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Subduction process of the Philippine Sea Plate off the Kanto district, central Japan, as revealed by plate structure and repeating earthquakes

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ABSTRACT

The structure of the Philippine Sea Plate in the offshore region adjacent to the Boso Peninsula in central Japan is resolved by comparison of recent oceanic seismic survey data with natural repeating earthquake data. This region is characterized by a range of seismic and aseismic phenomena associated with subduction motion of the Philippine Sea Plate, including slow slip events (SSEs), large backslip events, and repeating earthquakes. This offshore region is also the site of the largest aftershock of the 1923 Kanto earthquake (M7.9). The detailed structure of the Philippine Sea Plate is successfully resolved, and the upper boundary of plate is clearly traceable to depths of 20 km. The reflection intensity of the upper boundary varies spatially in accordance with the depth of the reflector. The upper boundary continues smoothly with a line of repeating earthquake hypocenters regarded as an indicator of subduction shear. A continuous model extending into the offshore region can thus be proposed. The variation in reflection intensity on the upper boundary of the Philippine Sea Plate also correlates well with variation in event types. A weak reflection zone overlaps the area of large backslip, while a moderately strong reflection zone encroaches into the large slip area of the Boso SSE. The reflectivity of the upper boundary is thus considered to be dependent on the physical properties and conditions of the reflector, which in turn affect the event types on the plate boundary. A source fault model is proposed for the largest aftershock of the 1923 Kanto earthquake. Based on geodetic data, the source fault is located eastward of the mainshock, with dimensions of 40 × 50 km and moment magnitude of 7.5. The source fault lies within the region of large backslip and the large slip area of the Boso SSE.

1. Introduction

In the vicinity of the Kanto region of central Japan, the Philippine Sea Plate (PHS) subducts beneath the Honshu island arc at the Sagami Trough, and the Pacific Plate (PAC) subducts beneath the PHS along the Japan Trench (Fig. 1) (Kasahara, 1985; Ishida, 1992; Matsubara et al., 2005; Sato et al., 2005). A variety of geodetic phenomena associated with PHS subduction has been observed off the Boso Peninsula in southeastern Kanto. Analysis of geodetic data reveals that slow slip events (SSEs) occurred in 1996, 2002, and 2007 off the Boso Peninsula (Ozawa et al., 2003; Sagiya, 2004; Sekine et al., 2007), while global positioning system (GPS) data indicate the presence of areas of large backslip in the southern Kanto region and offshore of the Boso Peninsula (Sagiya, 2004; Sagiya and Sato, 2005). Further inland, the seismic velocity structure has been imaged at high resolution by seismic tomography, and the configuration of the PHS and PAC has been determined with good accuracy (e.g., Matsubara et al., 2005). However, the accuracy of such analyses in the offshore region remains relatively poor, and the relationship between the observed phenomena and the plate structure remains unclear.

In addition to these aseismic phenomena, a seismic event (M7.6) occurred off the Boso Peninsula, in 1923 (Takemura, 2003). The event is the largest aftershock following to the 1923 Kanto earthquake ($M = 7.9$) on the subducting PHS (Kanamori, 1971; Matsu'ura and Iwasaki, 1983; Takemura, 2003). The largest aftershock produced larger ground motion than the mainshock, and triggered a large tsunami with a wave height of 1.5 to 1.8 m measured at Katsu'ura on the southeastern coast of the Boso Peninsula (Ishibashi, 1986). Although the source area is estimated to have been located off the Boso Peninsula, there remain many unresolved problems for this event.

Recently, numerous seismic surveys have shown that the reflection amplitude at the plate boundary correlates well with event types on the plate boundary (Fujie et al., 2002; Sato et al., 2005). It can reasonably be expected that different types of events on the plate boundary can be attributed to local differences in the physical state and/or material properties on the plate boundary, and these same differences are likely to cause differences in the reflection amplitude.

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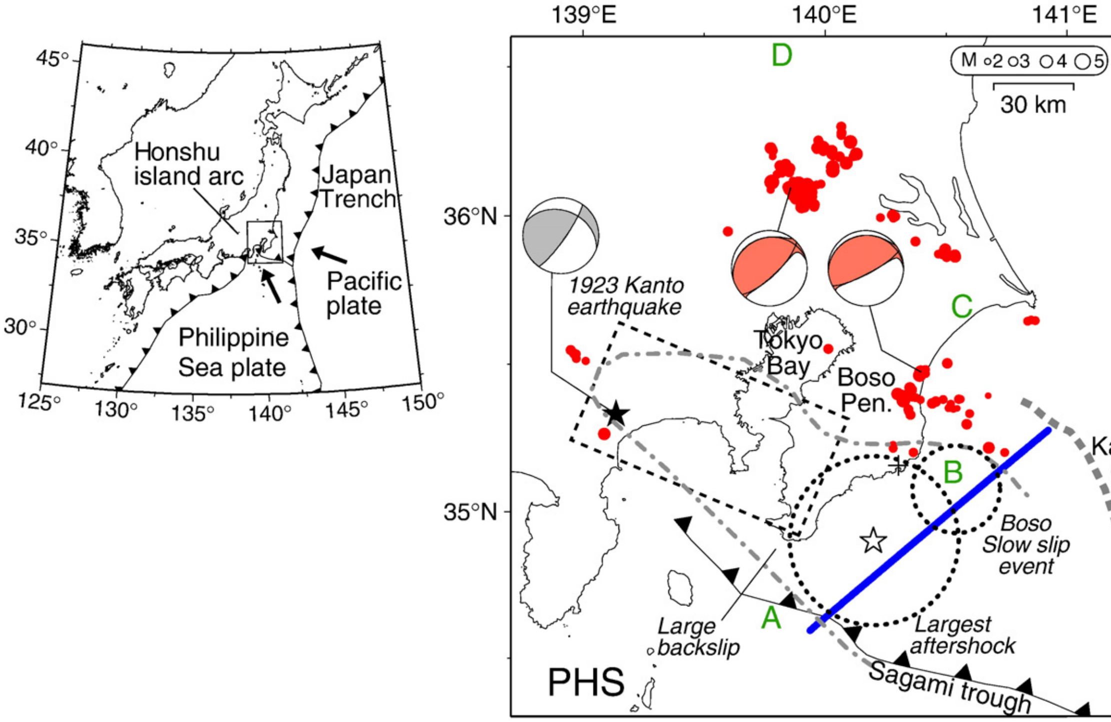

