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Stratigraphy and Subsurface Structure of Holocene Deposits around Uemachi Upland in the Central Osaka Plain

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(With 17 Figures and 2 Tables)

Abstract

This paper presents results of a recent geological study of the Holocene deposits in the Osaka Basin, especially at the central area around Uemachi Upland. The study was based upon the analysis of a large number of borehole data compiled in the computer database. ^{14}C datings of fossils sampled by boring and excavation sites were carried out at several key sites and used to interpret the processes of deposition. The Holocene deposit, named the Umeda Formation, is subdivided into three layers by facies. In some marginal zones at Tenma around the Uemachi Upland, where the Holocene deposit fades out, dense sand and gravel layers were found and were considered Pleistocene deposits without any geological indication. The subground structures in the Osaka Plain were obtained in vertical sections along eight lines; they show not only Holocene but also Upper Pleistocene structures in the area. Based upon ^{14}C dating, the marginal facies of sand and gravel layers around the Uemachi Upland were identified as Holocene deposits. They are interfingered with the main clay layer facies of the Umeda Formation. Other tectonic structures like flexures as well as geotechnical aspects are also discussed.

Key Words: stratigraphy, geological structure, ground subsidence, consistency, Holocene, Osaka Plain

1. Introduction

The underlying, unconsolidated formation in the Osaka Plain was defined as the Umeda Formation (Holocene) by YAMANE (1930). A great deal of effort has been made to detamine the stratigraphy of the formations underlying the Osaka Plain (Table 1; Ikebe *et al.*, 1970; MAEDA, 1976; FURUTANI, 1978). This formation has been recognized as a problem from the standpoint of the civil engineering; its identification was based on standard penetration tests (N-value) (The Publication Committee of the Ground of Osaka, 1966 ; MIKI *et al.*, 1987).

We have investigated the formation in the West Osaka area of the Osaka Plain (Fig. 1) with the database system of borehole data (HAYASHIDA *et al.*, 1987a ; IWASAKI *et al.*, 1990 ; YAMAMOTO *et al.*, 1992) and ^{14}C dating (MITAMURA, 1991; MITAMURA

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et al., 1992 ; MITAMURA and MIKI, 1992). This paper presents the results of detailed studies of the stratigraphy and the geological characteristics, of the Holocene formation in this area.

2. Alluvial Formation

The Alluvial Formation was at first defined as Holocene and named the Umeda Formation by YAMANE (1930). Since then, the Publication Committee of the Ground of Osaka (1966) sorted the Alluvial Formation with the civil engineering properties of the strata , for example, sands of less than 30 in N-values and unconsolidated clays. Hence, the formation is included with the Upper Pleistocene deposits from the Würm Maximum Stage (about 20000 years ago in age). Almost all the ^{14}C ages of the formation are younger than 10000 years, with the exception of the peaty beds at Fukono and Shin-Osaka Station sites which are from 20000 to 10000 years old (KAJIYAMA and ITIHARA, 1972). From this viewpoint, the Alluvial Formation in the Osaka Plain was defined as the Namba Formation (KAJIYAMA and ITIHARA, 1972) and the Osaka Bay Formation (MAEDA, 1976), which are included in the uppermost Pleistocene.

The coarse facies at less than 20 m depth, which were correlated with the upper Pleistocene, for example, with the gravelly bed in the Tenma area and the sands in the west side of the Uemach Upland, were reconsidered as Holocene deposits (MIKI *et al.*, 1987). The ^{14}C ages of the sands, including molluscan fossils at Azuchimachi on the west side of the Uemachi Upland, are from 6000 to 3000 years old (MITAMURA, 1991). The age of the wood fossil from the sand bed underlying the gravel bed at Tenma area is 8400±120 years B.P. (MITAMURA *et al.*, 1992). It follows from what has been

Table 1. Correlation of the stratigraphy of the Pleistocene - Holocene formations in the Osaka Plain.

		Yamane(1930)	Ground of Osaka(1966) *	Ikebe *et al.* (1970)	Maeda(1976)	Furutani(1978)	Ground of Osaka(1987)**	This study
Quaternary	Holocene	Umeda Formation	Alluvial Formation: Umeda clay bed	Umeda Formation	Osaka Bay Formation: Umeda bed Nanko bed	Namba Formation: Upper part Middle part Lower part	Alluvial Formation: Upper part Middle clay bed Lower part	Umeda Formation: Upper sand bed Middle clay bed Lower alternation
	Pleistocene	Tenma Formation	Tenma Formation: Tenma gravel bed Tenma clay bed	Upper Pleistocene Formation	Tenma Formation	Tenma Formation: Upper part Middle part Lower part	Tenma Formation	Tenma Formation
		Uemachi Formation	Uemachi Formation	Ma12		Ma12	Uemachi Formation	Ma12
				Ma11				

