# REGULARLY DEPTH DISTRIBUTION OF QUATERNARY MARINE CLAY BEDS IN THE OSAKA PLAIN AND THE GEOLOGIC STRUCTURE MAPPING

**Muneki Mitamura** [1]

[1] Department of Geosciences, Faculty of Science, Osaka City University

3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan

Email: mitamura@sci.osaka-cu.ac.jp

## ABSTRACT

*The Quaternary stratigraphy on subsurface geology of the Osaka Plain has been mainly built up with drilling cores sampled by 13 deep drilling investigations for the countermeasure ground subsidence and the analysis of activity on Quaternary faults. Meanwhile, seismic reflection surveys in the Osaka Plain have been carried out along 13 lines. Depth sections of the seismic surveys provided much additional information on the subsurface geological structure. But, the correlation between the depth section and the litho-stratigraphy of the Quaternary formation in the Osaka Plain was not complete. The upper part of the Quaternary formation in the Osaka plain intercalates 21 marine clay beds. The depth distribution of these marine clay horizons can be explained with a linear relation with the standard probability curve on base depth distribution at the OD-1 drilling site. This linear relation is used for the correlation between the reflectors in the depth section of the seismic survey and the base horizon of the each marine clay bed. The result of the correlation can be applied for the mapping on subsurface geologic structure in the Osaka Plain. The author tried to make geologic structure contour map of the horizons of the main marine clay beds. These Quaternary marine clay beds have been correlated with the oxygen isotope record from deep sea cores. Therefore, those geologic structure maps of the Osaka Plain are available for not only the geo-technical utilization but also the estimation of the historical basin activity.*

## 1. INTRODUCTION

The Osaka Plain is located in the northeastern part of the Osaka sedimentary basin (Figure.1). The Osaka Sedimentary Basin has continuously subsided from the late Pliocene to the recent and formed a tectonic basin. The central part of this basin is mainly filled up with Quaternary formation over 3000 meters in thickness. In the subsurface of the Osaka Plain, the thickness of the Quaternary sediment is at least 1500 meters.

The geological data on the Quaternary formation in the subsurface of the Osaka Plain and its surrounding hills are accumulated by geological perambulations, drilling and physical prospecting. But, the successive distribution of the Quaternary formation in the subsurface from the hilly area to the plain has not been compiled

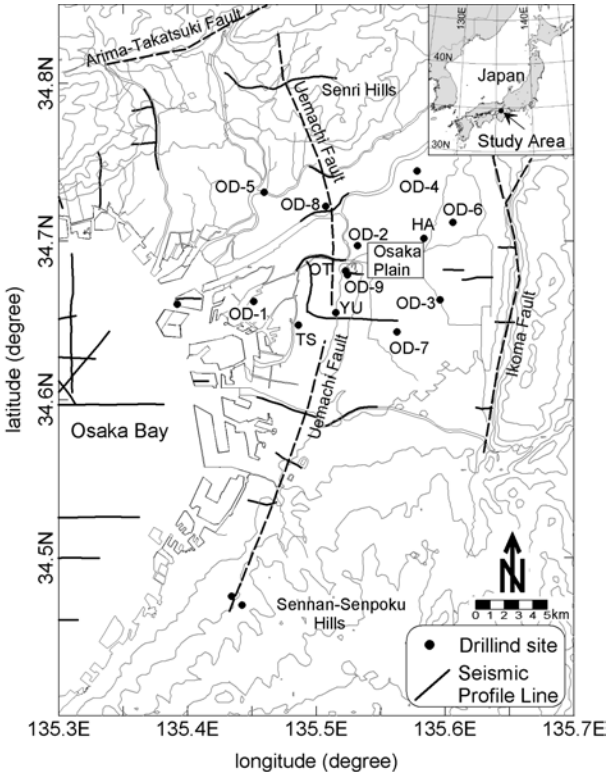


**Figure 1. Location of the study area.**

with planimetric map except the typical geologic profile. These compile maps are available for many kind of analysis on the basin environment.

In this paper, the distribution of main horizon in the Quaternary formation in the Osaka Plain and its surroundings is compiled as strip maps.

