

Wide-angle ocean bottom seismographic study in the western Nankai Trough: Initial report of KAIREI KR97-04

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The Nankai trough, southwestern Japan, is recognized as a vigorous seismogenic zone with well studied large underthrust earthquakes. This paper presents results of wide-angle ocean-bottom seismographs (OBS) study at the western Nankai Trough seismogenic zone. The OBS data used were acquired on a profile (250 km long) across a presumed co-seismic slip zone of the 1946 Nankaido earthquake ($M_s=8.2$). The main purpose of our seismic study is to map a structure the entire area of the seismogenic zone by the 1946 earthquake. The crustal model is characterized by gentle slope of subducting oceanic crust and thick sedimentary wedge (9 km thick at 70 km from the trough axis). The subducting oceanic crust traced down to 25 km depth shows that a subduction angle becomes steeper toward the land: 3.2° and 7.2° at 0–50 km and 50–100 km from the trough axis, respectively. From the results of the crustal model, it is emphasis that the down-dip limit of the co-seismic slip area does not reach at the landward end of the oceanic crust–island arc crust contact zone. The crustal model also clearly indicates that the up-dip limit of the co-seismic slip zone extent beneath the accretionary sediments.

Keywords : Nankai Trough, seismogenic zone, crustal structure, ocean-bottom seismograph, subduction.

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1. Introduction

The Nankai Trough, southwestern Japan (Fig. 1), is one of the best subduction zone for studying the mechanisms of large inter-plate underthrust earthquakes, since historic large earthquakes in the Nankai Trough have been well documented since 7th (e.g., Ando 1975): the recurrence interval between those events is estimated at 100–200 years (e.g., Ando 1975), and the last large events occurred in 1944 and 1946 at the central part and western part of the Nankai Trough, respectively (e.g., Kanamori 1972). The underthrust earthquakes are commonly recognized to be generated repeatedly at certain portion of a plate contact zone (e.g., Tichelaar and Ruff 1993), which is called a seismogenic zone. The present paper focuses on a structure of the seismogenic zone at the western Nankai Trough.

little is known about a nature of the earthquake mechanisms at the seismogenic zones. In order to understand the seismogenic zone, several fundamental question are arose, for example, 1) a physical nature of plate contact surface, 2) a temporal relationship between stress, strain and pore fluid composition through the earthquake cycle, 3) factors to control updip and downdip limit of the underthrust events and 4) mass flux throughout the seismogenic zone (MARGINS steering committee 1998). Even though multidisciplinary study consisting of geophysical, geochemical and geological study must be necessary to address the questions above, an image of the entire seismogenic zone including subducting oceanic lithosphere and island arc crust would provide the most fundamental and important information. Crustal and deep sedimentary structure has been obtained since 1960s in the western Nankai Trough, little study has imaged entire area of the Nankai Trough seismogenic zone, from the trough axis to the coast line of the Shikoku Is. For example Moore et al. (1990) showed high quality multichannel seismic reflection data. Their data clearly imaged thrust faults cutting from a decollement to seafloor. But their profile only limited around a deformation front. Several refraction and wide-angle reflection data have been also acquired in the Nankai Trough (e.g., Yoshii et al., 1973; Kinoshita and Matsuda 1989; Nishizawa and Suyehiro 1989). Those studies have obtained velocity structures at only a shallow area (Yoshii et al., 1973) and restricted around the trough axis (Kinoshita and Matsuda 1989).

This paper present a crustal and uppermost mantle structure across the entire seismogenic zone in the western Nankai Trough by mainly use of wide-angle Ocean-Bottom Seismographic (OBS) data. The OBS profile (Fig. 2) has been selected crossing the proposed co-seismic slip region of the 1946 Nankaido Earthquake (Ando 1982) and a presumed locked zone estimated by geothermal data (Hyndman et al. 1995). The main purpose of this study was to image the structure from the western Nankai Trough to the Shikoku Island. In this paper we also discusses spatial relationship among our obtained structure, proposed co-seismic and locked regions and present day seismicity.

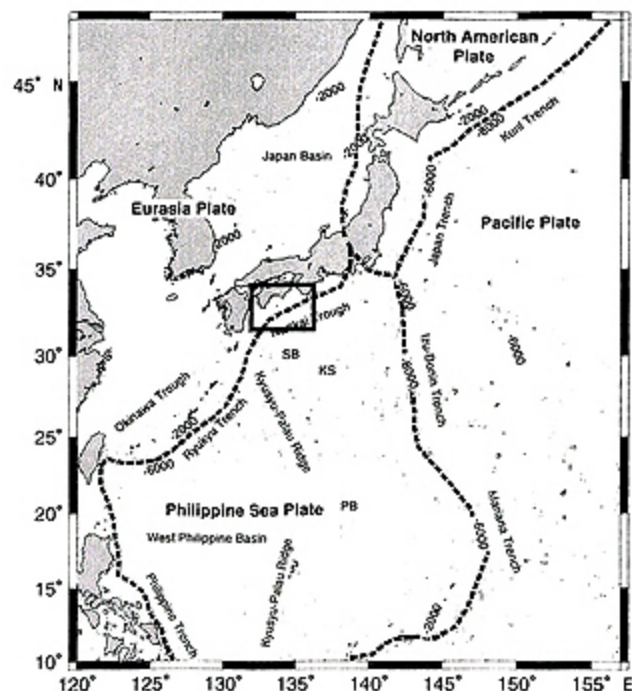


Fig. 1 Map around Japan. Thick broken lines indicate plate boundary. A framed area represents a survey area, the western Nankai Trough, of this study. The Philippine Sea Plate is subducting beneath the Eurasia Plate toward northwest. SB, Shikoku Basin; KS, Kuroshio Sea Mounts; PB, Parece Vera Basin.

