Article

Seismic reflection survey across the central part of the Arima-Takatsuki Tectonic Line, Kinki District, Central Japan

Shigeru TODA[1], Shigehiro KATOH[2], Fumio KOBAYASHI[2], Toshiyuki KAGAWA[3], Hiroshi YOKOTA[3], Koichi NAKAGAWA[4], Keiji TAKEMURA[5] and Atsumasa OKADA[5]

[1]*Department of Earth Sciences, Faculty of Education, Aichi University of Education. Hirosawa 1, Igaya-cho, Kariya, Aichi, 448-0001 Japan.*
[2]*Division of Earth Sciences, Museum of Nature and Human Activities, Hyogo, Yayoigaoka 6, Sanda, 669-1546 Japan.*
[3]*Hanshin Consultants Co.Ltd. 2-5-4 Nishihonmachi, Nishi-ku, Osaka, 550-0005 Japan.*
[4]*Department of Geosciences, Faculty of Science, Osaka City University, Sugimoto-cho 3-3-138, Sumiyoshi-ku, Osaka, 558-0022 Japan.*
[5]*Division of Earth and Planetary Science, Graduate School of Science, Kyoto University, Kitashirakawa-oiwake-cho, Sakyo-ku, Kyoto, 606-8224 Japan.*

Abstract

The subsurface structure in the northern Osaka Plain was revealed by a seismic reflection survey along the Ina River in Kinki District, Central Japan. The sediments were divided into four seismic layers (A to D), and they were compared with the stratigraphic units of the deep drilling cores of OD-5, B1, and B2. The A layer includes the Alluvium, terrace deposits, and the Osaka Group Upper Subgroup. The B, C, and D layers are the Osaka Group Middle Subgroup, the Osaka Group Lower Subgroup, and the underlying basement rocks, respectively. Our survey also revealed the subsurface features of the Arima-Takatsuki Tectonic Line, active faults forming the Hanayashiki and Koyaike grabens, and the Itami fault, confirming the eastern extensions of these faults. Among the four active faults, the subsurface characteristics of the Koyaike graben and the Itami fault differ markedly from their surface expressions. The Koyaike graben is a narrow depression with no clear vertical displacement of the Itami terrace across it, but has dislocated the boundary between the Osaka Group and the basement rocks by approximately 230 m. In contrast, the Itami fault appeared as the flexure of reflectors on the seismic section, although it has clearly displaced the surface and deposits of the terrace. On the basis of these subsurface features and the Quaternary tectonic history of the northern Osaka Plain, we concluded the generation of the Itami fault since the latest Middle Pleistocene in association with the change in dominant faulting mode along the Koyaike graben from vertical to lateral.

Key Words: Seismic reflection survey, Arima-Takatsuki Tectonic Line, Hanayashiki graben, Koyaike graben, Itami fault, Osaka Plain

Introduction

During the 1995 Hyogo-ken Nanbu Earthquake (Mj 7.2), surface fault ruptures have appeared in northern Awaji Island (e.g., Nakata et al., 1995; Lin et al., 1995; Ota et al., 1995). The aftershock distribution (Nemoto et al., 1996) and the trend of these ruptures suggested the reactivity of active faults in the Rokko-Awaji fault system (RFS) extending from Awaji Island through Kobe to Takarazuka (Fig.1). However, no aftershocks were detected at the northeast edge of the RFS and the Arima-Takatsuki Tectonic Line (ATL). Prior to the earthquake, Sangawa (1992) documented the movement of the ATL during the 1596 Keicho-Kinki Earthquake, based on historical earthquake records and many archaeological evidence. Together with the lack of aftershocks, the recent reactivity of the ATL led to the interpretation that a seismic gap in 1596 of the RFS had possibly been reactivated

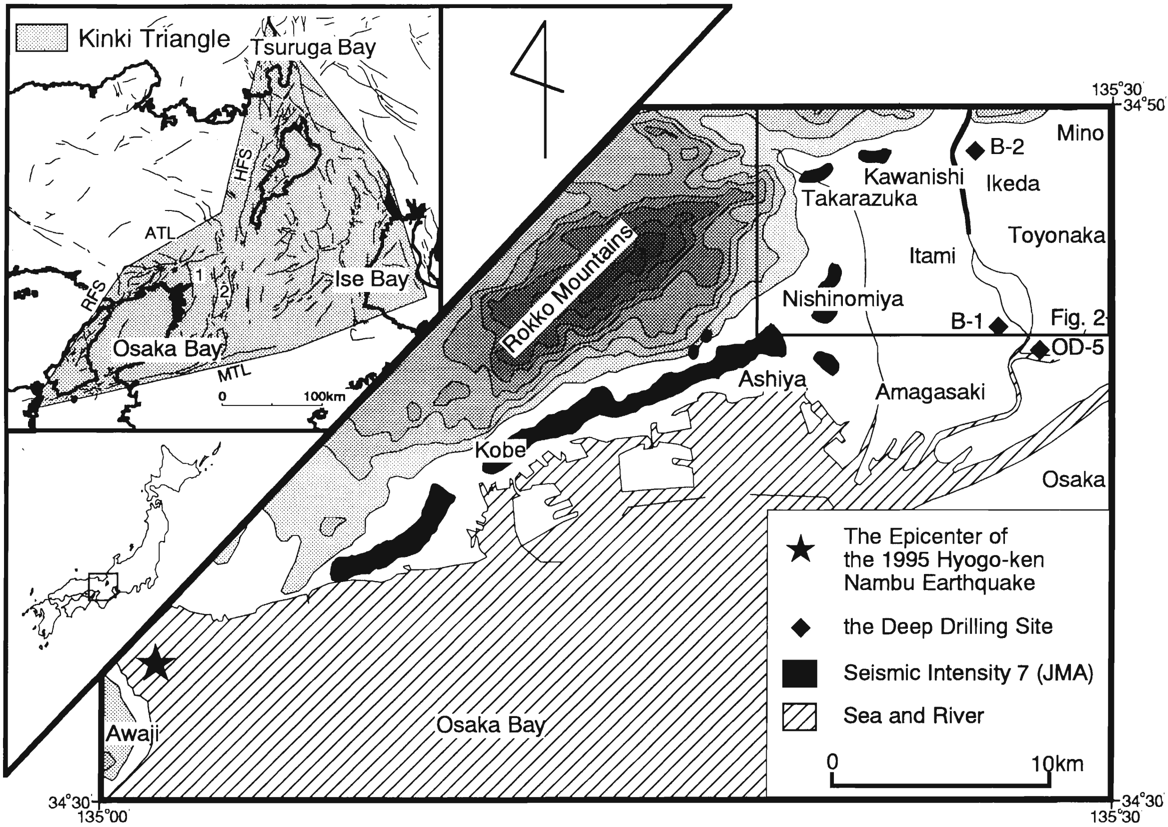


Fig.1. Topography of the northern Osaka Plain, and active faults in and around the Kinki Triangle (Huzita, 1962), Chubu and Kinki Districts, Japan. RFS: Rokko-Awaji fault system, ATL: Arima-Takatsuki Tectonic Line, HFS: Hanaore fault system, MTL: Median Tectonic Line, 1: Uemachi fault, 2: Ikoma fault system. Active faults are after the Research Group for Active Faults of Japan (1991). The thick line shows the seismic reflection survey line. Contour intervals are 100 m.

in 1995 (Matsuda, 1995).