## 2. QUATERNARY STRATIGRAPHY IN THE OSAKA PLAIN

The Plio-Pleistocene stratigraphy has been investigated by geological perambulations in the hilly areas. The standard litho-stratigraphy of the Quaternary formation was confirmed with the detail geologic map in the hilly areas (Osaka Group Research Group, 1951; Itihara *et al*., 1975). The natural history has been traced on the base of the litho-stratigraphy in these areas (Itihara *et al*., 1987; Table 1). As the result of these geological surveys, typical marker bed was traced in detail and the contour map of the marker bed was compiled as the geologic structure map in hilly areas.

**Table 1. Quaternary stratigraphy in the Osaka area.**

| Geological System | | | Itihara et al. (1987) | | Yoshikawa and Mitamura (1999) |
|---|---|---|---|---|---|
| | | | Hill and Terrace Area | | Subsurface of Osaka Plain |
| Holocene | | | Alluvial deposit | | Namba Formation |
| Pleistocene | Upper | | Lower Terrace deposit | | Tanaka Formation |
| | | | Middle Terrace deposit | | |
| | Middle | | Higher Terrace deposit | | |
| | Lower | Osaka Group | | Upper Part | |
| | | | | Lower Part | Miyakojima Formation |
| Pliocene | | | | Lowermost Part | |

The Plio-Pleistocene consists of unconsolidated clay, silt, sand and gravel. The Plio-Pleistocene intercalates more than 20 marine clay beds and 40 volcanic ash layers which are available as marker bed for geological survey. The total thickness of the formation in hilly areas is measured up to 300-400 meters. The lower half part of the Plio-Pleistocene consists of fluvial and lacustrine sediments. Meanwhile, the upper half part consists of alternation of marine and fluvial sediments. Marine clay beds (called as Ma-1, Ma0, Ma1, …, Ma12 and Ma13 in ascending order, Ma: condensation code of Marine clay), which were deposited in shallow bay environments, are intercalated in the upper half part. The Plio-Pleistocene formation forming the hilly area is called the Osaka Group (Itihara et al., 1955). The Osaka Group unconformably underlies terrace deposits and alluvial deposits. The Osaka Group is divided into lowermost part (Pliocene), lower part (Lower Pleistocene) and upper part (Middle Pleistocene), in ascending order (Table 1).

The stratigraphy in the subsurface of the Osaka Plain has been investigated with geological deep drillings. During the 1960s, 9 deep drillings, called as OD-1 to OD-9, were carried out for countermeasure of the ground subsidence disaster (Ikebe *et al*., 1970). OD-1 drilling core, which was drilled at the bay side area more than 900 meters depth, is the deepest continuous drilling sample in the Osaka Plain (Figure 2). That drilling core is available for the standard litho-stratigraphy in the subsurface of the

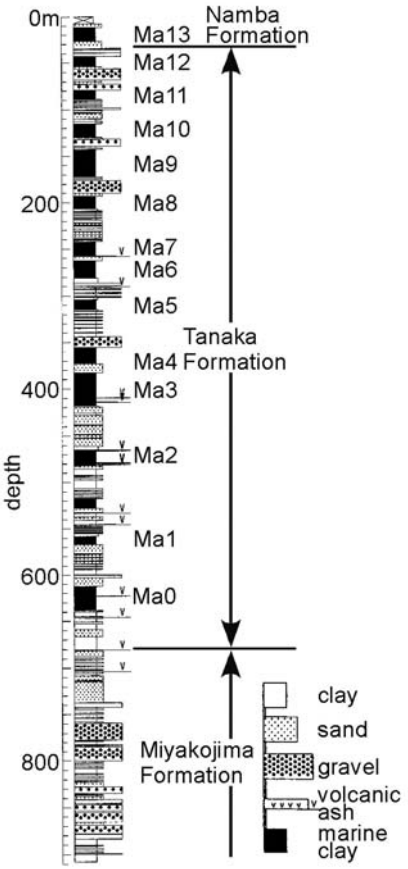


**Figure 2. Geologic columnar section of OD-1 drilling core.**

Osaka Plain. OD-2 drilling located at the northern part of the Uemachi area, central Osaka Plain reached basement rocks at 650 meters depth. This drilling data is also available for the standard stratigraphy.