It is believed that understanding of the seismogenic zone provides fundamental scientific knowledge and societal importance, particularly around the Japanese subduction zone which is located only 100–200 km off from highly populated regions. In spite of this recognition,

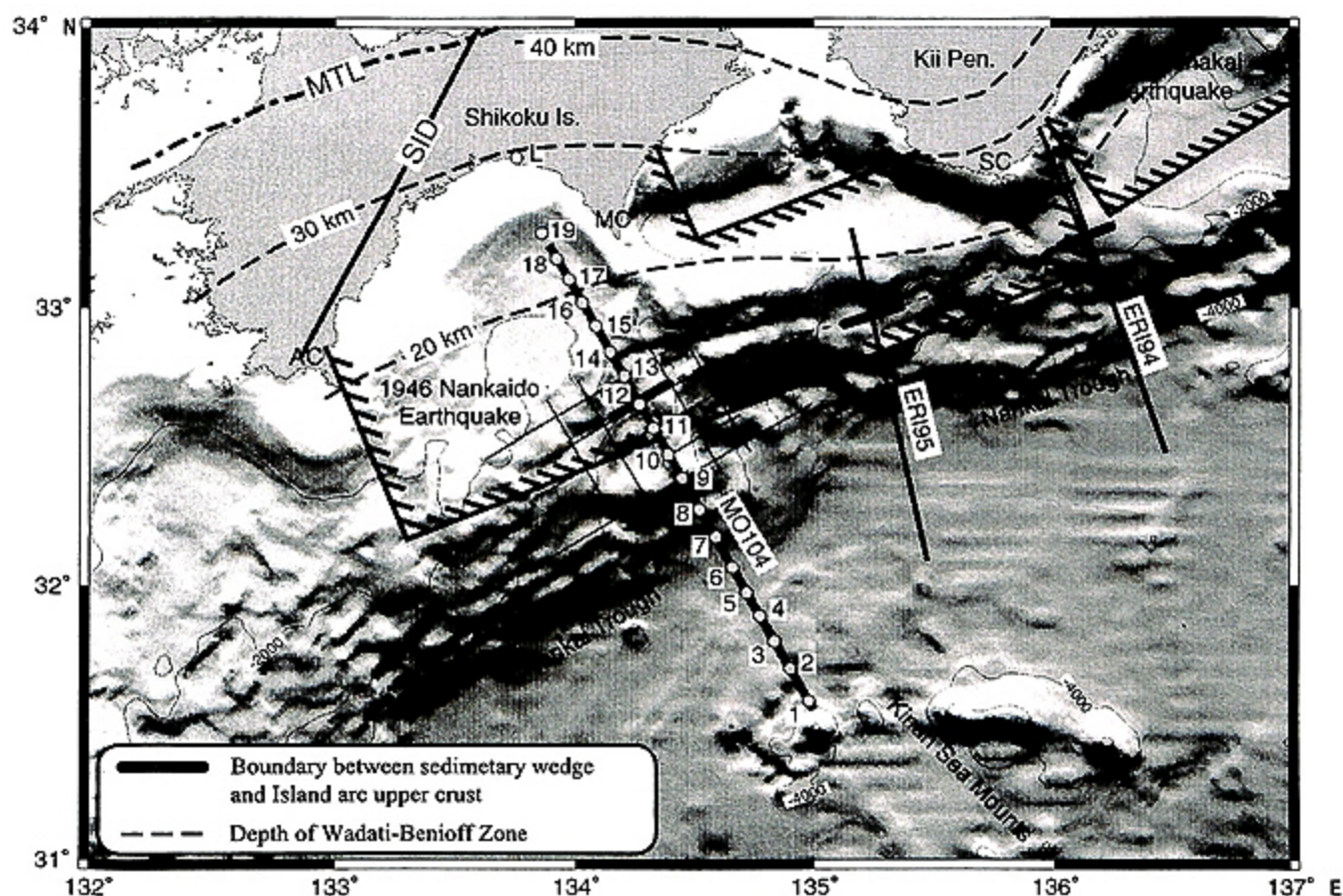


Fig. 2 Survey area with an OBS profile. The wide-angle OBS data used were acquired along MO104. Circles with numbers indicate OBS positions. Multichannel seismic reflection (MCS) data were acquired along thin lines and a part of MO104 from OBS1 to OBS13. ERI94 and ERI95 indicate previously obtained OBS profiles (Nishisaka et al., 1997). SID indicates a profile of land wide-angle survey (Ikami et al., 1982). Thick broken lines represent iso-depth contour of the Wadati-Benioff zone (after Hyndman et al., 1995). Rectangular areas show co-seismic slip areas of the 1944 Tonankai Earthquake ($M_s=8.2$) and the 1946 Nankaido Earthquake ($M_s=8.2$) (after Ando 1982; Hyndman et al., 1995). SC, Shiono-misaki cape; MC, Muroto-misaki cape; AC, Ashizuri-misaki cape; MTL, Median Tectonic Line.

2. Data acquisition and modeling procedure

In June–July/1997, Japan Marine Science & Technology Center (JAMSTEC), in cooperation with universities of Tokyo, Chiba and Kochi, Japan, performed an extensive geophysical experiment at the western Nankai Trough, off SW Japan (Figure 1), across the presumed co-seismic slip area of the 1946 earthquake (Ando, 1982). The wide-angle OBS data, as well as multichannel reflection data, modeled in this study have been acquired by JAMSTEC's R/V KAIREI, as a part of this experiment. The wide-angle OBS data were acquired along a 250 km long profile (Figure 2) including a land station which was located in extension of air-gun shot line, and a total of 19 OBSs were deployed with 10–15 km intervals on the profile. The multichannel reflection data were also acquired using 120 ch streamer (ca. 3,000m), on a part of the wide-angle OBS profile, from

OBS 1 to OBS 13 (Figure 2). An air gun array with total volume of 4,000 cubic inches (ca. 68 L) was fired every 50 m on the multichannel reflection profile, while shooting interval was 100 m on wide-angle OBS profile to reduce noise generated by direct water wave of previous shots. The OBS used is designed by Shinohara et al. (1993), which is digital recorder version of an OBS originally designed by Kanazawa and Shiobara (1994). The OBS have three-component gimbal-mounted geophones (4.5 Hz) and a hydrophone. The digital recorder includes a 16-bit A/D converter and store data on 4 ch with 100 Hz continuously for 17 days. Wide-angle OBS data were only processed with minimum-phase band-pass filter (5–20 Hz) to reduce ambient noise and trace mixing with adjoining two traces resulting 200 m shot spacing.