Although surface fault ruptures did not appear in the Hanshin area (Kumaki et al., 1995), severe damage was restricted to the narrow zone called the earthquake disaster belt (Shimamoto et al., 1995), where a seismic intensity of 7 on the Japanese Meteorological Agency Intensity Scale was registered after the earthquake (Fig.1). Similar damage was also found in Takarazuka, Itami, and Kawanishi cities east of Kobe.

For a few years after the earthquake, it remained unclear whether this disaster belt was mainly caused by the movement of subsurface active faults in the Hanshin area (e.g., Shimamoto et al., 1996; Sawa et al., 1996), or by the focusing effect of seismic waves controlled by the nature and geometry of underlying geologic structures (Nakagawa et al., 1995; Irikura, 1996). However, it has been found that the main cause is the geometry of the interface between the basement rocks and the overlying sediments resulting from the activity of several active faults, including subsurface ones. Huzita and Sano (1996) also pointed out the importance of the subsurface structure in evaluating the earthquake-induced disaster.

In this paper, we reveal the subsurface structure in the northern Osaka Plain by using a seismic reflection survey, in order to better understand the Quaternary tectonic history in and around the plain, especially in the region along the RFS and ATL, and to provide basic data for the evaluation of future earthquake-induced disasters. We also herein present a possible interpretation of the subsurface structure in this area, in addition to Toda et al. (1995).

Geologic Setting

The Kinki Triangle (Fig.1) is defined as a tectonic region bounded by such active fault systems as the ATL and RFS (Huzita, 1962). Most active faults have been formed under an east-west compressive stress regime in this region since the Middle Pleistocene (Huzita and Kasama, 1982). The region is characterized by active strike-slip faults on its northeast and northwest sides, and

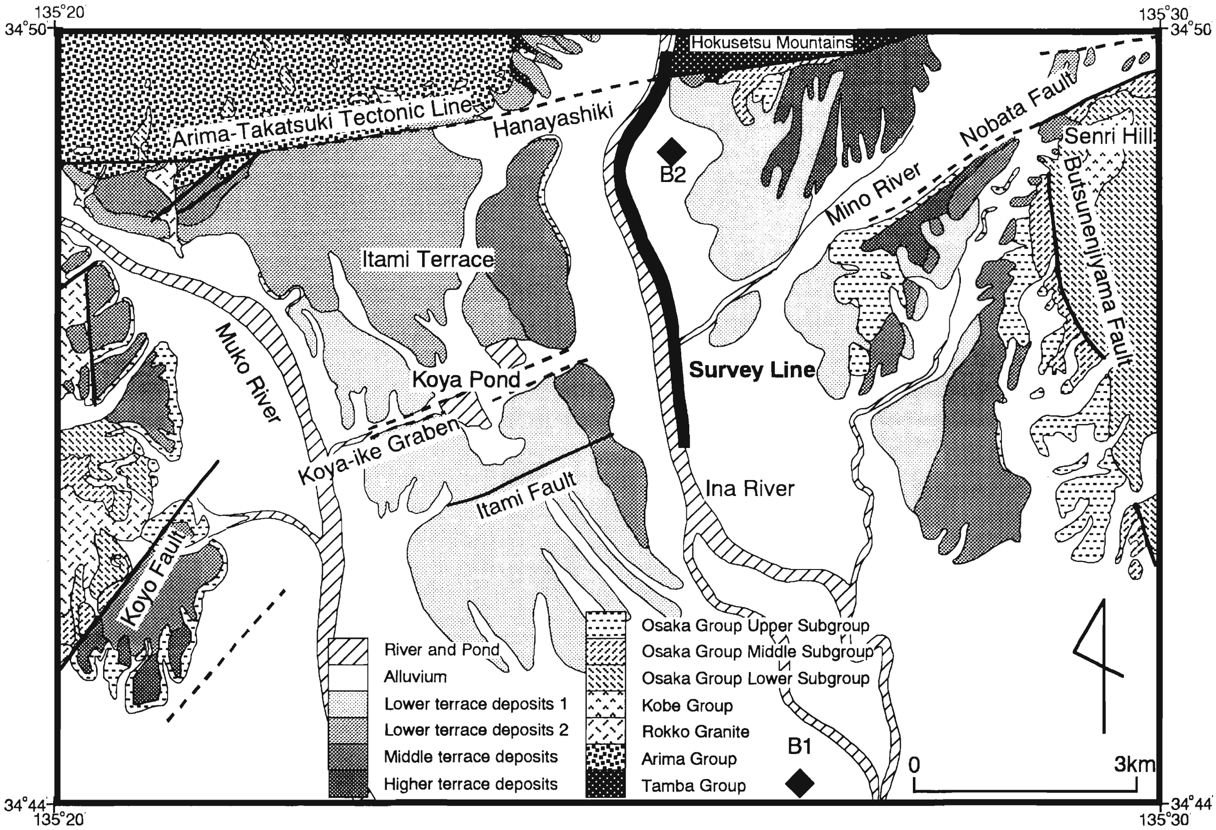


Fig.2. Generalized geologic map in and around the study area (modified after Huzita and Kasama, 1982). Active faults are after the Research Group for Active Faults of Japan (1991). Thick dashed lines show concealed faults and grabens. Other symbols see Fig.1.

by north-south trending active reverse faults inside. The northwest fault zone consists of right-lateral faults in the RFS, ATL, and Hanaore fault system (HFS).

The Osaka Plain and Osaka Bay comprise the Osaka basin (Fig.1), the western structural unit in the triangle formed by the crustal movements during the last 3 Ma (Huzita, 1969). The basin is surrounded by highlands ranging in altitude from 300 to 1000 m, such as the Hokusetsu, Rokko, Ikoma, and Izumi Mountains, and Awaji Island. Many right-lateral faults in the ATL and RFS are developed along the northern and western edges of the basin, whereas reverse faults mainly in the Ikoma fault system (IFS) dominate along the eastern margin (Fig.1).

Thick unconsolidated Neogene and Quaternary sediments are deposited in the basin. They are divided into four stratigraphic units, the Kobe Group, the Osaka Group, the terrace deposits, and the Alluvium, in ascending order (Fig.2). The following description of these units is mainly based on Huzita and Kasama (1982).

The Miocene Kobe Group is restricted to the Senri Hill near the Butsunenjiyama fault in the northern Osaka Plain (Fig.2). This is characterized by acidic to intermediate pyroclastics alternating with mudstone, sandstone, and conglomerate. The Osaka Group is subdivided into the Lower, Middle, and Upper Subgroups from the tectonic point of view. According to Huzita and Kasama (1982), depositional ages of the three subgroups are about 3 to 1.3 Ma, 1.3 to 0.6 Ma, and 0.6 to 0.2 Ma, respectively. The Lower Subgroup consists of non-marine sand and gravel with less extensive silt and clay. The Middle and Upper Subgroups consist of alternating beds of non-marine sand and gravel, silt, clay, and marine clay. Sand and gravel beds dominate in the non-marine sediments of the Upper Subgroup. Many tephra layers are also contained in the Osaka Group. They are stratigraphically important as well as the marine clay.

