity body identified beneath Cape Shionomisaki by Kodaira et al. (2006) and the subducted seamount identified off Cape Muroto by Kodaira et al. (2000) are also shown. The boundary between the Nankai and Tonankai ruptures is from Baba and Cummins (2005). Epicenters of the 1944 Tonankai and 1946 Nankai earthquakes are from Kanamori (1972). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

are based on 2-D active source data and are thus in need of refinement.

Microearthquake activity is an indicator of interplate coupling and structural heterogeneity. Several ocean-bottom seismograph (OBS) surveys have been conducted to attempt to improve our understanding of microearthquake activity in this offshore region. In the Tonankai seismogenic zone, Obana et al. (2004, 2005) detected active seismicity within the oceanic crust near the trough axis. In the Nankai seismogenic zone, Obana et al. (2003) defined the updip limit of the seismogenic zone and observed seismicity within the mantle of the uppermost slab near the subducted seamount identified by Kodaira et al. (2000). However, the areas covered by these studies are too narrow to allow meaningful investigation of the boundary between the Tonankai and Nankai seismogenic zones. On the basis of 4 yr of repetitive OBS observations in both the Nankai and Tonankai segments, Mochizuki et al. (2010) and Akuhara and Mochizuki (2014) established the extent of active seismicity within the oceanic crust and mantle in the area of the Kii Channel, but they used too few OBSs within the Tonankai segment to allow examination of the segment boundary.

Three-dimensional seismic tomographic data should clarify the areal extent of the structural heterogeneities described above, and also allow a detailed analysis of the spatial distribution of microseismicity. Recent seismic tomographic studies have not resolved these structural anomalies (Liu and Zhao, 2014), even though they used offshore observations (Akuhara et al., 2013). To obtain a structural image of higher resolution than those of previous studies, wider and denser OBS coverage is required.

From 2010 to 2012, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) conducted two phases of large-scale, long-term passive-source OBS experiments, one in the Kii Channel area and the other off Kumano. Each phase included short periods of recording active-source survey data. Combining the data from these surveys enables us to investigate the boundary between the Nankai and Tonankai segments and identify differences in the seismic activity within them. We used a 3-D velocity model and seismic tomographic modeling to clarify the patterns of microseismicity and the areal extent of structural heterogeneities in the study area and to consider their relationships with interplate coupling and the distribution of coseismic slip.

2. Data and analyses

The first phase of observations was from October 2010 to September 2011 in the Kii Channel area. We used 154 OBSs for short-term observations over two months and 19 OBSs for long-