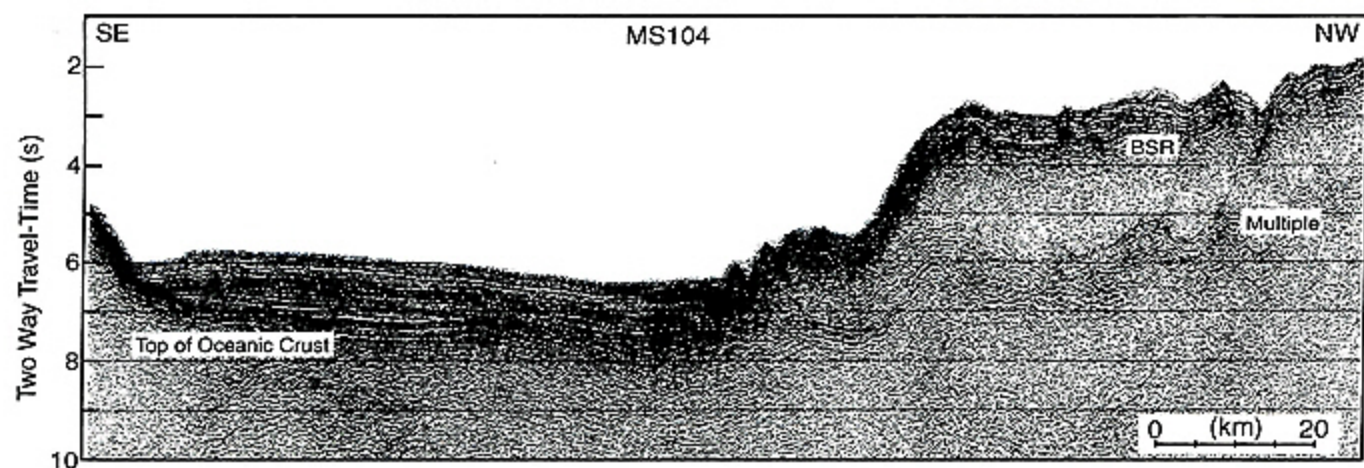


Fig. 3 Time-migrated MCS section acquired between OBS1 and OBS13 on MO104 (after Park *et al.*, 1998). BSR, Bottom Simulated Reflector indicating existence of methane hydrate. Geometry of the top of the oceanic crust is used for making a deep crustal model by the OBS data.

The shallow structure down to the top of the oceanic crust between OBS1 and OBS9 was obtained by simplified version of the multichannel reflection data (Figure 3). The wide-angle OBS data provide the subducting oceanic crust and overlying accretionary sediments by using the two-dimensional travel time inversion method of Zelt and Smith (1992) together with forward kinematic and dynamic modeling (Zelt and Ellis 1988). This inversion is performed in a layer stripping fashion, where the parameters of successively deeper layers are determined whilst the parameters defining the shallower layers remain fixed. First arrivals and reflection travel times observed on the OBSs were digitized with uncertainties depending on signal to noise ratios (0.1–0.3 s). Both the velocities (top and bottom in each layer) and geometry of the crustal models were derived using these observed travel times. In order to obtain good resolution in the deeper part of the subducting oceanic crust (oceanic layer 3), the velocities and geometry of the oceanic layer 3 and the Moho were inverted simultaneously using refraction and Moho reflection phases (PmP).

3. Seismic data

3-1 Multichannel reflection data

Figure 3 shows the multichannel reflection section processed by Park *et al.* (1998). The section clearly images sedimentary layer at the trough, shallow part of the accretionary sediments, a bottom simulated reflector

and the top of the subducting oceanic crust up to OBS9. Immediately land side of the trough axis several faults can be recognized in the accretionary sediments. Those are probably related to the accretion process of the sediments (Park *et al.*, 1998). The deeper structure below the top of the oceanic crust and the top of oceanic crust at the land side of OBS9 are not well imaged.

3-2 Wide-angle data

The wide-angle OBS data were acquired at the all OBSs except for OBS8, 16 and 18. Those three OBSs record no data due to a mechanical problem. Data quality was excellent on the OBSs (OBS1–7) located oceanic side of the trough, rather poor on the OBS9–17, and good on the two stations at the northern end of the profile (OBS19 and the land station). The poor data quality might be attributed to high attenuation or scattering in sedimentary layers. The similar pattern on the data quality is recognized on OBS data acquired at the middle part of the Nankai Trough, off the Kii peninsula (Nishisaka *et al.*, 1997). Sample record sections of the OBSs and the land station are shown in Figures 4–6.

