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Widely distributed thrust and strike-slip faults within subducting oceanic crust in the Nankai Trough off the Kii Peninsula, Japan

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ABSTRACT

We identified widely distributed thrust and strike-slip faults within subducting oceanic crust in the Nankai Trough, southeast of the Kii Peninsula, Japan, on the basis of 2D and 3D seismic reflection data. The seafloor seaward of the trough axis is deformed by displacement on these intraoceanic reverse faults, producing topographic highs (part of Kashinosaki Knoll). Because the thrust faults extend to the Moho and offset the Moho reflection, they may be related to serpentinization of the mantle due to seawater invasion. These faults are seismically active, given that their geometries are consistent with the focal mechanisms of intraplate earthquakes and microearthquakes. The thrust faults appear to extend landward to a high-density dome within the accretionary prism off the Kii Peninsula. Because the dome and the associated thick accretionary prism are expected to generate high friction at the plate interface due to their large vertical load, the intraoceanic thrusts are likely to have grown with ongoing subduction. Furthermore, because the geometry of the fault system we identified off the Kii Peninsula has characteristics similar to faults at Zenisu Ridge east of our study area, the thrusts observed in the study area may be considered to be the westward continuation of those at Zenisu Ridge. Since the Euler rotation pole of relative motion between the Philippine Sea plate and Zenisu Ridge is consistent with the high-density dome off the Kii Peninsula, we interpret the high-density dome as well as Kashinosaki Knoll as a westward termination of the Zenisu compression zone.

1. Introduction

The Nankai Trough is a convergent margin where the Philippine Sea plate is subducting beneath southwest Japan. Because this subduction zone has repeatedly generated great earthquakes with Mw > 8 (Ando, 1975), seismic studies have been carried out over the entire Nankai Trough region (Fig. 1) (e.g., Moore et al., 1990; Park et al., 2002), as well as numerous drilling operations aimed at characterizing the accretionary prism and seismogenic mega-splay faults (e.g., Taira et al., 1991; Tobin et al., 2009). However, the role of subducting oceanic crust at this convergent margin remains poorly understood. On the eastern part of the Nankai Trough, the intraoceanic thrust and its relationship with the collision of Japan and the Izu–Bonin arc have been extensively studied (e.g. Lallemant et al., 1989; Le Pichon et al., 1987; Mazzotti et al., 1999, 2002). Active thrusting in the area off the Kii Peninsula has also been reported (Aoki et al., 1982; Lallemant et al., 1989; Le Pichon et al., 1987). However, because of the low resolution of seismic reflection data, the intraoceanic faulting system in the deep oceanic crust has not been fully revealed. This low resolution arises because signal attenuation and a broad Fresnel zone result in a dominantly low-frequency seismic signal within the deep oceanic crust (Yilmaz and Doherty, 2001).

Recent analyses of 3D seismic reflection data have revealed the presence of intraoceanic thrusts developed as imbricate structures within the subducting Philippine Sea plate off the Kii Peninsula (Tsuji et al., 2009; Fig. 2). Three-dimensional prestack depth-migrated seismic data have relatively high signal-to-noise ratio even in the deep oceanic crust, mainly because 3D geometrical effects can be taken into account during data processing (French, 1974). These intraoceanic thrusts are located around the hypocenters of the 2004 intraplate earthquakes off the Kii Peninsula ($M_w > 7$), and their geometry could explain the complex rupture pattern of the earthquakes (Tsuji et al., 2009). Therefore, the intraoceanic thrusts identified from 3D seismic data appear to be active.

In this study, we extracted the geometry of faults in the oceanic crust from dense multi-channel seismic reflection data. Intraoceanic thrusts identified previously from 3D seismic data (Tsuji et al., 2009) are limited to the area of the 3D seismic survey, whereas we determined the distribution of intraoceanic thrusts using 2D seismic data from more than 40 survey lines widely distributed in the Nankai Trough off the Kii Peninsula (Fig. 1). A comparison of the 2D and 3D seismic data (Fig. 3) enabled us to characterize and map intraoceanic thrusts from 2D seismic data. In this paper we discuss seismic activity on the intraoceanic thrusts and their origin.