The terrace deposits consist mainly of sand and gravel with some intercalated tephra layers. They are classified into the Higher, Middle, and Lower. Depositional ages of these deposits are considered to be about 200 to 130 ka, 130 to 70 ka, and 70 to 15 ka, respectively, after many previous chronologic studies (see Itihara, 1993). Some of the Higher terrace consist of the Osaka Group Upper Subgroup (Huzita and Kasama, 1982; 1983), and others of the Higher terrace deposit (Itihara, 1993). Two marine clay beds named Ma11 and Ma12 are intercalated in the Higher and Middle terrace deposits, respectively. The Lower terrace deposit are subdivided into Lower terrace deposits 1 and 2, in some places (Fig.2). The Alluvium underlie a wide area in the Osaka basin. They consist mainly of marine sand, silt, and clay (Ma13) near the coast of Osaka Bay, while terrestrial sand and gravel are extensively deposited along the up to mid stream of rivers running into the bay.

The survey line is located in the northern Osaka Plain along the Ina River, and crosses the central part of the ATL (Fig.2). The Hokusetsu Mountains north of the ATL is underlain mainly by the Jurassic Tamba Group and the Cretaceous Arima Group. The terrace deposits and Alluvium are extensively deposited along the Muko and Ina Rivers in the plain south of the ATL (Fig.2). They unconformably overlie the Osaka Group, or the Cretaceous Rokko Granite.

The terraces in the survey area have been displaced by the ATL, the Itami fault, and the faults forming the Hanayashiki and Koyaike grabens (Fig.2). On the basis of the displacements and ages of these terraces, mean rates of vertical displacement of the active faults were estimated to be from 0.2 to >0.6 mm/yr. (Sangawa, 1978).

Adjacent to the survey line, there are three deep drilling cores: OD-5, B1, and B2 (Figs.1 and 2). The OD-5 is one of a series of drilling cores conducted to take measures against the ground subsidence in the Osaka Plain (Osaka City, 1964). The core sediments are stratigraphically divided into the three Osaka Subgroups, the terrace deposits, and the Alluvium. The B1 and B2 cores were drilled to locate hot water, indicating the depths of the interface between the Osaka Group and the basement (Itihara et al., 1991).

Previous Seismic Refrection Survey

Before the 1995 Hyogo-ken Nanbu Earthquake, Yoshikawa et al.(1987) revealed the subsurface feature of the Uemachi fault from the seismic reflection data in the central Osaka Plain. They suggested the northern extension and connection of the fault to the Butsunenjiyama fault. Iwasaki et al.(1994) found the submarine active fault (the Osaka-wan fault) under Osaka Bay. The northern extension of the submarine fault was found off the coast from Kobe to Ashiya by Yokota et al.(1996) after the earthquake. They also revealed many subsurface and submarine active faults parallel to the RFS, and demonstrated the appearance of these faults as flexure zones in the unconsolidated sediments, like the Osaka Group. Other seismic reflection surveys were performed across the IFS in the eastern Osaka Plain (Horike et al., 1995), across the ATL in the northeastern part of the plain (Kawasaki et al., 1994), and along the Muko River in the northwestern part (Yokota et al., 1996). The last survey detected the subsurface features corresponding to the Koyaike graben and the northern extension of the Koyo fault.

These seismic reflection surveys show common characteristics of the velocity structure of P-wave and those of reflectors in the basement rocks and the overlying sediments. The velocity of P-wave is larger than about 3.0 km/s in the basement rocks, and lower in the sediments. There are few clear reflectors in the basement rocks and the lower half of the Osaka Group Lower Subgroup, but the interface between the two generally becomes a relatively strong reflector. In contrast, the Middle and Upper Subgroups of the Osaka Group show a vertical repetition of many clear and laterally traceable reflectors.

As mentioned above, many seismic reflection data have been accumulated regarding the Osaka basin, resulting in a better understanding of the basin structure. However, there are few data on the subsurface structure in the northern part of the basin, in spite of many active faults in this area.

Methods

Data acquisition

Our seismic reflection survey was carried out from March to April in 1995 after the 1995 Hyogo-ken Nanbu Earthquake. In order to make the survey line as straight as possible, a 6-km survey line was chosen in parallel to the course of the southward-flowing Ina River (Fig.2). A 250 kg accelerating weight-drop source (BISON, EWG-3) was used for the survey. The detectable depth by the

Table 1. Parameters for the seismic reflection survey.

Survey Line length	6000 m
Shot interval	10 m
Vertical stacks	3 - 12
Pick interval	20 m (6 strings)
CMP interval	5 m
Number of channels	24
CMP Folds	12
Exploration System	McSEIS16000 (OYO)
Sampling interval	0.001 sec.
Sampling words	2048
Low cut filter	30 Hz
High cut filter	250 Hz
Notch filter	60 Hz
Source	EWG3 (BISON)
Spread	End on shooting
Geophone	28 Hz (Natural frequency)

source was deeper than 1400 m (Toda et al., 1992; Yamamoto et al., 1992).

The spread of the source and receivers was the end-on-shooting type with shot and receiver intervals of 10 and 20 m, respectively. A 24 channel exploration system was used for this survey. Single geophones of 28 Hz natural frequency and additional groups of 6 geophones were used. Details of the survey parameters in this survey are summarized in Table 1.

CMP processing

Field data were analyzed by using the general CMP stack method. Static correlation was made by using the first arrival times based on the seismic reflection method, and the predictive deconvolution (autocorrelation length 1 sec., prediction length 5-10 milli-sec., and white noise 3 percent) was applied. Velocity analysis was carried out by the constant velocity stack and velocity-spectrum methods. The RMS velocity was picked up at every 200 CMP no., and the interval velocities were calculated from the resultant RMS velocities.

Results

Characteristics of the seismic section and the interval velocity structure

Figs.3 and 4 show the interval velocity structure calculated at every 200 CMP no. and the CMP time section. Because few clear reflectors appeared below the 1.0 sec. horizon on the time section, the interval velocities below the level are less reliable. At every picked CMP no., the interval velocity rapidly increases from 3000 m/s up to 4000 m/s in the lower part, suggesting the presence of basement rocks with a P-wave velocity more than 3000 m/s. Interval velocities less than 3000 m/s are roughly classified into three groups: around 1900 m/s, around 2200 m/s, and around 2500 m/s.

The time section shows a similar feature as that obtained by the previous studies in the Osaka basin (Fig.4). The part above the 0.6 sec. horizon is characterized by many clear and laterally traceable reflectors, whereas the part from the 0.6 to 1.0 sec. horizons shows several obscure reflectors. Below the 1.0 sec. horizon, few reflections are observable, suggesting the presence of basement rocks and/or the part close to the detectable depth.

Layer division on the time section

Since a flat-layered structure is clearest around CMP no.300 on the time section, the sediments are first divided into four layers (A to D), based on the features of reflectors and the interval velocities (Fig.5).

1) A layer Around the 0.3 sec. horizon, a very clear reflector is traceable laterally on the entire section in Fig.5. The A layer is the part from the ground surface to the reflector with an interval velocity of 1500 to 2000 m/s. This layer is characterized by the lack of reflectors in the upper part and by the discontinuous but clear reflectors in the lower part.