Characters of seismic arrivals are also classified into three patterns. The record sections of the OBSs on the trough show simple four principal phases, which are interpreted as refraction arrivals from oceanic layer 2, 3, upper most mantle and wide-angle reflection from Moho. For example, in Figure 4, the refraction from the oceanic layer 2 and 3 are identified at 7–15 km offsets and 15–30 km offsets,

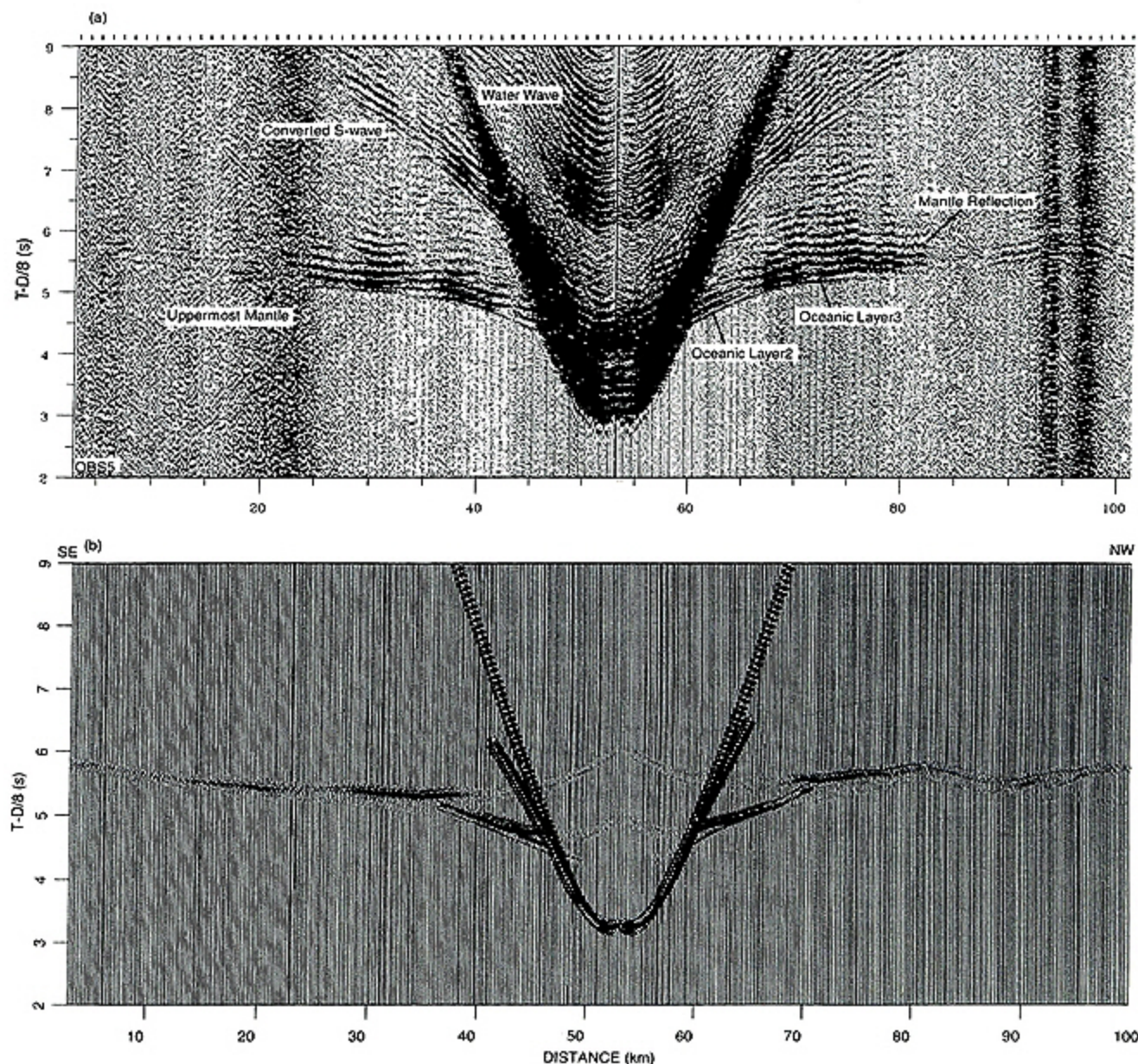


Fig. 4 observed wide-angle OBS recorded on the vertical component of OBS 5.5–20 Hz bandpass filter and amplitudes are scaled proportional to the square root of offsets. Calculated travel time curves from the final crustal model are superimposed on the observed data. The reduction velocity is 8 km/s. The horizontal axis represents the distance from the southwestern end of the profile (Fig. 2). (b) Ray theoretical synthetic seismograms of OBS 5 calculated from the final crustal model.

respectively. And also low amplitude first arrivals observed farther than 30 km offset and high amplitude later arrivals observed from 15 km offset are interpreted as the uppermost mantle refraction and the Moho reflection. A simple layered oceanic structure oceanic side of the trough would be inferred by those arrivals. It is noticed that clear converted share wave arrivals are also recognized on the OBSs at oceanic side of the trough. This might be attributed to high impedance gap between the sedimentary layer and

the top of the oceanic crust (e.g., Kodaira *et al.* 1996a).

Record sections of OBS9–17 shows significantly different character compared with the data on the OBSs at the oceanic side of the trough. The record section of those OBSs are characterized by lower apparent velocity (3–5 km/s) phases recognized up to 20–40 km offset and a high amplitude later phase whose intercept times are 5–7 s in reduced travel time (Figure 6). Those significant differences are interpreted to be strongly reflected to a