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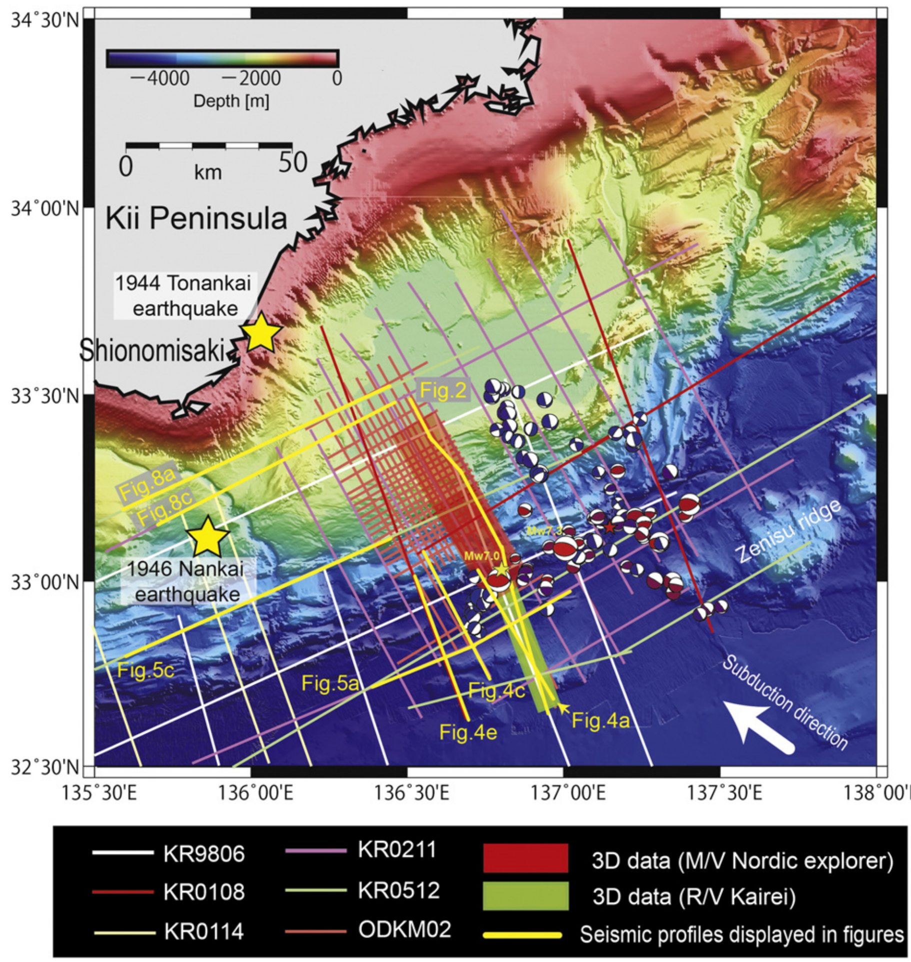

Fig. 1. Seafloor topography of the Nankai Trough region off the Kii Peninsula, showing locations of seismic reflection survey lines and the 3D seismic survey areas. Focal mechanisms and distribution of mainshocks and aftershocks of the 2004 off the Kii Peninsula earthquake (Ito et al., 2005) are also shown. Color of moment tensors indicates the Kagan's angle.

2. Seismic data

We used multi-channel seismic reflection data acquired by 3D seismic surveys as well as several 2D seismic surveys. Many seismic data have been acquired in the Nankai Trough off the Kii Peninsula, mainly by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), to map seismogenic faults of interplate earthquakes (i.e., plate boundary décollement and mega-splay faults) (Fig. 1). In this study, however, we focus on delineating intraplate structures using these seismic data.

Two 3D seismic reflection surveys have been performed in the Nankai Trough southeast of the Kii Peninsula. The first of these was on the landward side of the trough axis. The data were acquired by *M/V Nordic Explorer* in 2006 (Moore et al., 2009) and interpreted by Tsuji et al. (2009) as showing intraoceanic thrusts. The 12 × 56 km survey area includes a plate boundary décollement as well as a mega-splay fault within the thick accretionary prism. In this area, we can identify the fault system within the oceanic crust even beneath the accretionary prism. The second survey was by *R/V Kairei* in 2006 (Park et al., 2008) on the seaward side of the trough axis. The survey area of 3.5 × 52 km partially overlaps the area of the first 3D survey (Fig. 1), allowing us to integrate them both in a long (~100 km) seismic profile along the direction of plate subduction (Fig. 2). We applied 3D prestack depth migration to the 3D seismic data using a tomography-based approach (Fig. 2; Moore et al., 2009; Park et al., 2008). Strong seafloor multiples were attenuated before migration processing. For seismic velocities within the deep oceanic crust for prestack depth migration, we used P-wave velocity structures estimated by the wide-angle ocean-bottom seismograph study of Nakanishi et al. (2008).

To characterize intraoceanic thrusts of the wide area off the Kii Peninsula, we relied mainly on 2D seismic reflection data acquired around the area of the 3D seismic surveys (Figs. 4 and 5). We used the data from five multi-channel seismic reflection surveys conducted by *R/V Kairei*: KR9806, KR0108, KR0114, KR0211, and KR0512 (Fig. 1). These surveys employed an airgun array of ~200 L (12,000 in.^{3}) volume fired at 50 m intervals and a streamer ~5 km long with 204 receivers. We also used multi-channel reflection data acquired during cruise ODKM03 by *R/V Polar Princess* in 2003, which employed a tuned airgun array with a total volume of ~70 L (4240 in.^{3}) fired at 50 m intervals and a streamer 6 km long with 480 channels. Data processing for the 2D seismic reflection data involved filtering, velocity analysis, stacking, deconvolution, and post-stack migration (Yilmaz and Doherty, 2001). To extract fault planes from intersecting seismic reflection lines (using fence diagrams; Fig. 6), we did not apply depth conversion to the time-domain seismic profiles, because the seismic velocity was not accurately determined in the deep oceanic crust due to small moveout in the velocity analysis.

3. Results

3.1. Intraoceanic thrusts on seismic profiles

Seismic reflection data reveal that intraoceanic thrusts are widely distributed in the Nankai Trough southeast of the Kii Peninsula (Figs. 2–5).