2) B layer The part from the 0.3 to 0.5 sec. horizons corresponds to the B layer with an interval velocity of

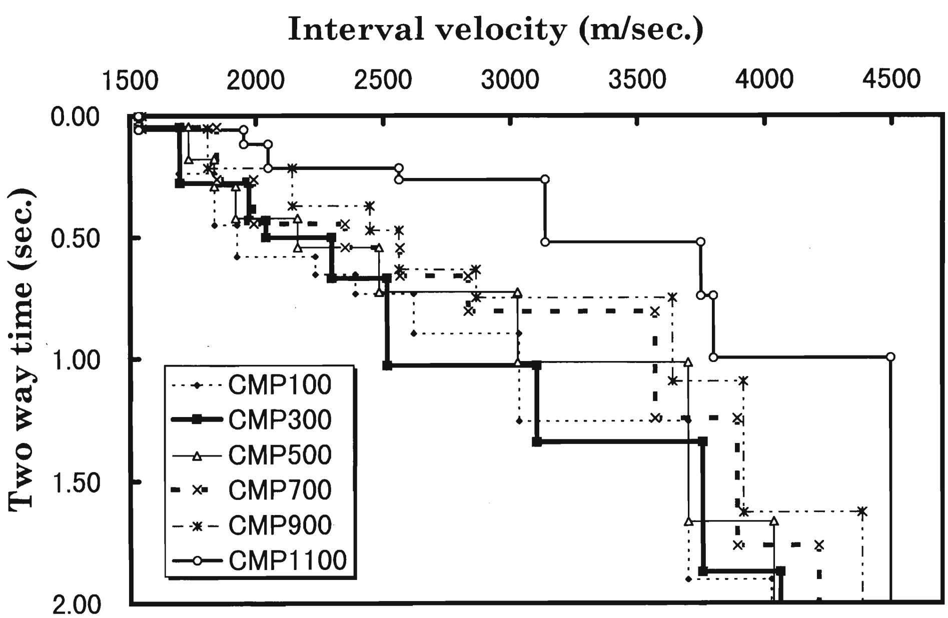


Fig.3. P-wave interval velocity structure at every 200 CMP no. along the survey line estimated by velocity analysis.

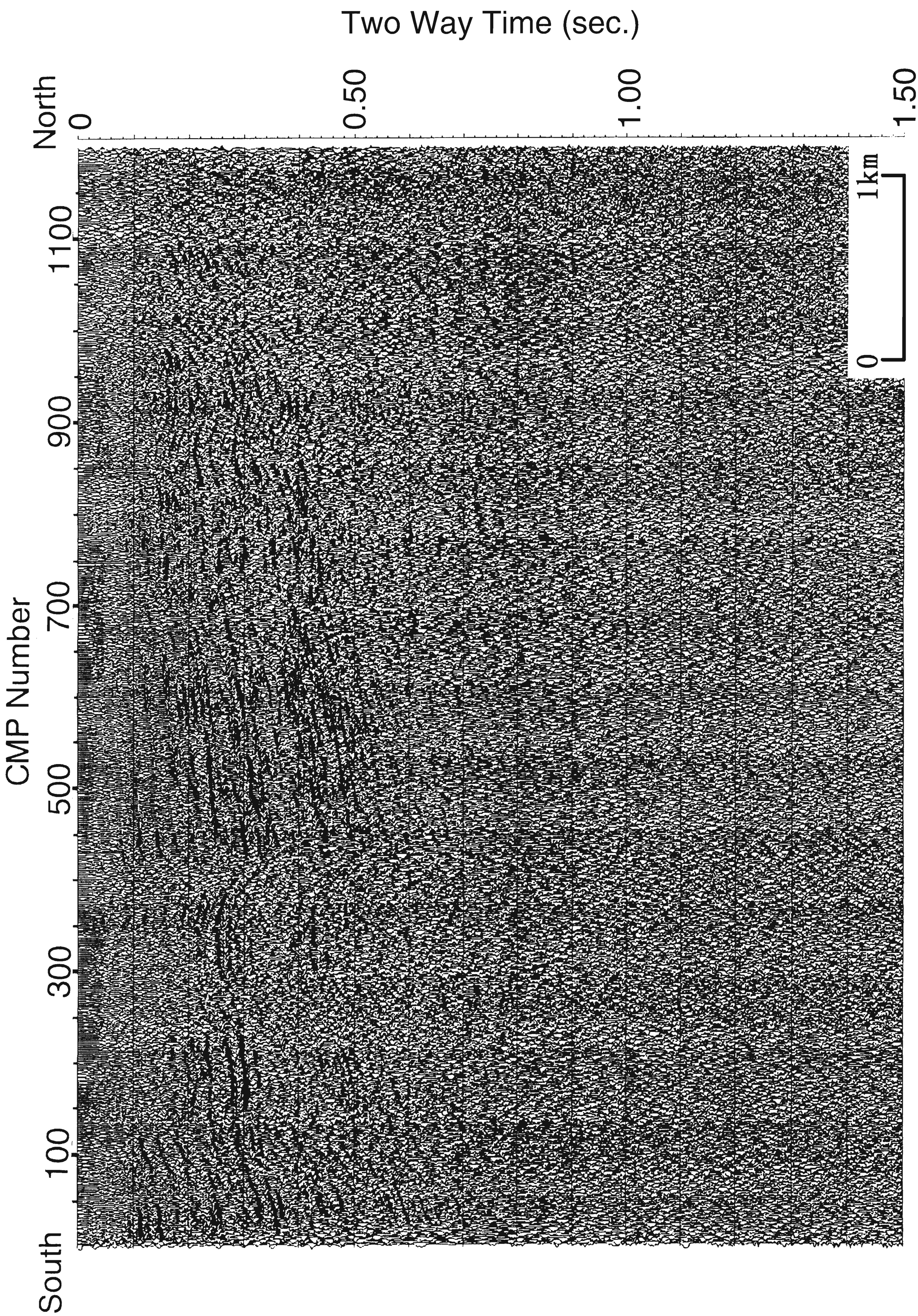


Fig.4. CMP time section along the survey line.

2000 to 2300 m/s. This layer clearly shows a series of cyclic and laterally traceable reflectors.

3) C layer A weak reflector is recognized around the 1.0 sec. horizon. The C layer extends from the 0.5 sec. horizon to the reflector, with an interval velocity of 2300 to 3000 m/s. This layer is characterized by fragmentary reflections with low frequency.

4) D layer The D layer is the deepest part below the reflector around the 1.0 sec. horizon. This layer has the largest interval velocity, more than 3000 m/s, and shows very few reflectors.