In 1995, the Kobe Earthquake (M=7.3) was occurred, and the main shock of the earthquake struck the constructions in the Osaka Plain. 4 drilling investigation are carried out for research of the activity of Quaternary fault and the future disaster prevention by Osaka City and Geological Survey Japan (Yoshikawa *et al*., 1997,1998). The Quaternary litho-stratigraphy in the subsurface of the Osaka Plain is divided into Miyakojima Formation, Tanaka Formation and Namba Formation, in ascending order, with compiling of those 13 drilling data (Yoshikawa and Mitamura, 1999; Table 1). Miyakojima Formation is correlated with the Lowermost and the Lower Part of the Osaka Group. Tanaka Formation corresponds to the horizons from the upper Lower Part to Lower Terrace deposit. Namba Formation is comparable to the alluvial deposit in the Osaka Plain (Table 1). The depth of the upper surface of the basement rocks is directly recognized at several points by deep wells for pumping hot springs. Thus, total thickness of the Quaternary sediments in the western part of the Osaka Plain is at least 1500 meters.

Drilling data is useful as individual point data for the confirmation of the stratigraphy in the subsurface. Seismic reflection profiles are available for the interpolation among the drilling data. In the Osaka Plain, many seismic reflection surveys have been carried out for the investigation of the geologic structure since the 1980s (Yoshikawa *et al*., 1987; Yamamoto *et al*., 1992, i.e.). Particularly, after the Kobe Earthquake, seismic reflection survey was extensively carried out for the investigation on the Quaternary fault activity not only in the Osaka Plain but also in the Osaka Bay by several organizations (Osaka City, 1996; Sugiyama, 1997; Yoshioka *et al*., 1998, i.e.). The distribution of the basement rocks under the Osaka Plain is clarified as the results of those seismic surveys and gravity survey., Vertical displacement of the basement rock is estimated about 1000 meters along the Uemachi Fault running north and south in the central part of the Osaka Plain.

## 3. ORDERLY DISTRIBUTION OF THE MARINE CLAY BEDS

The thick conformable sequence of the Quaternary sediments is confirmed with drilling data (OD-1, OD-3, OD-6, TS, HA) located at the western and eastern lowland area in the Osaka Plain. Thickness of the sediment underlying in and around the Uemachi area is thinner than the lowland areas. With all things considered, the depth of the horizon of the same marine clay bed in the lowland areas is deeper than the Uemachi area.

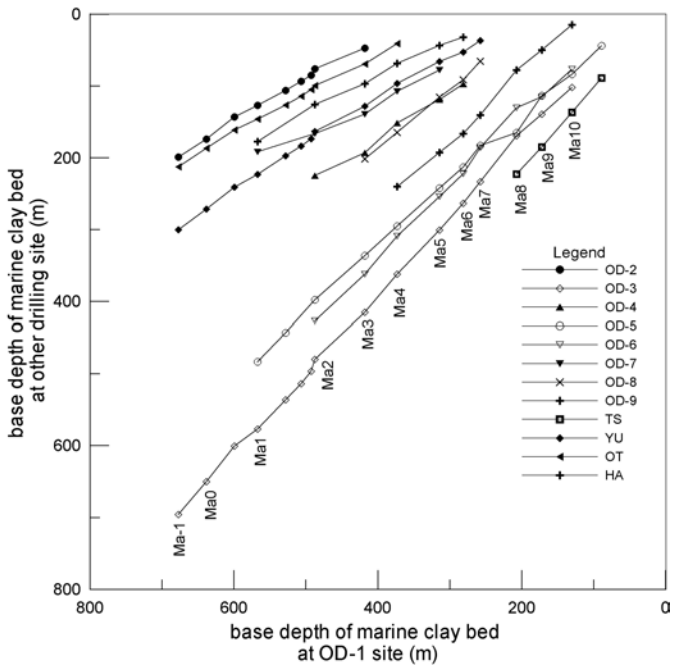


**Figure 3. Correlation of base depth of marine clay beds between OD-1 site and the other sites.**

Figure 3 shows the correlation on the basal depth of each marine clay bed between the OD-1 site and the others. The depth distributions of the marine clay beds at the drilling sites have clearly positive correlations with the distribution at the OD-1 site. The basal depth distributions of marine clay beds at the OD-5, TS, OD-3, OD-6 and HA

have linear relations with nearly 1:1 gradient to the distribution at the OD-1 site. Meanwhile, the distribution of marine clay beds at OD-2, OD-9, OT and YU sites located in the Uemachi area have linear relations with gentle gradient. Those gentle gradients indicate that thickness of the Quaternary formation is generally thin in the subsurface of the Uemachi area. Those linear relations suggest that the Quaternary formation in the Osaka Plain has been formed in the orderly relation between subsidence of basin and sedimentation.