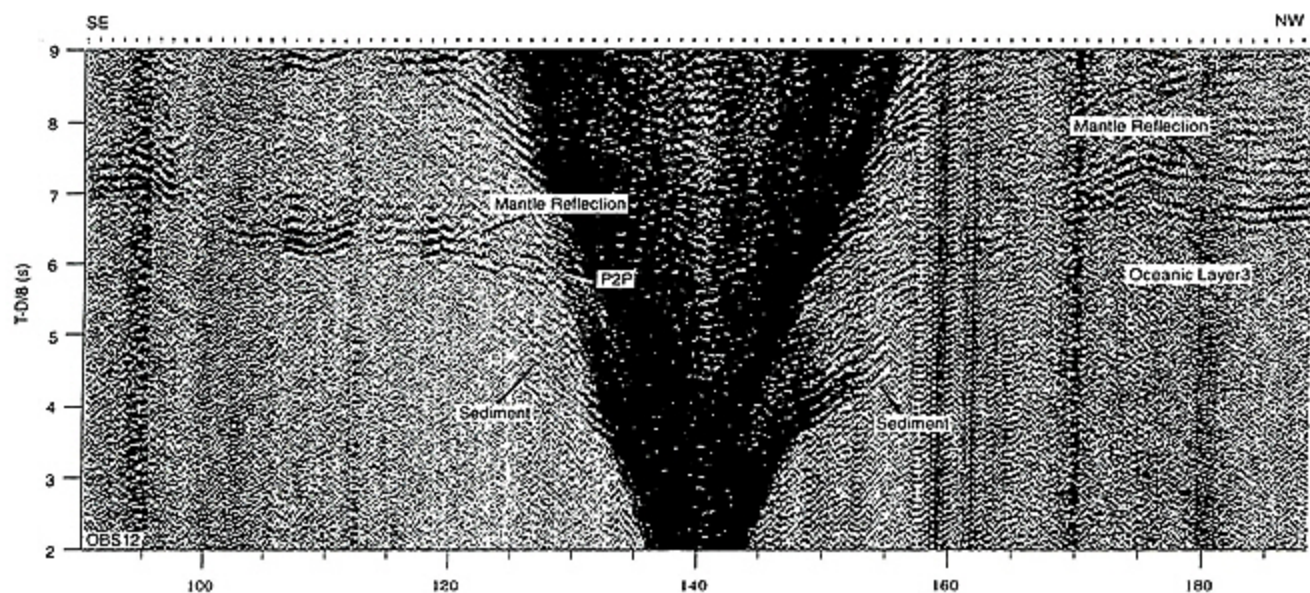


Fig. 5 Observed wide-angle OBS recorded on the vertical component of OBS 12. 5–20 Hz bandpass filter and amplitudes are scaled proportional to the square root of offsets. Calculated travel time curves from the final crustal model are superimposed on the observed data. The reduction velocity is 8 km/s. The horizontal axis represents the distance from the southwestern end of the profile (Fig. 2). P2P, reflection phase from the top of oceanic layer 2.

sub-bottom structure rather than water depth change. For example, since the multichannel reflection data show the thick sedimentary layers in this area (Figure 3), the observed low apparent velocity phases were interpreted as refraction phases from the sedimentary layers. The high amplitude later phases were interpreted the wide-angle reflection phases from the bottom of the subducting oceanic crust. Several previous OBS studies performed at the Nankai Trough and the Ryukyu Trench (Iwasaki *et al.*, 1989; Nakanish *et al.*, 1994; Kodaira *et al.*, 1996b; Nishisaka *et al.*, 1997) show similar high amplitude later arrivals which were modeled as wide-angle reflection phases from the subducting Moho. The data on OBS19 and the land station shows another character. As shown in Figure 6, the land station notably shows intra-crustal reflection phases, PcP and PiP on Figure 11, 1–1.5s before the Moho reflection.

4. Crustal model and Discussion

A crustal model along the wide-angle OBS profile is shown in Fig. 7. We modeled the wide-angle data recorded on 16 OBSs and one land station. In the following section, we describe the models with dividing into three parts on the basis of characteristics of the structure: i.e. from the Shikoku basin to the Nankai Trough, an accretionary

prism and an island arc crust. Detailed description of resolution and geological interpretation of the model are fully described by Kodaira *et al.* (in preparation).

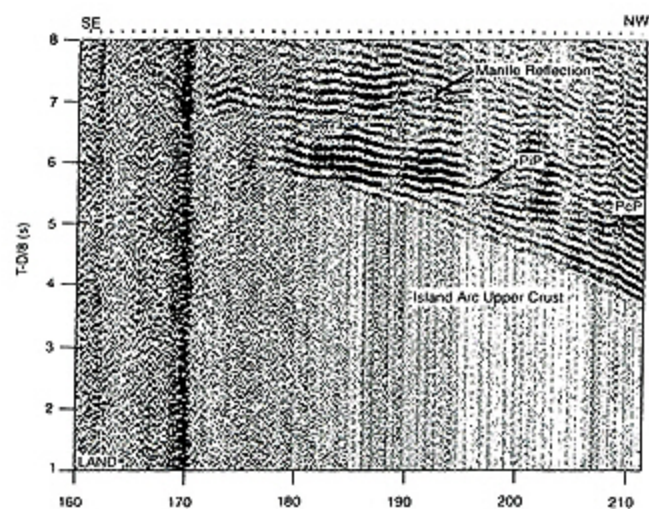


Fig. 6 Observed wide-angle recorded on the vertical component of the land station. 5–20 Hz bandpass filter and amplitudes are scaled proportional to the square root of offsets. Calculated travel time curves from the final crustal model are superimposed on the observed data. The reduction velocity is 8 km/s. The horizontal axis represents the distance from the southwestern end of the profile (Fig. 2). PcP wide-angle reflection phase from a boundary between the island arc upper and lower crust; PiP, wide-angle reflection phase from deep crustal reflector in the island arc lower crust.

4.1 Shikoku basin to Nankai trough

The structure at the Shikoku basin to the Nankai Trough, that is between OBS1 and OBS7, shows a simple layered oceanic crust. The model consists of three layers, which are interpreted to be a sedimentary layer, oceanic layer 2 and 3 due to their thickness and velocities. As mentioned above the geometry of the top of the oceanic crust is digitized from the MCS data acquired during the survey. The velocities in the sedimentary layer (1.6–2.4 km/s) are obtained from the wide-angle OBS data; i.e., intercept times of the crustal refraction arrivals. The estimated velocities show good agreement with a velocity analysis of MCS data (Park *et al.*, 1998). It is underlined that the velocity and velocity gradient are varied laterally around OBS7. This position corresponds to the location of a deformation front interpreted from previous MCS data (Moore *et al.*, 1990). Deformation within the sedimentary sequence is also recognized at the landside of OBS7 in the MCS data along the profile (Park *et al.*, 1998).