Fig. 1. (Left) Plate distributions around Japan. The Kanto region is indicated by a rectangle. Arrows denote the directions of plate motion relative to the Kanto region (Seno et al., 1996). (Right) Map of Kanto region. The seismic survey line is indicated in bold. Repeating earthquakes on the PHS are represented by small circles with typical moment tensor solutions (Kimura et al., 2006). The source fault, epicenter, and focal mechanism of the 1923 Kanto earthquake (Kanamori, 1971; Matsu'ura and Iwasaki, 1983; Takemura, 2003) and epicenter of the largest aftershock (open star; Takemura, 2003) are shown. The slow-slip area of the 2002 Boso SSE and large backslip area are plotted by dotted lines and dot-and-dash lines, respectively (Ozawa et al., 2003; Sagiya, 2004; Sagiya and Sato, 2005; Sekine et al., 2007). Katsu'ura City is indicated by a small cross.

Analysis of reflection intensity is therefore useful for characterizing the plate boundary structure.

This study reveals the PHS plate boundary configuration, including the spatial variation of reflection intensity, from deep seismic survey data and repeating natural earthquakes. Furthermore, we compare these results with various seismic and aseismic phenomena off the Boso Peninsula to reveal relation between plate structure and event types on the PHS. Based on these results, a source fault model for the largest aftershock is then estimated on the basis of crustal deformation data assuming that the largest aftershock occurred on the PHS.

2. Tectonic setting off the Boso Peninsula

2.1. Geodetic deformations

The deployment of a dense GPS network and high-sensitivity seismographic network including tiltmeters around Japan has lead to the detection of SSEs off the Boso Peninsula (Fig. 1) (Ozawa et al., 2003; Sagiya, 2004; Sekine et al., 2007). Analysis of these geodetic data indicates that SSEs occurred in 1996, 2002, and 2007 off the Boso Peninsula. The slip areas of these SSEs are largely coincident, and a characteristic silent earthquake model, in which silent earthquakes repeat at regular intervals on the same fault, has been suggested (Ozawa et al., 2003). Crustal tilt data suggests that the source fault of this latest SSE is in the same location as for the previous SSEs. Furthermore, the depth of the source is consistent with the configuration of the PHS determined by the localization of repeating earthquakes (Kimura et al., 2006; Sekine et al., 2007).

The backslip distribution determined by GPS analysis reveals two areas of large backslip, in southern Kanto, and off the Boso Peninsula (Fig. 1) (Sagiya, 2004; Sagiya and Sato, 2005). The backslip area in southern Kanto encompasses the source fault of the 1923 Kanto earthquake, while the backslip area off the Boso Peninsula includes the largest aftershock of the 1923 Kanto earthquake. The backslip area extends over the Sagami Trough fill basin determined in previous studies, indicating that the GPS-based delineation of the backslip area provides poor resolution in the offshore region (Fig. 1).

2.2. The largest aftershock of the 1923 Kanto earthquake

Through detailed study of the major aftershock sequence of the 1923 Kanto earthquake (M7.9), Takemura (2003) indicated that 6 major aftershocks ($M>7.0$) occurred. Immediately following the mainshock (within 1 h), 3 major aftershocks occurred beneath terrestrial Japan, followed by numerous M6-class events. After these events, a small number of aftershocks occurred over a short period, to be followed the next day by two major aftershocks in the offshore region adjacent to the Boso Peninsula. The offshore event off Katsu'ura was the largest of the aftershocks (Fig. 1), and is estimated to have been an M7.6 event (Takemura, 2003). This event produced larger ground motion than the mainshock and a tsunami with a wave height of 1.5 to 1.8 m at Katsu'ura (Ishibashi, 1986). The source fault of the largest aftershock has been estimated based on geodetic data using an existing plate configuration model of Sato et al. (2005) (Tabuchi et al., 2006). However, the plate structure off the Boso Peninsula includes substantial uncertainty, and the details of this aftershock event are not well resolved.

2.3. PHS plate structure and repeating earthquake

The Sagami Trough is generally regarded as a convergent plate boundary on the northern edge of the PHS. This interpretation of the Sagami Trough as a convergent plate boundary based on seafloor topography was confirmed by the observation of crustal structures at depths shallower than typical upper crust through reflection seismic