Those relationships between the depth distribution ($X$) of marine clay beds at the OD-1 and the distribution ($Y$) at the other sites are analyzed by least square with a linear expression of $Y=aX-b$ ($a$: coefficient on thickness; $b$: coefficient on vertical displacement). Table 2 shows the result of the analysis. All correlation coefficients ($R$) are over 0.99. The coefficient on thickness ($a$) of the sites in the lowland area is near 1.0. Meanwhile, the coefficients on thickness of the Uemachi area, approximately 0.5, indicate that the thickness of the Quaternary formation almost equals half of the thickness in the OD-1 site. The large values of coefficients of vertical displacement ($b$) of the Uemachi area suggest the relative uplift to the lowland area.

Basal depths of each marine clay bed are converted to the depth at the OD-1 site with those relational expressions. Then, the converted depths are averaged with respect to each marine clay horizon. A probability distribution curve on basal horizons from Ma-1 to Ma10 beds at the OD-1 site is made with averages and standard deviations of those converted depth data.

This probability distribution curve indicates the standard distribution of the marine clay beds in the Osaka Plain. The distribution of marine clay bed at any point in the Osaka Plain can be explained with this curve and the two coefficients on thickness (vertical expanding and contracting of the curve) and vertical displacement (vertical shifting of the curve). Thus, this curve makes it possible to correlate between seismic reflection profiles and horizons of marine clay beds. The correlation of seismic reflection profiles using with this curve is mentioned as follows.

More than 20 seismic reflection surveys are carried out in the Osaka Plain. In the Osaka Bay, many acoustic reflection survey lines are located. Many profiles are made by those surveys. In those profiles, reflectors on boundary between the upper layer of low acoustic impedance and lower layer of high acoustic impedance are plotted with phases filled black in trace of the CMP combine. These well-continuous reflectors can be correlated with basal planes of marine clay beds.

**Table 2. Coefficient of the linear expression between OD-1 and the others.**

| | a | b (m) | R |
|---|---|---|---|
| OD−2 | 0.59 | 208 | 0.997 |
| OD−3 | 1.09 | 46 | 0.999 |
| OD−4 | 0.63 | 80 | 0.995 |
| OD−5 | 0.88 | 33 | 0.999 |
| OD−6 | 1.00 | 63 | 0.998 |
| OD−7 | 0.52 | 85 | 0.990 |
| OD−8 | 0.83 | 146 | 0.999 |
| OD−9 | 0.47 | 101 | 0.996 |
| TS | 1.14 | 11 | 0.999 |
| YU | 0.62 | 129 | 0.998 |
| OT | 0.55 | 166 | 0.998 |
| HA | 0.96 | 112 | 0.997 |

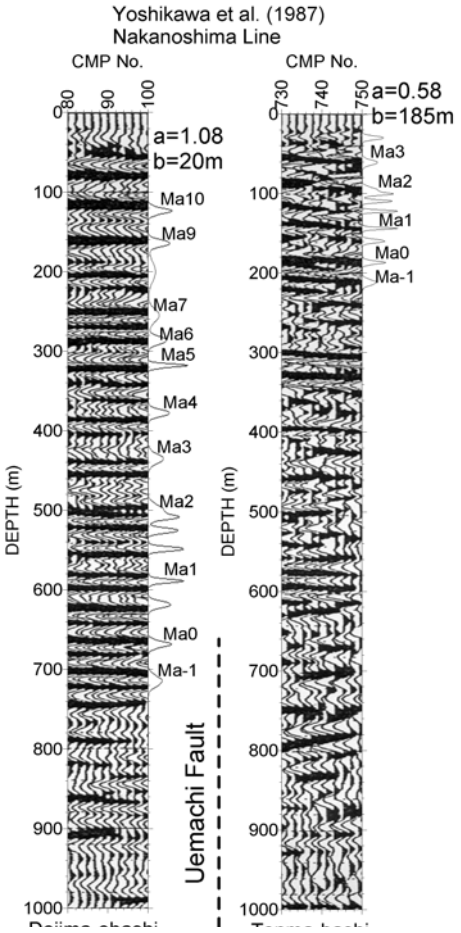


**Figure 4. Examples of the correlation between the seismic profile and the standard curve of the marine clay distribution.**

Consequentially, these traces in seismic profiles are correlated with the probability distribution curve on the distribution of marine clay beds with the two coefficients on thickness (*a*) and vertical displacement (*b*). Fig. 4 shows a example of the correlation.

