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Seismicity and structural heterogeneities around the western Nankai Trough subduction zone, southwestern Japan

Yojiro Yamamoto [a,*], Koichiro Obana [a], Tsutomu Takahashi [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] Disaster Mitigation Research Center, Nagoya University, Furocho, Chikusa-ku, Nagoya, Aichi 4648601, Japan

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ABSTRACT

The Nankai and Hyuga-nada seismogenic segments, in the western part of the Nankai subduction zone off southwestern Japan, have sometimes ruptured separately and sometimes simultaneously. To investigate the relationships among heterogeneities of seismic structure, spatial variation of the incoming plate, and the seismogenic segments, we carried out seismic observations in the western Nankai subduction zone and modeled the area with 3D seismic tomography using both onshore and offshore seismic data. Our seismic observations suggested that the pattern of seismicity is related to heterogeneities within the subducted plate rather than the seismogenic segments. The up-dip depth limit of seismicity along the plate boundary and in the oceanic crust is typically around 15 km, corresponding to the depth of dehydration of the oceanic crust. In addition, the seaward-extended seismicity observed where the subducted plate was considered to have rough internal structures. In the resulting velocity model, the up-dip limit of the area where the P-wave velocity just above the plate boundary exceeds 6 km/s corresponds to the up-dip limit of coseismic slip in the 1968 Hyuga-nada and 1946 Nankai earthquakes. Between the two coseismic rupture zones is an area of lower P-wave velocity about 40 km wide that is evidence of lateral heterogeneities in the upper plate along the trough-parallel direction. Structural heterogeneities in the upper plate may explain the variety of coseismic slip patterns in this region.

1. Introduction

Southwestern Japan is in a subduction zone where the Philippine Sea plate is subducting northwestward beneath the Eurasia plate at about 5–6 cm/yr at the Nankai Trough (e.g., DeMets et al., 2010). In the Nankai Trough subduction zone, earthquakes rupturing the Tokai, Tonankai, and Nankai seismogenic segments have repeated at average intervals of 100–200 years, occurring sometimes separately and sometimes simultaneously (Ando, 1975) (Fig. 1). Structural heterogeneities are thought to underlie these complicated rupture processes (e.g., Kodaira et al., 2006).

In 2013, the assumed coseismic rupture area of the largest events in the Nankai Trough was extended westward across the whole Hyuga-nada region, to the end of the Nankai Trough, by the Headquarters for Earthquake Research Promotion (http://www.bousai.go.jp/jishin/nankai/taisaku_wg/index.html) on the basis of an update of its 2003 assumptions (Fig. 1). The Hyuga-nada segment, whose western end was at the Kyushu–Palau Ridge, appears to have ruptured simultaneously with the Nankai segment during the 1707 Hoei earthquake (Furumura et al., 2011). However, the coseismic slip area of the 1946 Nankai earthquake did not extend past Cape Ashizuri, which marks the western end of the Nankai segment (Baba and Cummins, 2005; Sagiya and Thatcher, 1999). These variations of historical coseismic behavior suggest that there are some seismological or structural heterogeneities between the Hyuga-nada and Nankai segments, but these heterogeneities are not well understood. In addition, there is some complexity in the incoming plate, represented for example by the Kinan Seamount Chain and the Kyushu–Palau Ridge. The subducted parts of these features have been seismically imaged as subducted seamounts (Kodaira et al., 2000) and a subducted ridge (Yamamoto et al., 2013), respectively. It is possible that these geometric heterogeneities are related to the seismic heterogeneity in this region.

To explore the segmentation and synchronization of seismic ruptures along the Nankai Trough subduction zone, the Japan Agency for Marine–Earth Science and Technology (JAMSTEC) has carried out wide-angle active-source surveys and local seismic observations. In this study, we used seismic tomography to

* Corresponding author. Tel.: +81-45-778-5468; fax: +81-45-778-6439.
E-mail addresses: yamamotoy@jamstec.go.jp (Y. Yamamoto), obanak@jamstec.go.jp (K. Obana), ttaka@jamstec.go.jp (T. Takahashi), ann@jamstec.go.jp (A. Nakanishi), kodaira@jamstec.go.jp (S. Kodaira), Kaneda.yoshiyuki@i.mbox.nagoya-u.ac.jp (Y. Kaneda).