The igneous oceanic crust we obtained shows slightly different character from normal igneous oceanic crust as

described in the following. The model indicates the velocity of the oceanic layer 2 and 3 of $V_p=5.0$ – 5.6 km/s and $V_p=6.6$ – 6.8 km/s, respectively. Those values are within mean velocities of the oceanic layer 2 ($V_p=2.5$ – 6.6 km/s) and layer 3 ($V_p=6.6$ – 6.8 km/s) (White *et al.*, 1992), except beneath OBS5 where the model shows slightly slower velocity in the oceanic layer 3. White *et al.* (1992) carefully compiled large number of seismic refraction results, they then concluded that the igneous section of normal oceanic crust averages 7.1 ± 0.8 km thick. The oceanic crust presented in this study at the northern Shikoku basin shows 5.3–6.3 km thick, which is thinner than the average thickness. The similar thin oceanic crust has been obtained off the Kii peninsula, where is 100–150 km northeast of our profile. Recently acquired wide-angle OBS data provided 5.2–5.7 thick igneous crust at the central Nankai Trough off the Kii Peninsula (Nishisaka *et al.*, 1997). The previous refraction studies (Yoshii *et al.*, 1973; Nishizawa and Suyehiro 1989) also showed thinner oceanic crust (> 6.2 km) at the Nankai trough, although their structures have been obtained 2 ship refraction study

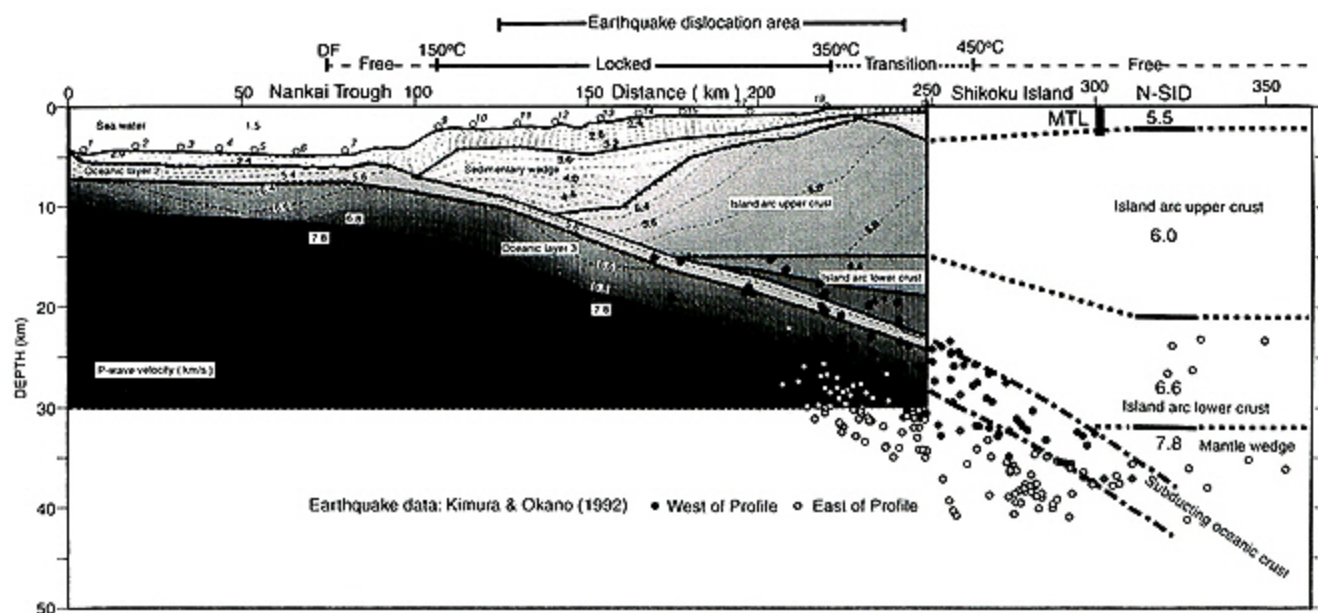


Fig. 7 The P-wave velocity model. The horizontal axis indicates the distance from the southwestern end of the profile (Fig. 2). The numbers represent P-wave velocities (km/s) at the top and bottom of the layers. The italic numbers represent the OBSs. The iso-velocity contour interval is 0.2 km/s. Hypocenter distributions (Kimura and Okano, 1992) and a result from a land refraction survey (Ikami *et al.*, 1982) are superimposed. N-SID indicate one-dimensional version of the crustal structure at the northern part of SID profile (Ikami *et al.*, 1982) showing in Fig. 2. Earthquake dislocation area estimated by tsunami and geodetic data of the 1946 earthquake. Free, Locked and Transition area represent presumed zones of stable-sliding, stick-slip and transition from stick-slip to stable-sliding zone on the top of the oceanic crust, respectively. 150°C, 350°C and 450°C indicate critical temperatures between those zones (Hyndman *et al.*, 1995). MTL, Median Tectonic Line; DF, deformation front.

and sparsely deployed OBS. It might thus mention here that the northern part of the Shikoku basin would consist of the thin igneous oceanic crust rather than normal oceanic crust, which is proposed by *White et al.* (1992). The velocity of the uppermost mantle of 7.8 km/s (Fig. 7) is inverted from clearly identified the refraction arrivals (e.g. Fig. 4). The same velocity value has been obtained at the central Nankai Trough off the Kii Peninsula (*Nishisaka et al.*, 1997).

