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The source fault of the 1983 Nihonkai–Chubu earthquake revealed by seismic imaging

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ABSTRACT

From 2011 to 2012, we conducted marine seismic surveys using a multichannel seismic reflection (MCS) system and ocean bottom seismometers (OBSs) in and around the hypocentral region of the 1983 Nihonkai–Chubu earthquake. The survey covered the area from the Japan coast of the Japan Sea to the Yamato Basin and the Japan Basin. We investigated the relationship between the Nihonkai–Chubu earthquake and the crustal structure obtained from seismic reflection imaging and the P-wave velocity structure near the hypocentral region. The focus in the present paper is on seismic data that were acquired using both the MCS system and OBSs. Based on the results, the crustal structure of the Japan Sea around the hypocentral region of the 1983 Nihonkai–Chubu earthquake is divided into three types: island arc crust, thick oceanic crust, and oceanic crust. The Nihonkai–Chubu earthquake occurred near the boundary between the thick oceanic crust and the island arc crust. There is a strong possibility that the east-dipping reflector detected in the crust was the source fault of the Nihonkai–Chubu earthquake. In addition, the location of anticlines formed by the east-dipping reverse fault occurring in the boundary of the crustal structure associated with the source fault of the Nihonkai–Chubu earthquake was confirmed in the range of latitude from 39°20′ to 41°15′N, although they were not found south of this segment. There is also a concentrated area of reverse faults and folds approximately 100 km west of the source region of the Nihonkai–Chubu earthquake. This area is located near the boundary between the thick oceanic crust and the oceanic crust.

1. Introduction

The Japan Sea is one of many back-arc basins in the western Pacific Ocean. The Japanese islands were broken off from the Eurasian Continent, and the Japan Sea was formed approximately 25–15 Ma (Jolivet and Tamaki, 1992). The Japan Sea, mainly in its eastern area, has been influenced by compressive stress field tectonics since approximately 3.5 Ma (Sato, 1994). In addition, reverse faults and anticlines in the eastern margin of the Japan Sea have been formed by inversion tectonics, and normal faults formed during the opening of the Japan Sea were reactivated by the opening of the Japan Sea in the compressive stress field (Okamura et al., 1995). Many of these structures are distributed into multiple belts along the eastern margin of the Japan Sea, and they have formed contractive deformation zones (Okamura, 2002; Okamura et al., 2007) (Fig. 1). The 1833 Shonai-oki earthquake (M7.5), 1964 Niigata earthquake (M7.5), 1983 Nihonkai–Chubu earthquake (M7.7), 1993 Hokkaido Nansei-oki earthquake (M7.8) and other destructive earthquakes over M7, triggered by reverse fault mechanisms, have occurred within these contractive deformation zones along the eastern margin of the Japan Sea (e.g., Ohtake, 1995, 2002). The Japan Sea is one of the most seismically active regions among the back-arc basins in the world.

Nakamura (1983) and Kobayashi (1983) have proposed that a nascent convergent plate boundary has formed in this region (Fig. 1). Based on bathymetry data, seismicity, focal mechanisms, and other information Nakamura (1983) has argued that the lithosphere of the Japan Sea started to subduct under the eastern margin of the Japan Sea since 1–2 Ma. Furthermore, Kobayashi (1983) has proposed that the eastern margin of the Japan Sea started to subduct after stress fields in northeastern Japan changed to compression.

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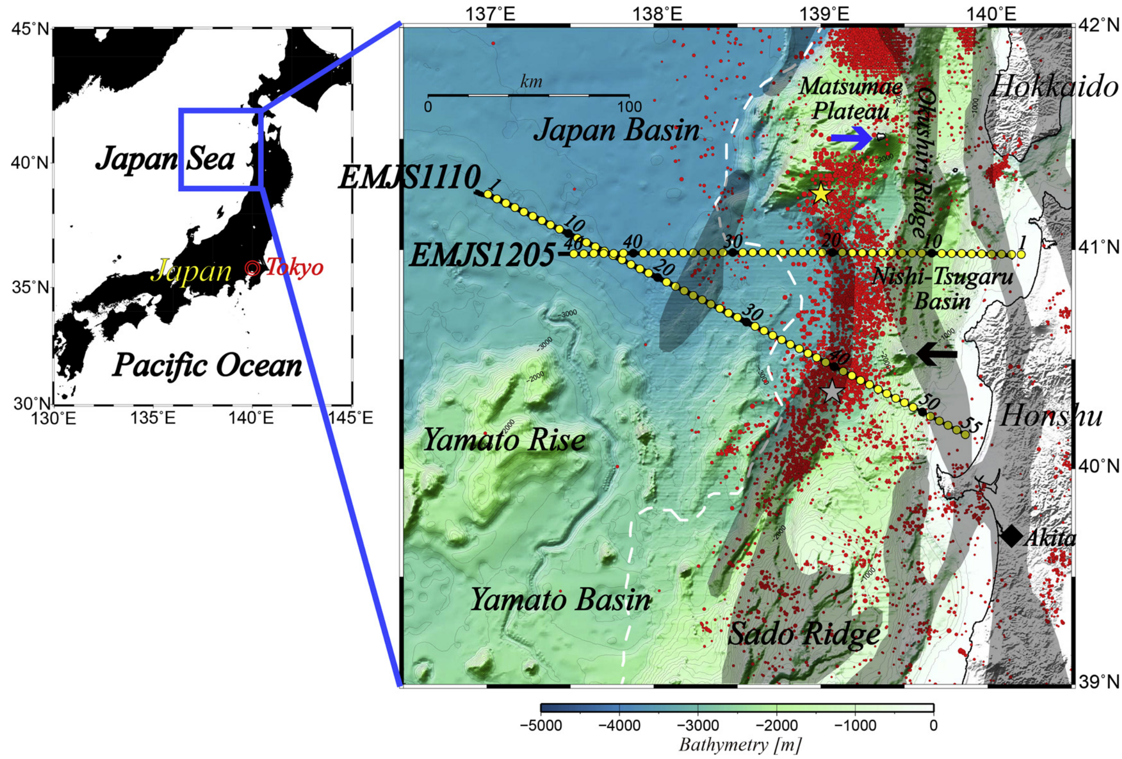