## 4. COMPILE OF THE STRIP MAP

Geologic map in the hilly area, drilling data in the plain and correlated seismic profiles are used for making strip maps on the horizon of each marine clay bed. The strip map signifies the morphology stripped the overlying strata above the horizon of each marine clay bed from topographic map. Figure 5 shows several examples of the strip map in the Osaka Plain.

The strip map of the base of the Ma13 marine clay bed deposited at Holocene transgression mainly made with the database of shallow drilling indicates the paleo-topography adjacent Holocene transgression at 10 ka. The strip map of the horizon of older marine clay beds indicates tectonic movements of the basement rocks. For example, the strip map of Ma3 marine clay bed shows vertical displacement along the Uemachi Fault running north and south in the central part of the Osaka Plain. The vertical displacement of the Ma3 bed along this fault ranges from 250 m to 400 m. In the east part of the Osaka Plain, the distribution of the base of the Ma3 bed is higher in the northwest part than the southeast part. This distribution suggests the tilting of the basement block framed by active Quaternary faults such as Uemachi, Ikoma and Arima-Takatsuki faults. Meanwhile, there are several small basement blocks and generally dip to the center of the Osaka Bay in the west side of the Uemachi Fault. The base horizon of the Ma3 bed is correlated with the base boundary of the 21st stage of the $\delta^{18}O$ stratigraphy of deep sea sediments (Yoshikawa and

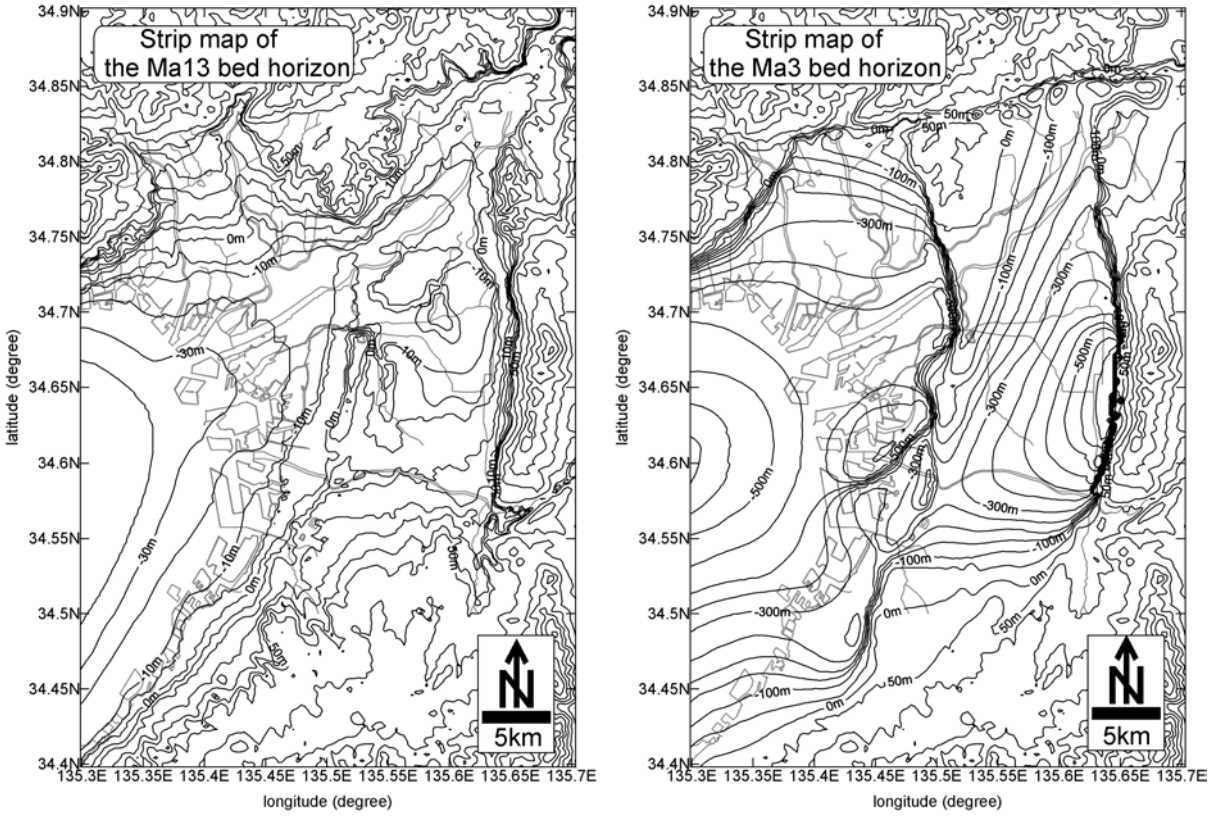


**Figure 5. Examples of the strip map Ma13(Holocene marine clay bed) and Ma3(Marine clay bed at 0.87Ma) in the Osaka Plain.**

Mitamura, 1999). Therefore, the distribution of the basal horizon of the Ma3 bed indicates the same time horizon at 0.865Ma.