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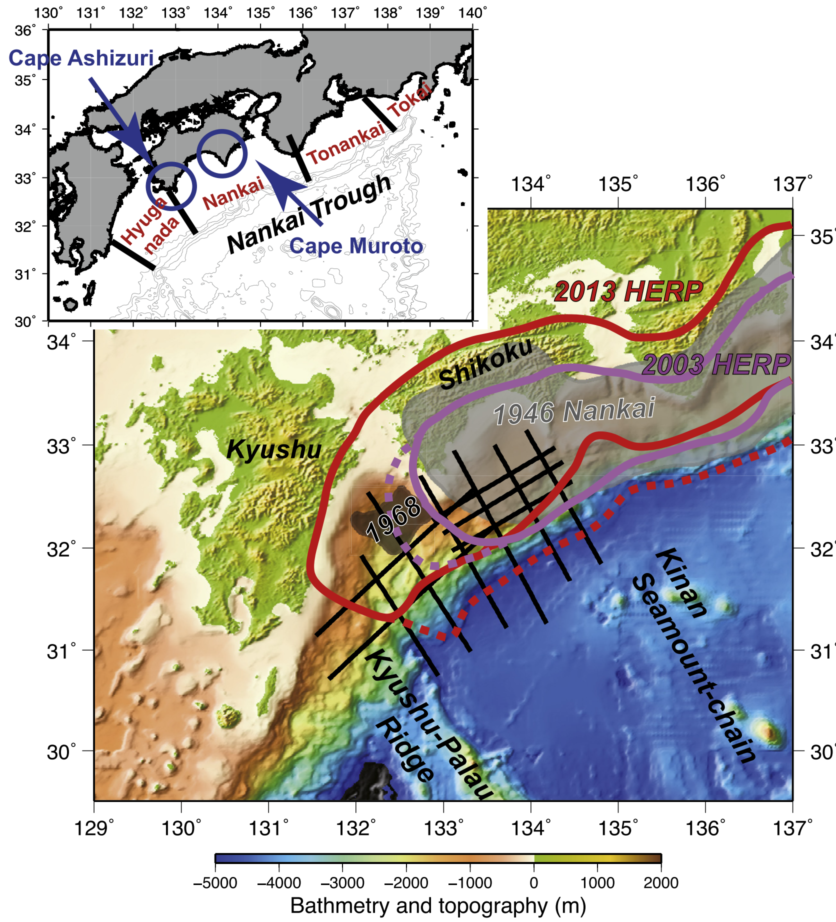

Fig. 1. Map of study area. Inset map shows the division of the Nankai Trough into seismogenic segments in southwestern Japan. Black lines are the survey lines used in this study. Gray regions are coseismic slip areas of the 1968 Hyuga-nada (Yagi et al., 1998) and 1946 Nankai earthquakes (Sagiya and Thatcher, 1999). Red and purple lines outline the area of the Nankai seismogenic zone specified by Headquarters for Earthquake Research Promotion (HERP) in 2013 and 2003, respectively. Red and purple dotted lines indicated the additional areas of tsunamigenic zones assumed in 2013 and 2003, respectively. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

investigate the spatial distribution and heterogeneities of the seismicity and seismic velocity structure from Hyuga-nada to the part of the Nankai segment off the island of Shikoku. In this paper we discuss the relationships among these heterogeneities, structural features of the incoming plate, and the coseismic slip distribution of past large earthquakes in the western Nankai Trough subduction zone.

2. Observations and data

JAMSTEC conducted active-source surveys and passive seismic observations using ocean bottom seismographs (OBSs) from 2008 to 2009 in the Hyuga-nada region (Yamamoto et al., 2013) and from 2009 to 2010 off Shikoku in the western part of the Nankai segment (Fig. 2 and Table 1). These observations were performed by *R/V Kairei* and *R/V Kaiyo* of JAMSTEC. During both campaigns, active-source surveys were done using a tuned airgun array deployed by *R/V Kairei* (7800 cu. in.) with shot intervals of 200 m.

In this study, we used a portion of the OBS data from Hyuga-nada and all available OBS data in the western Nankai region (Fig. 2). In addition to the OBS data, we used data from 102 land seismic stations operated by the National Research Institute for Earth Science and Disaster Prevention (NIED), the Japan Meteorological Agency (JMA), and several universities. These data are gathered by JMA in real time, and JMA publishes the earthquake list as the JMA catalogue. In sum, we used data from 330 OBSs and 102 land seismic stations.

The first arrival times at the OBSs were picked for the airgun shots of the same survey lines used for 2-D structural analyses (Nakanishi et al., 2010, 2011). As the number of active-source shots was too large for our analysis, we first restricted the data to shot points at 1 km intervals and then selected shot points with at least five first-arrival data. This yielded 1893 shots for analysis. Then, we added the arrival time data of airgun shots at land seismic stations that were near the coastline.

For the passive seismic data, we detected events by using the amplitudes of the OBS records. Then we picked the P- and S-wave first arrivals with a picking accuracy of 0.1 and 0.2 s, respectively, and checked the P-wave first-arrival polarities using the WIN system (Urabe and Tsukada, 1992). We also used arrival time data from the JMA catalogue when these were available. We then selected events for use in the tomographic inversion for which the azimuthal coverage had gaps of less than 180°, or for which the minimum epicentral distance was less than 30 km. As a result, we obtained 548 events from the Hyuga-nada segment and 256 events from the western Nankai segment.

Most of the earthquakes recorded by the OBS network occurred near or beneath the land seismic network. To obtain the precise location and velocity structure around these earthquakes, we added the 2870 JMA catalogue events, including 466 deep low-frequency earthquakes that occurred from 2008 to 2010 outside the periods of the OBS observations. According to the JMA catalogue, seismicity was less active in the eastern part of the study area than in the western part. To obtain homogeneous ray distributions, we used