Fig. 1. Bathymetry and location maps of the survey area. Solid lines are MCS lines of the survey, and yellow and black circles are the positions of the OBS sites. Gray areas show the contractive deformation zones by Okamura et al. (2007). Red dots are the epicenters of earthquakes with $M \geq 2.0$ and depth ≤ 50 km from 1925–2011 (Japan Meteorological Agency, 2013). White dashed line shows a plate boundary proposed by Nakamura (1983). The black arrow indicates Kyuroku-jima. The blue arrow indicates Oshima–Oshima.

These hypotheses have influenced studies of the seismogenic zone and tsunamis in the Japan Sea. For example, based on the long-term evaluation of subduction-zone earthquakes by the Headquarters for Earthquake Research Promotion (2003), the entire region of the eastern margin of the Japan Sea was determined a region where large interplate earthquakes occur due to east-dipping reverse faults. However, observational data related to studies of earthquakes and tsunamis in the Japan Sea are very limited, and there is no conclusive evidence that the eastern margin of the Japan Sea is a plate boundary zone. As a result, there are different views on the subject of the plate boundary (Ohtake, 1995). Because crustal structure data on the seismogenic zone in the Japan Sea are especially limited, the relationship between crustal structure and seismogenic zones has not been adequately examined.

Among the large earthquakes that have occurred in the Japan Sea, the 1983 Nihonkai–Chubu earthquake was one of the largest along the plate boundary proposed by Nakamura (1983). The hypocentral region of this earthquake was located in a zone approximately 140 km in length striking a north–south trend along the contractive deformation zones of the eastern margin of the Japan Sea, offshore of the Akita Prefecture (Umino et al., 1985). The aftershock distribution changed near Kyuroku from a NE–SW direction in the southern segment to a NW–SE direction in the northern segment (Umino et al., 1985). Furthermore, based on the analysis of the aftershock distribution and focal mechanisms, the source fault of this earthquake was determined as an east-dipping reverse fault (Urabe et al., 1985; Sato, 1985). The main shock occurred with a hypocentral region in the south, and the largest aftershock (M7.1) occurred in the northernmost part of the hypocentral region. A M6.9 earthquake occurred in 1964 and a M6.4 earthquake occurred on the day after the 2011 Tohoku-oki Earthquake within the 1983 hypocentral region (e.g., Fukao and Furumoto, 1975; Hirose et al., 2011). This area is one of the most seismically active regions within the eastern margin of the Japan Sea. However, the relationship between this earthquake and the crustal structure is not very clear, because the amount of seismic exploration data is very limited.

In this paper, we describe the relationship between the Nihonkai–Chubu earthquake and the crustal structure, obtained from seismic reflection imaging and the P-wave velocity structure around the hypocentral region.

2. Data acquisition and processing

We conducted marine seismic surveys from 2011–2012 to study the crustal structure in and around the hypocentral region of the 1983 Nihonkai–Chubu earthquake (Fig. 1) (No et al., 2012; No and Kodaira, 2013). We used a multichannel seismic reflection (MCS) system and ocean bottom seismometers (OBSs) of the deep-sea research vessel Kairei from the Japan Agency for Marine–Earth Science and Technology (Miura, 2009). The survey covered the areas from the eastern coast of the Japan Sea to the northern Yamato Basin and the eastern half of Japan Basin. Because we discuss the relationship between the Nihonkai–Chubu earthquake and crustal structure, the present study focuses on the lines EMJS1205 and EMJS1110, which acquired seismic data using both MCS and OBSs (Fig. 1).

To obtain good-quality MCS data, we used an airgun array at a spacing of 50 m. This corresponds to a spacing of 20–30 s, depending on the vessel speed (average 3.5–5 kn). The tuned airgun array has a maximum volume of 7800 cubic inches (approximately 130 l), and consists of 32 airguns. The standard air pressure was 2000 psi (approximately 14 MPa). The airgun array was kept at a depth of 10 m below the sea surface throughout the experiment. During the airgun shooting, we towed a 444-channel hydrophone streamer cable. The interval of each group was 12.5 m and the length of the cable was approximately 6 km. The towing depth of the streamer cable was maintained at 12 m below the sea