4.2 Sedimentary wedge and subducting oceanic crust

The structure of the central part of the profile, between OBS7 and OBS15, is characterized by a thick sedimentary wedge and subducting oceanic crust (Fig. 7). The model indicates that the sedimentary wedge consists of two layers; i.e. $V_p=1.8-3.2$ km/s layer and $V_p=3.4-4.6$ km/s layer. The thickness of the upper layer does not varied significantly between OBS 9–15, while the second layer shows a wedge shape. The maximum thickness of the second layer is about 7 km thick at 70 km landward of the trough axis, where a total thickness of the two sedimentary layers is consequently 9 km thick. *Nishisaka et al.* (1997) also found a similar thick sedimentary wedge (8 km thick) at the central Nankai Trough off the Kii peninsula. The thickest point in their model, which is located more seaward than that in our model (40 km from the trough axis). Similar thick sedimentary wedges are found at the eastern Nankai Trough; 10 km at 50 km away from the axis (*Nakanishi et al.*, 1994). Moreover, larger scale of the sedimentary wedges is recognized in the Ryukyu trench, which is situated at the northwestern edge of the Philippine Sea plate as southern continuation of the Nankai Trough. *Iwasaki et al.* (1990) found a sedimentary wedge with 12 km thick at 100 km from the trench axis. *Kodaira et al.* (1996b) also shows a 10 km thick wedge at the central part of the Ryukyu Trench.

We found the landward dipping oceanic crust underlying the sedimentary wedge (Fig. 7). The oceanic crust can be traced down to 25 km by using the observed wide-angle reflection arrivals from the Moho. No significant structural variation is recognized in the oceanic crust through the entire model: the thickness and velocities does not changed significantly with subducting beneath the

Shikoku Island, even through the velocities in the oceanic layer 2 does not resolved well beneath the sedimentary wedge as described below.

The model clearly shows that the subduction angle becomes steep toward the land: 3.2° at 0–50 km from OBS7, while 7.2° at 50–100 km from OBS7. The subduction angle farther than 100 km from OBS7 is as steep as that at 50–100 km from OBS7 with a little undulation. Those subduction angles are calculated from the shape of the top of oceanic layer 3, since it is resolved better than the other interfaces. Several previous seismological studies revealed a lateral variation of the subduction angle along the Nankai Trough on the basis of hypocenter distributions associating with the subduction of the Philippine Sea plate (e.g., *Shiono* 1988; *Kimura and Okano* 1994; *Nakamura et al.*, 1997). Although those studies mainly mentioned the earthquakes deeper than 20 km depth due to no seismological station at shallow part (i.e., off shore area), the subduction angle they obtained is the steepest beneath the Kii peninsula and become shallower toward both sides along the Nankai Trough. Crustal studies, including this study and *Nishisaka et al.* (1997), shows that the lateral variation of the subduction angle is probably exist even shallower than 20 km. The crustal model obtained by *Nishisaka et al.* (1997) indicates the angle of subducting oceanic crust of 9.5° only at 40 km from the trough axis. This value represents remarkably steep compared with our obtained angle at 0–50 km from OBS7 (3.2°).

4.3 Island arc crust

At the landward of the sedimentary wedge, we found crustal blocks, which become thicker toward the Shikoku Island (Fig. 7). The model indicates the velocity of the upper part of the block of 5.4–5.8 km/s and that becomes faster toward the Shikoku Island. A previous refraction study on shore of the Shikoku Island (*Ikami et al.*, 1982) has obtained a layer with velocity of 6.0 km/s at the upper part of the crust (0–20 km depth). Our obtained velocity and its lateral velocity change seem to smoothly continue the structure of the Shikoku Island. We thus interpret the 5.4–5.8 km/s-layer as the Japan island arc upper crust. Several previous wide-angle OBS study obtained similar structure at the landward of the sedimentary wedge at the eastern and central Nankai Trough (*Nakanishi et al.*, 1994, *Nishisaka et*

et al., 1997; *Nakanishi et al.*, 1998) and the Ryukyu Trench (*Iwasaki et al.* 1990, *Kodaira et al.* 1996b): i.e., velocities of 5.4–5.8 km/s and wedge shaped crustal body between a sedimentary wedge and subducting oceanic crust.

We did not obtain precise information below the island arc upper crust due to no landward extension of the profile. Two intra-crustal reflection phases are, however, observed at OBS19 and the land station. In particular the two reflection phases are clearly identified on the record section of the land station (PiP and PcP in Fig. 6). Depths of the two reflectors for PiP and PcP (Fig. 7) was inverted assuming the lower crustal velocities of 6.4 and 6.7 km/s by referring *Ikami et al.* (1982) and *Kimura and Okano* (1991).

4.4 Up-dip and down-dip limit of the seismogenic zone

We discuss a spatial relation between our obtained structure and presumed seismogenic zones in this section: i.e. the co-seismic slip zone of the 1946 earthquakes (*Ando*, 1975; *Aida*, 1981; *Ando*, 1982; *Hyndman et al.*, 1995) and the locked zone estimated by thermal data (*Hyndman et al.*, 1995) which is shown on the top of Fig. 7. *Ando* (1975) and *Ando* (1982) defined coseismic slip zone by using the tsunami and geodetic data, while *Hyndman et al.* (1995) defined the interseismic locked zone from the geothermal data and confirmed it by the geodetic data. *Hyndman and Wang* (1993) concluded that the zone of stick-slip locked behavior may be limited between a temperature of 150–350°C and that the transition stable sliding zone can extend by a temperature of 450°C.