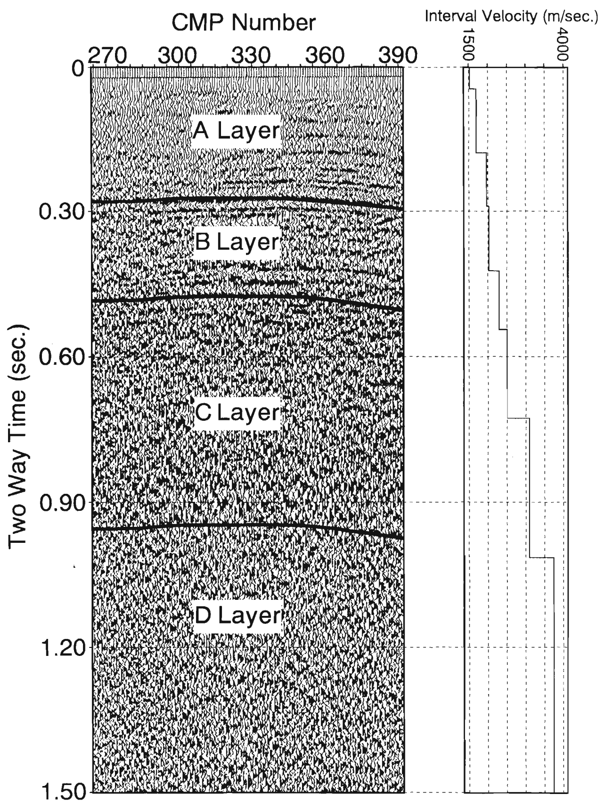


Fig.5. Standard layer division on the time section around CMP no. 300., and the structure of P-wave interval velocity at CMP no. 300 estimated by velocity analysis. The sediments are divided into four seismic layers (A to D).

This standard division is extended north and south from CMP no. 300 along the entire survey line. The boundary between the C and D layers is decided mainly based on the velocity structure at the segments where the reflector around the 1.0 sec. horizon is not clear. Boundaries of the four layers are shown in the section converted to depth (Fig.6).

Subsurface structure appearing on the depth section

The part between CMP nos. 420 and 1150 shows a wide graben (Fig.6). Around CMP no.400, there is a narrow wedge-like structure with no clear reflectors in the A and B layers. Boundaries among the A, B, and C layers and clear reflectors in the A and B, all indicate a flexure zone around here. The boundaries and reflectors just south of this point sharply dip north, whereas from CMP nos. 430 to 850, they are relatively smooth and less steeply tilted south, with accumulation of tilting (Fig.6). Based on this evidence, a high-angle fault is inferred around CMP no.420.

Reflectors from CMP nos. 900 to 950 show a narrow graben structure (Fig.6). They dip south steeply in the north of CMP no. 950 and break down around CMP no.1100. No clear reflections can be found north of this point, suggesting the existence of the D layer near the surface. Therefore, a large fault zone is estimated around CMP no. 1100.

On the other hand, boundaries and reflectors indicate a monocline structure south of CMP no. 400 (Fig.6). They increase in dip downwards, showing accumulated tilting. Reflectors in the A and in the upper part of the B layer show more local flexure around CMP no.80 (Fig.6). The inclination of the reflectors south of this point becomes larger downwards, indicating the successive growth of the flexure. However, the amount of deformation of reflectors does not increase below the lower half of the B layer. Accordingly, the flexure around CMP no. 80 is considered to have generated after the deposition of the lower half of the B layer.

Discussion

Correlation between the seismic layers and the stratigraphic units

The four seismic layers of A to D are compared with the stratigraphic units of the three available deep drilling cores, OD-5, B1, and B2 (Fig.6). Although the sites of the OD-5 and B1 are apart from the survey line, no large geologic gap is inferred between the sites and the line, according to the gravity studies of the Osaka basin (Huzita and Kasama, 1982; Gravity research group in Southwest Japan, 1994) and other seismic reflection studies (Yoshikawa et al., 1987; Yokota et al., 1996). Thus, it is thought to be possible to correlate the two cores with our seismic layers.

The boundary between the C and D layers almost coincides with the interface between the basement rocks