## 5. CONCLUDING REMARKS

The thick Quaternary formation in the Osaka Plain is formed by the tectonic subsidence of basement blocks and global sea level change. The result of the statistic investigation of the depth distribution of marine clay beds in the subsurface of the Osaka Plain made it appear that the marine clay distribution is explained with the linear relationship to the standard stratigraphy at the OD-1 site. That linear relationship is available to correlation between the seismic profile and litho-stratigraphy of the Quaternary formation.

The strip maps on the main horizons of marine clay base in the Quaternary formation are made with drilling data and correlated seismic profiles. Because those marine clay horizons are correlated with the $\delta^{18}O$ stratigraphy of deep sea sediments, the each strip maps indicate distribution and geologic structure on the same time horizon. Therefore, those strip maps are useful as base map on subsurface structure in the Osaka Plain for 3D basin analysis.

## 6. REFERENCES


Ikebe, N., Iwatsu, J., Takenaka, J., 1970. Quaternary Geology of Osaka with special reference to land subsidence. *Jour. Geosci., Osaka City Univ.*, Vol 13, 39-98.

Itihara, M. Yoshikawa, S., Inoue, K., Hayashi, T. Tateishi, M. and Nakajima, K., 1975. Stratigraphy of the Plio-Pleistocene Osaka Group in Sennan-Senpoku area, south of Osaka, Japan. *Jour., Geosci, Osaka City Univ.*, Vol 19, 1-29.

Itihara, M., Kamei, T., Yoshikawa, S. and Nasu, T., 1987. Late Neogene and Quaternary stratigraphy of Kinki District, Japan. *Proc. First Inter. Strati., Asia and Pacific Area, Osaka,* 1986, 74-83.

Osaka City, 1996. *Research Report on the Uemachi fault*. Osaka City, 224p.

Osaka Group Research Group, 1951. Osaka Group and the related Cenozoic formations. *Chikyu-Kagaku* (*Earth Science*), Vol 6, 13-24.

Sugiyama, Y., 1997. Seismic reflection survey of the Uemachi fault system. *Res. Doc. Geol. Survey Japan*, No. 303, 105-113.

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-. *Proc. 1992 annual meeting of the Japan Soc. of Eng. Geol.*, 185-188.

Yoshikawa, S. and Mitamura, M., 1999. Quateranry stratigraphy of the Osaka Plain, central Japan and its correlation with oxygen isotope record from deep sea cores. *The Jour. Geol. Soc. Japan*, Vol 105, 332-340.

Yoshikawa, S., Mitamura, M., Nakagawa, K., Nagahashi, Y., Iwasaki, Y., Echigo, T., Tsujie, K. and Kitada, N., 1998. Lithostratigraphy and tephrostratigraphy of the Tsumori, Otemae and Hama drilling cores in the Osaka Plain, central Japan. *The Jour. Geol. Soc. Japan*, Vol 104, 462-476.

Yoshikawa, S., Tsukuda, E., Mitamura, M., Nakagawa, K., Mizuno, K., Higashiwaki, A., Kataoka, K. and Tkahashi, M., 1997. Litho- and tephrostratigraphy of the Yuhigaoka boring cores from the Osaka Plain, central Japan. *Bulletin of the Geological Survey of Japan*, Vol 48, 661-672.

Yoshikwa, S., Machida, Y., Teramoto, M., Yokota Y., Nagao, H. and Kajiwara, M., 1987. Seismic reflection survey in Osaka City. *Proc. 77th Spring Tech. Meetings Soc. Explor. Geophys. Japan*, 114-117.

Yoshioka, T., Kano, N., Yamaguchi, K., Miyazaki, M., Ikawa, T., Ohta, Y., Kawanaka, T. and Abe, S., 1998. Seismic profiling of deep geological structure in the Osaka Bay area. *Bull. Geol. Survey Japan*, Vol 49,571-590.