Ando (1982) and *Hyndman et al.* (1995) mentioned that the landward limit of the zones, which are situated at the landward end of our model, with small uncertainty: e.g., *Hyndman et al.* (1995) estimated the uncertainty less than 15 km. As shown in Fig. 7, the landward end of our model does not seem to reach the landward end of the oceanic/island-arc crust contact zone, which is probably located beneath the Median Tectonic Line. If the co-seismic slip or/and locked zones are accepted as the seismogenic zone, it could be therefore concluded that the landward end of the Nankai Trough Seismogenic Zone does not extend to the oceanic/island-arc crust contact zone but to the depth of 20–25 km along the oceanic crust beneath the Island arc crust. On the other hand, recently *Kimura and Okano*

(1998) proposed that the source region of the 1946 earthquake extend to the Median Tectonic Line based on the recent study of micro-earthquakes. This means the Seismogenic Zone could extend in the entire area of the oceanic/island-arc crust contact zone, because our model in Fig. 7 suggests that the Median Tectonic Line is located near the landward end of the contact zone. There is, however, one problem with *Kimura and Okano's* result. A number of authors suggested that the downdip behavior of a fault zone must change from brittle to ductile above some critical temperature (e.g., *Savage and Plafker* 1991; *Savage and Thatcher*, 1992; *Tichelaar and Ruff*, 1993; *Hyndman and Wang*, 1993). Laboratory data for common crustal rocks indicate a maximum temperatures for brittle deformation of crustal rocks of about 350°C (e.g., *Tse and Rice*, 1986; *Blanpied et al.*, 1991; *Hyndman et al.*, 1995). According to this critical temperature, the temperature beneath the Median Tectonic Line is estimated too high to generate earthquakes at the oceanic/island-arc crust contact zone. The earthquakes beneath the Median Tectonic Line must occur in the mantle rock in which earthquakes can occur to about 800°C. The earthquakes plotted in Fig. 7 must located in the mantle, and we should therefore accept the data with open circle in Fig. 7 as the earthquakes occurred beneath our model.

The seaward end of the two zones shows 15–20 km differences in Fig. 7. As described by *Hyndman et al.* (1995), however, the seaward end is only poorly constrained by the land geodetic data, but the two zones are consistent with the both seaward end extending to a few tens of kilometers from the trough axis, where is beneath the accretionary sediments. *Hyndman and Wang* (1993) and *Hyndman et al.* (1995) defined the lower critical temperature for stick-slip (locked) behavior as temperature of 150°C on the basis of dehydration of clays. If we adopt their discussion concerning the dehydration, it could be concluded from our model that the dehydration which is enough to change behavior of the sedimentary rocks from stable-sliding to stick-slip has been already occurred at 8–10 km depth in the base of the accretionary prism.

5. Conclusions

In this paper we present the detailed crustal and uppermost mantle structure across the seismogenic zone

in the western Nankai Trough obtained by wide-angle OBS data. Well documented historical record clearly shows that large earthquakes have occurred repeatedly in the Nankai Trough with a recurrent interval of 100–200 years. Understanding of the Nankai Trough seismogenic zone is thus considered to be a societal/scientifically important and urgent issue, since it has been already passed more than 50 years since the last large earthquake (the 1946 Nankaido earthquake). The OBS data were acquired along a dip profile (250 km long), which was designed to cross a presumed co-seismic slip zone of the 1946 earthquake ($M_s = 8.2$). A total 19 OBSs and a land station were deployed and a total volume of ca. 68 liter air-gun array has been fired at every 100 m. Multichannel seismic reflection data were also acquired on a part of the profile. The wide-angle OBS data were modeled by use of the two-dimensional travel time inversion method together with forward kinematic and dynamic modeling.

The crustal structure we obtained is characterized by the subducting oceanic crust and the thick sedimentary wedge. The oceanic crust at the western Nankai Trough shows a normal velocity values in the oceanic layer 2 ($V_p = 5.0$ – 5.6 km/s) and layer 3 ($V_p = 6.6$ – 6.8 km/s), but slightly thinner (5.3–6.3 km thick) than a mean thickness of the normal oceanic crust (7.1 ± 0.8 km thick). Several previous studies also found similar thin oceanic crust at the central and western Nankai Trough. The model does not indicate any significant velocity and thickness variation in the subducting oceanic crust, which are well resolved up to 100 km landward from the trough. The subducting oceanic Moho can be traced down to 25 km depth by using wide-angle Moho reflection phases. The subduction angle becomes steeper toward the land: 3.2° and 7.2° at 0–50 km and 50–100 km from the deepest part of the trough, respectively. Our obtained oceanic crust is smoothly continued to the hypocenter distributions, which are determined down to 40 km depth beneath the Shikoku Island. We found a thick sedimentary wedge overlaying the subducting oceanic crust. The model indicates that the sedimentary wedge consists of two layers ($V_p = 1.8$ – 3.2 km/s and $V_p = 3.4$ – 4.6 km/s). The maximum thickness of the wedge is 9 km thick at the 70 km landward from the trough. Similar thick sedimentary wedges are widely observed along the eastern to western

Nankai Trough and the Ryukyu trench. Between the sedimentary wedge and the subducting oceanic crust, the data from the OBS and the land station provide a crustal body, which becomes thicker toward land. This crustal body is interpreted as an island arc upper crust on the basis of its velocity ($V_p = 5.4$ – 5.8 km/s). Two clear wide-angle reflection phases are also observed at the land station, and intra-crustal reflectors are obtained from those phases at 15 and 17.5 km depth.

By comparing a presumed co-seismic slip and locked area with the crustal transect consisting of our model, it is emphasized that the down-dip limit of the co-seismic slip or locked area does not reach at the landward end of the oceanic crust – (island arc crust contact zone. Even though there is large uncertainty of the seaward limit of the co-seismic slip and locked zone, the crustal model clearly indicates that the up-dip limit of the co-seismic slip and locked zone extent beneath the sedimentary wedge.

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