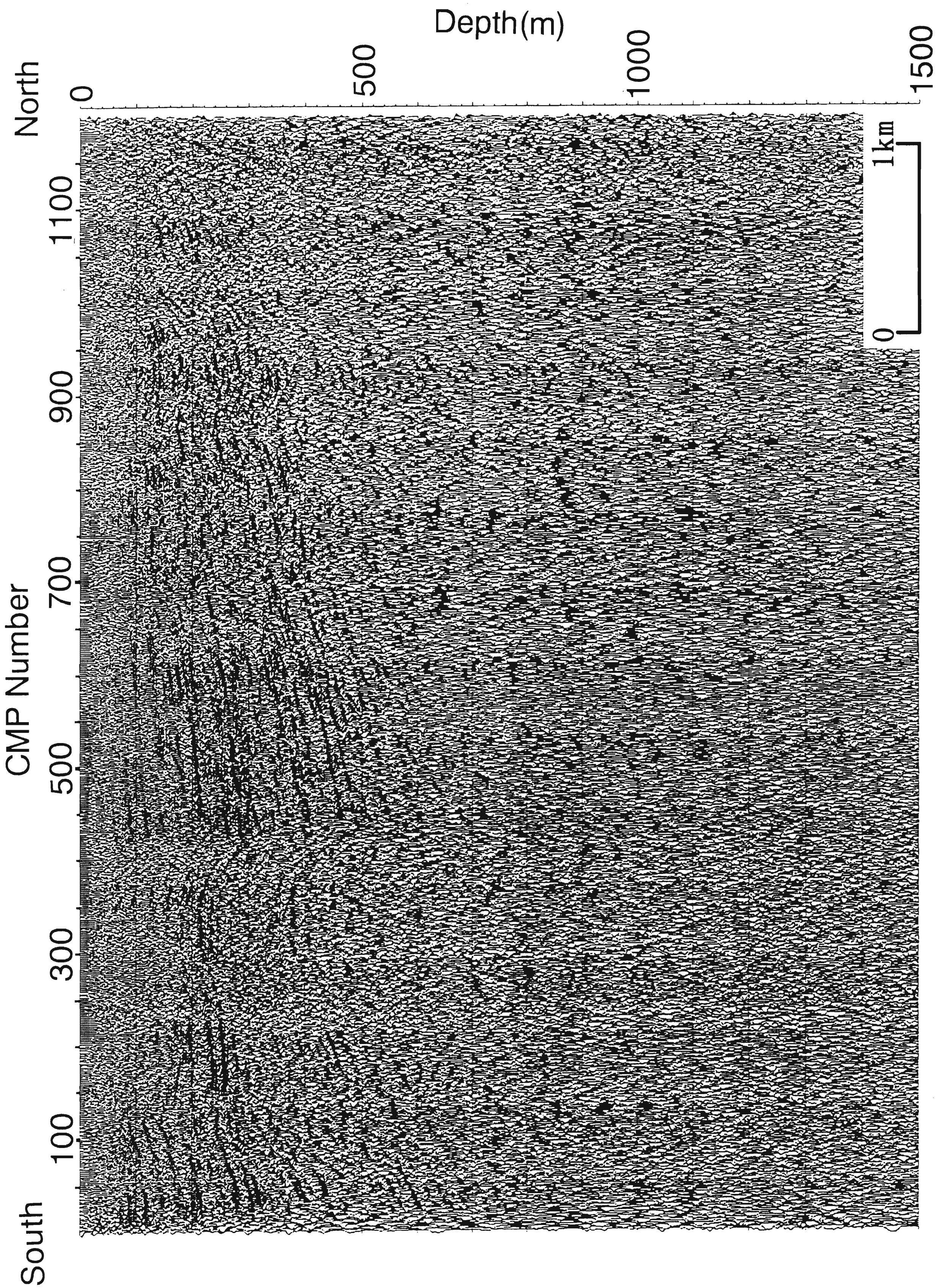
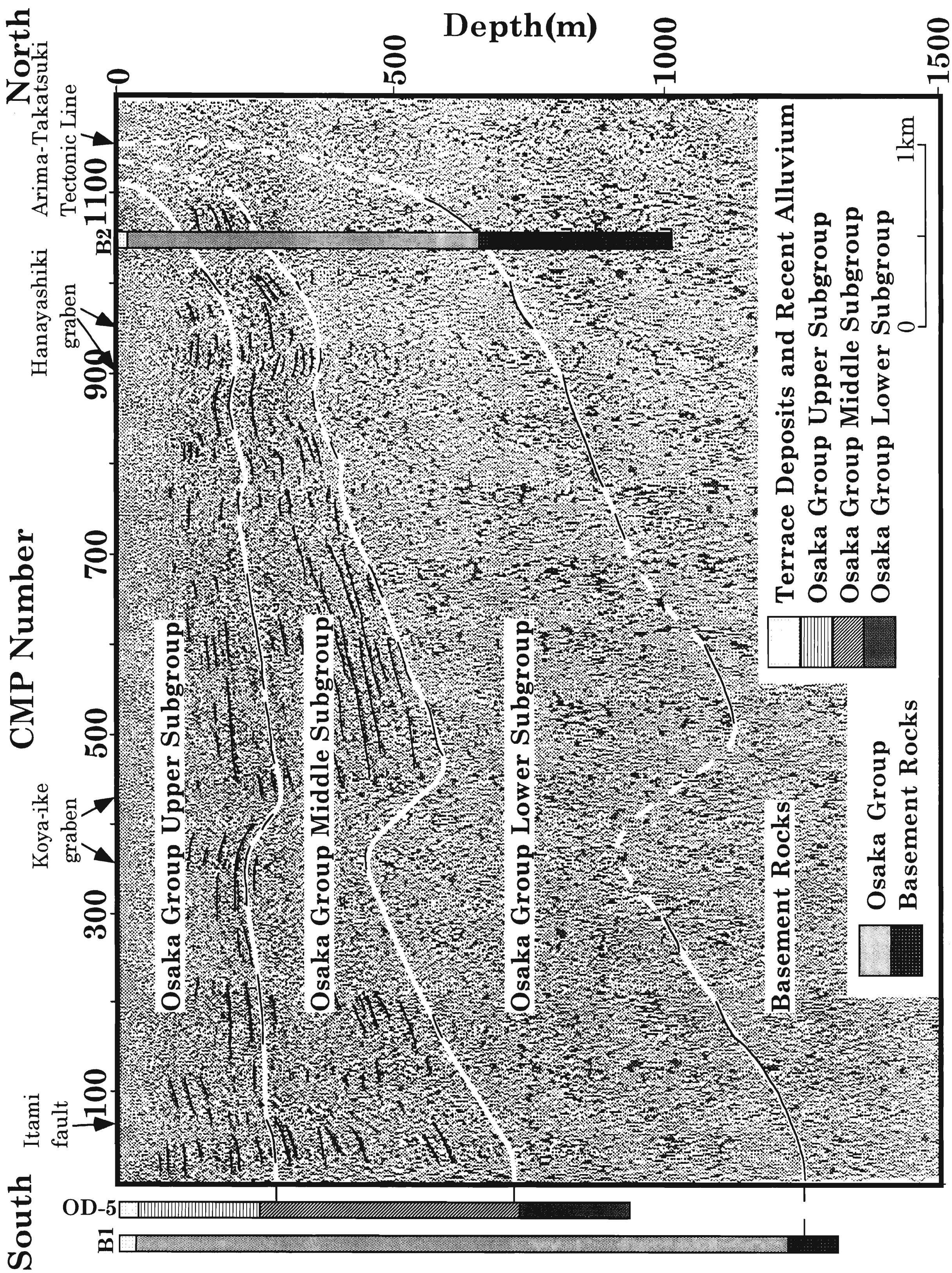


Fig.6. Final section converted to depth (left side) and the interpreted depth section (right side) along the survey line, with the stratigraphic division of the deep drilling cores of OD-5, B1, and B2 (after Itihara et al., 1991). Arrows show the locations of the active ↗



↘ faults on land after the Research Group for Active Faults of Japan (1991). Four Seismic layers (A to D) correspond to the Upper, Middle, and Lower Subgroups of the Osaka Group, and the basement rocks, respectively.

and the Osaka Group recognized in the B1 and B2 cores. Compared with the stratigraphy of the OD-5 core sediments, the B and C layers roughly correspond with the Middle and Lower Subgroups of the Osaka Group, respectively.

In the previous seismic reflection data near Osaka Bay, the upper part of the Osaka Group Lower Subgroup shows some clear continuous reflectors (Yoshikawa et al., 1987). The boundary between the two subgroups is situated above the horizon below which the clear reflectors disappear. On the contrary in our results, it coincides with the horizon, probably because of the difference in sedimentary environments of the two subgroups in our survey area and in the coastal area. Namely, near the margin of the Osaka basin far from the present coast line, the Lower Subgroup is dominated by non-marine sand and gravel with few silt and clay beds, and thus has no clear and continuous reflectors. In contrast, the Middle Subgroup consists of alternating beds of marine clay and non-marine sand and gravel even in this marginal area. The boundaries between the beds can be clear and continuous reflective surfaces.

The A layer is ascribed to the Osaka Group Upper Subgroup, the terrace deposits, and the Alluvium (Fig.6). The boundary between the A and B layers almost corresponds to the stratigraphic horizon between the Upper and Middle Subgroups. Because this boundary is represented as a clear and laterally well traceable reflector on the seismic section (Fig.6), we can obtain a reliable chronologic level, as well as the boundary between the B and C layers.

Relationship between the subsurface structure and the surface active faults

In the study area, surface active faults in the ATL, those forming the Hanayashiki and Koyaike grabens, and the Itami fault, are arranged southwards in this order (Fig.2). They were also confirmed by the dislocations of strata revealed by several shallow drilling data (Huzita and Maeda, 1971; Huzita and Kasama, 1982). The subsurface structure described above are compared with these active faults.

The large fault zone around CMP no. 1100 is the subsurface expression of the ATL. Across the fault zone, vertical displacement of the boundary between the C and D layers is estimated to be at least 500 m on the depth section (Fig.6). Additionally, the equivalent of the Osaka Group Lower Subgroup corresponding to the C layer remains sporadically up to about 400 m in altitude in the Hokusetsu Mountains near the ATL (Itihara et al.,1991). Thus, total vertical displacement of the boundary between the Lower Subgroup (the C layer) and the basement rocks (the D layer) is evaluated to be about 900 m. The mean rate of the vertical displacement is calculated to be approximately 0.3 mm/yr by using the depositional age of the subgroup, being similar to that estimated by Sangawa (1978).

The wide subsiding and southwards-tilting block was detected between the ATL and the Koyaike graben on the seismic section (Fig.6), although it could not be known only from the topographic and geologic evidence. Judging from the width of the block and the trends of the ATL and Koyaike graben, it probably extends under the depression between the ATL and the Nobata fault on the east side of the Ina River (Fig.2).

The wavy shape of the horizons from CMP nos. 900 to 950 represents the subsurface configuration of the eastern extension of the Hanayashiki graben. Prior to this study, although the graben was identified from the vertical displacement of the Itami terrace (Sangawa, 1978), it was questioned whether it extended further to the east or not, because the recent alluvial lowland is extensively developed along the Ina River. Now, the deformed reflectors on the seismic section confirms the Hanayashiki graben extending further to the east beyond the river.

The fault around CMP no.400 is located under the eastern extension of the Koyaike graben (Fig.6). The fault has vertically dislocated the boundaries between the A and B, the B and C, and the C and D layers by approximately 70, 140, and 230 m, respectively (Fig.6). The average rate of the vertical displacement is calculated to be about 0.1 mm/yr by using the depositional ages of the three subgroups of the Osaka Group. If the fault has been activated with the rate until now, the Itami terrace correlative with the Middle terrace should have been vertically displaced by at least 7 m. However, there is no displacement of the terrace across the graben (Huzita and Kasama, 1982). Furthermore, the Itami clay (Ma12) and Kawanishi clay beds under the terrace also show no clear vertical displacement across the graben. Judging from the shallow drilling data compiled by Oka (1963), the latter clay bed can be correlated with either Ma10 or Ma11. Thus, it is likely that strike-slip faulting has been dominated along the fault since the latest Middle Pleistocene, resulting in the formation of the Koyaike graben as a near-surface expression of the fault. Yokota et al.(1996) also suggested the appearance of the western extension of the graben characterized by strike-slip faulting during the last 0.3 Ma or so.

The Itami fault appears as a clear fault-scarp facing south on the Itami terrace (Huzita and Maeda, 1971; Sangawa, 1978). According to Huzita and Kasama (1982), it has also displaced the Itami clay and Kawanishi clay beds by about 10 and 20 m, respectively. Nevertheless, no vertical displacement of reflectors could be detected across the fault by our survey (Fig.6). Instead, the flexure of reflectors was recognized around CMP no. 80 on the seismic section, being considered as the subsurface expression of the fault.

Huzita and Maeda (1971) reported the tectonic history of the Itami area as follows: the area had been tilted west since the Middle Pleistocene but left at the lower position near the sea-level until the latest Middle Pleistocene. After then, the area was uplifted with southward tilting, resulting in the emergence of the Itami terrace in combination with the sea-level lowering at the end of the Last Interglacial.

Taking into consideration this history of the Itami area and the subsurface features of the Itami fault and Koyaike graben, we concluded that the fault had generated since the latest Middle Pleistocene in association with the change in dominant faulting mode along the graben from vertical to lateral.

Conclusion

We carried out the seismic reflection survey along the Ina River in Kinki District, Central Japan, to clarify the subsurface structure of the northern Osaka Plain. The sediments were divided into four seismic layers (A to D). Compared with the stratigraphy of the deep drilling cores of OD-1, B1, and B2, the A layer was ascribed to the Alluvium, terrace deposits, and the Osaka Group Upper Subgroup, and the B, C, and D layers were to the Osaka Group Middle Subgroup, the Osaka Group Lower Subgroup, and the underlying basement rocks, respectively.

Our seismic reflection survey also detected the subsurface expressions of the Arima-Takatsuki Tectonic Line, the Hanayashiki and Koyaike grabens, and the Itami fault. It confirmed the former three tectonic structures extending further to the east beyond the Ina River.

The Arima-Takatsuki Tectonic Line appeared as the fault zone bounding the Osaka Group and the basement rocks. Vertical displacement by the tectonic line was estimated to be about 900 m on and after the deposition of the group. A wide subsurface graben structure was recognized between the Arima-Takatsuki Tectonic Line and the Koyaike graben on the seismic section. The subsiding block is tilted south toward the Koyaike graben.

Across the Koyaike graben, there is no vertical displacement of the Itami terrace, but that of about 230 m was found between the boundary of the Osaka Group and the basement rocks. In contrast, the Itami fault appeared as a narrow flexure of reflectors in the Upper and Middle Subgroups of the Osaka Group, although it has given clear vertical displacement to the surface and deposits of the terrace. On the basis of these subsurface features and the Quaternary tectonic history of the Itami area, we concluded that the Itami fault had generated since the latest Middle Pleistocene in association with the change in dominant faulting mode along the Koyaike graben from vertical to lateral.

Huzita and Maeda (1971) mentioned that on the eastern side of the Ina River it was difficult to identify the extensions of the Arima-Takatsuki Tectonic Line, and the Hanayashiki and Koyaike grabens. Other previous studies have also failed to reveal their eastern extension from geomorphologic and geologic evidence. As a result, it was inferred the north-south tending fault interrupted the above tectonic features. However, our present work has confirmed the eastern continuity of these features, indicating the absence of the inferred fault.

Acknowledgments

We would like to thank Ms. Myra Leounakis, Dr. Jessie A. Daligdig and Prof. Yoshimasa Kobayashi of Kyoto University for their timely assistance in preparation of the manuscript. Special consideration by the Ministry of Construction of the Ina River Construction Work-Office, Itami City, Kawanishi City, Ikeda City and each Board of Education is deeply appreciated. We wish to thank inhabitants of the research area for enduring the noise and nuisance during the survey. Thanks are also due to Dr. Shinji Kawasaki, Messrs. Takehiko Mori, Yoshihiro Matsumoto and Makoto Nakaboh of Kyoto University, Naoto Inoue, Takeo Morii, Satoshi Nishiura of Osaka City University and Koji Uno of Kobe University for their assistance in data acquisition. The financial support for this survey was provided by the Museum of Nature and Human Activities, Hyogo.

References

Gravity research group in Southwest Japan (1994) A Bouguer gravity anomaly map in Central Japan. *Jour. Geol. Surv. Japan*, (280) : 29-36.

Horike, M., Takeuchi, Y., Toriumi, I., Fuzita, T., Yokota, H. and Noda, T. (1995) Seismic reflection survey of the boundary region between the Ikoma Mountains and the Osaka basin. *Zisin2*, **48**: 37-49. (In Japanese with English abstract)

Huzita, K. (1962) Tectonic development of the median zone(Setouti) of Southwest Japan, since Miocene. *Jour. Geosci. Osaka City Univ.*, **2**: 103-144.

Huzita, K. (1969) Tectonic development of Southwest Japan I: The Quaternary period. *Jour. Geosci. Osaka City Univ.*, **12**: 53-70.

Huzita, K. and Maeda, Y. (1971) Itami Terrace: with special reference to the Late Pleistocene transgression in Japan. *Jour. Geosci. Osaka City Univ.*, **14**: 53-70.

Huzita, K. and Kasama, T. (1982) Geology of the Osaka-Seihokubu district. *Quadrangle Series*, Scale 1:50,000, Geol. Surv. Japan, 112 p. (In Japanese with English abstract, 8 p.)

Huzita, K. and Kasama, T. (1983) Geology of the Kobe district. *Quadrangle Series*, Scale 1:50,000, Geol. Surv. Japan, 115 p. (In Japanese with English abstract, 8 p.)

Huzita, K. and Sano, M. (1996) The Great Hanshin-Awaji earthquake disaster and the Rokko movement. *Iwanami-Kagaku*, **66**: 793-805. (In Japanese)

Irikura, K. (1996) Strong ground motion causing the earthquake disaster belt. *Iwanami-Kagaku*, **66**: 86-97. (In Japanese)

Itihara, M. ed. (1993) *The Osaka Group*. Sohgensya, Osaka, 340p. (In Japanese with English concluding remarks, 3p.)

Itihara, M., Yoshikawa, S., Mitamura, M., Mizuno, K. and Hayashi, T. (1991) 1:25,000 Quaternary geological map of Osaka and adjacent areas, Kinki, Japan, *Urban Kubota*, no.30. (An attached map)

Iwasaki, Y., Kagawa, T., Sawada, S., Matsuyama, N., Ohshima, K., Ikawa, T. and Onishi, M. (1994) Basement structure by airgun reflection survey in Osaka Bay, Southwest Japan. *Zisin2*, **46**: 395-403. (In Japanese with English abstract)

Kawasaki, S., Toda, S., Nakagawa, K. and Kobayashi, Y. (1994) Seismic reflection exploration in the eastern part of the Arima-Takatsuki Tectonic Line, Kinki District, Central Japan. *Zisin2*, **47**: 173-182. (In Japanese with English abstract)

Kumaki, Y., Une, H., GSI Research Group for Disaster Geography, Wakisaka, Y., Ota, Y. and Toda, S. (1995) Active faults and surface movements in and around Rokko Mountains. *1995.1.17 Hyogo-ken Nanbu Earthquake preliminary report*. Japan Association for Quaternary Research, pp. 51-52. (In Japanese)

Lin, A., Imiya, H., Uda, S., Iinuma, K., Misawa, T., Yoshida, T., Abematsu, Y., Wada, T. and Kawai, K. (1995) Investigation of the Nojima earthquake fault occurred on Awaji Island in the southern Hyogo Prefecture earthquake. *J. Geography*, **104**: 113-126. (In Japanese with English abstract)

Matsuda, T. (1995) The transition of active fault problem and future prospect: the history and the present condition of research of active faults. Fault Research Data Center, pp. 10-15. (In Japanese)

Nakagawa, K. and O. C. U. Investigation Team on the Hanshin Great Earthquake Disaster (1995) A relation between earthquake ground failure and subsurface structure. *The proceeding of symposium on the Great Hanshin-Awaji earthquake and its geo-environments*. The committee of environmental geology, Geol. Society of Japan, pp. 233-238. (In Japanese with English abstract)

Nakata, T., Yomogida, K., Odaka, J., Sakamoto, T., Asahi, K. and Chida, N. (1995) Surface fault ruptures associated with the 1995 Hyogoken-Nanbu earthquake. *J. Geography*, **104**: 127-142. (In Japanese with English abstract)

Nemoto, H., Katao, H. and Suzuki, E. (1996) The spreading of aftershocks area directly after the 1995 Hyogoken Nanbu Earthquake. *Prog. and Abst.*, Seismol. Society of Japan, No.2, C 67. (In Japanese)

Oka, Y. (1963) The geomorphological development of the north-western Osaka Plain. *Geogr. Rev. Japan*, **36**: 309-322. (In Japanese with English abstract)

Osaka City (1964) The research report of ground subsidence in Osaka city (OD-1). Osaka City, Osaka, 213 p. (in Japanese)

Ota, Y., Torino, M. and Survey Group on Disasters, Geographical Survey Institute (1995) Notes on the earthquake fault on Awaji Island, associated with the 1995 Hyogoken-Nanbu earthquake and related disasters. *J. Geography*, **104**: 143-155. (In Japanese with English abstract)

Sangawa, A. (1978) Fault topography and Quaternary faulting along the middle and eastern parts of the Arima-Takatsuki Tectonic Line, Kinki district, Central Japan. *Geogr. Rev. Japan*, **51**: 760-775. (In Japanese with English abstract)

Sangawa, A. (1992)*Earthquake Archaeology-Earthquake records preserved at ruins-*. Chuo-Kohronsya, Tokyo, 251 p. (In Japanese)

Sawa, H., Ikeda, Y., Togo, M., Katoh, S. and Kumamoto, T. (1996) Behavior of subsurface faults during the 1995 Hyogo-ken Nanbu earthquake inferred from the movements of tomb stones by ground motion. In the committee of environmental geology, Geol. Society of Japan, ed., *The Great Hanshin-Awaji earthquake disaster-the earthquake generated under* *large cities and its geo-environments*, Tokai Univ. Press, Tokyo, pp. 147-156. (In Japanese)

Shimamoto, T., Tsutsumi, A., Ohtomo, Y. and Kawamoto, E. (1995) Earthquake disasters in Kobe, Ashiya and Nishinomiya, and presumed earthquake-generating faults. *1995.1.17 Hyogo-ken Nanbu Earthquake preliminary report*. Japan Association of Quaternary Research, pp. 41-42. (In Japanese)

Shimamoto, T., Kawamoto, E., Tsutsumi, A. and Ohtomo, Y. (1996) Relation between the earthquake disaster belt of the 1995 Hyogo-ken Nanbu earthquake and the active faults in Kobe area: Revival of the subsurface earthquake-generating faults as the cause of the belt-. In the committee of environmental geology, Geol. Society of Japan, ed., *The Great Hanshin-Awaji earthquake disaster-the earthquake generated under large cities and its geo-environments*, Tokai Univ. Press, Tokyo,pp, 122-134. (In Japanese)

The Research Group for Active Faults of Japan (1991) *Active faults in Japan-Sheet maps and inventories* (revised edition)-. Univ. of Tokyo Press, Tokyo, 437 p. (In Japanese with English summary, 2 p.)

Toda, S., Nakagawa, K., Mitamura, M., Nishida, T., Yamamoto, E., Terada, Y., Uda, H. and Yokota, H. (1992) Seismic reflection method at the central Osaka Plain-Yamato River (Oriono ~ Yata) Line-. *Proceedings of the 92th JSEG Conference*, pp. 189-192. (In Japanese)

Toda, S., Kawasaki, S., Takemura, K. and Okada, A. (1995) Graben structures along the Arima-Takatsuki Tectonic Line inferred from seismic reflection sections. *Zisin2*, **48**: 511-520. (In Japanese with English abstract)

Yamamoto, E., Nakagawa, K., Mitamura, M., Toda, S., Nishida, T., Terada, Y., Uda, H. and Yokota, H. (1992) Seismic reflection method at the central Osaka Plain-Yodo River (Juso ~ Kunijima) Line-. *Proceedings of the 92th JSEG Conference*, pp. 185-188. (In Japanese)

Yokota, H., Ikawa, T., Sano, M. and Takemura, K. (1996) Reflection seismic survey results across the northern part of Osaka Bay and Rokko Mountain foothill. In Museum of Nature and Human Activities, Hyogo, ed., *The Great Hanshin-Awaji earthquake disaster and the Rokko movement: report on active structures in the area damaged by the 1995 Hyogo-ken Nanbu earthquake*. Rokko Civil Engineering Office, Kobe, PP. 57-89. (In Japanese)

Yoshikawa, S., Machida, Y., Teramoto, M., Yokota, H., Nagao, H. and Kagiwara, M. (1987) Reflection seismic survey in Osaka city. *Proceedings of the 77 th SEGJ Conference*, pp. 114-117. (In Japanese)

Received: November 30, 1997
Accepted: March 13, 1998