* The Publication Committee of the Ground of Osaka (1966)
** Miki et al. (1987)

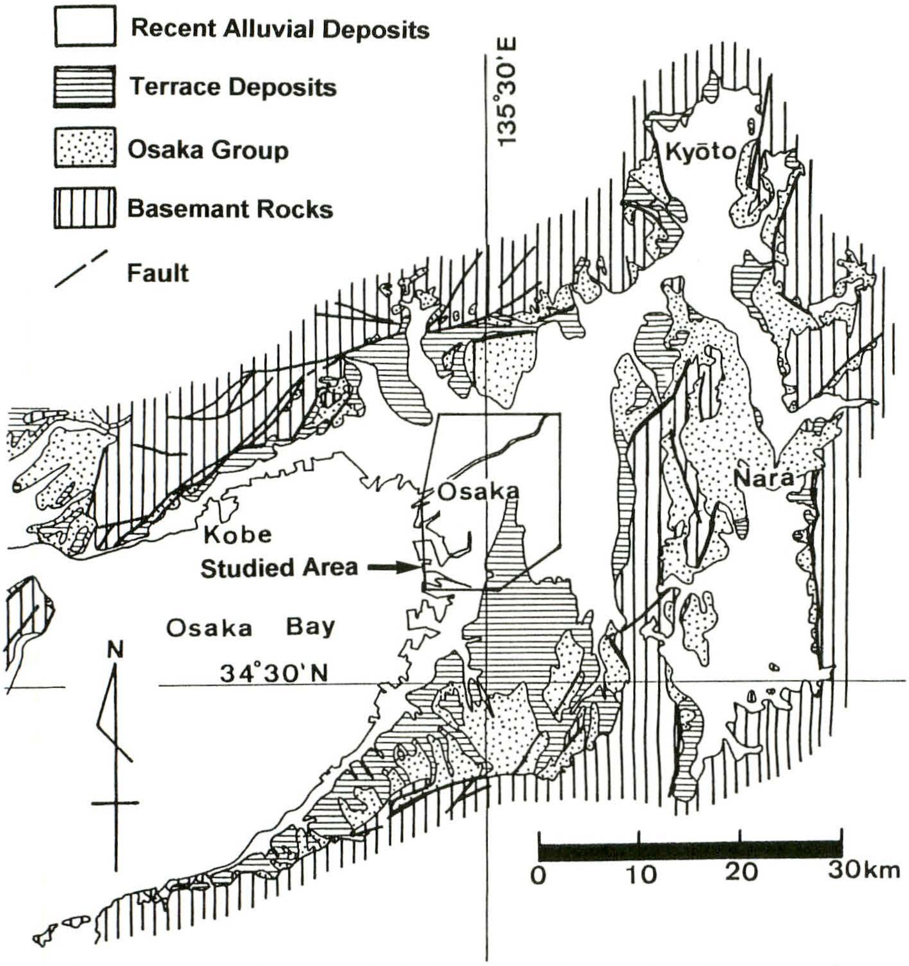


Fig. 1. Generalized geologic map of the Keihanshin area (adapted from ITIHARA *et al.*, 1991 and TANAKA *et al.*, 1982).

said that these facies are correlated with the Holocene deposits.

In addition to the above ^{14}C dating, seven fossil samples at six sites were tested, and the results of the ^{14}C dating in this study are presented in Table 2 and Fig.3. These results indicate that the Alluvial Formation, defined from the civil engineering side, is younger than 10000 years in age. In this paper, judging from the above, the Holocene deposits in the Osaka Plain are named the Umeda Formation. The Umeda Formation is described in detail below.

Table 2. ^{14}C age of the Umeda Formation.

Site No.	Location	Latitude Longitude	Alt. (OP)	Lab. No.	^{14}C Date (yrs. B. P.)	Materials
1-1	Fukushima 4chome[1]	34°41'29"N 135°29'12"E	-27.0m	OCU-45	9550±100	wood
1-2	Deiribashi[2]	34°41'37"N 135°29'37"E	-3.6m	OCU-23	1800±70	wood
			-4.9m	OCU-18	1680±60	shell
			-5.7m	OCU-17	1570±60	shell
			-7.0m	OCU-31	1930±60	shell
			-14.7m	OCU-38	3350±70	shell
1-3	Umeda 1chome[1]	34°41'42"N 135°30'04"E	-26.2m	OCU-46	9750±100	wood
1-4	Nishi-Tenma[1]	34°41'40"N 135°30'35"E	-25.2m	OCU-49		plant fragments
1-5	Minamimorimachi[3]	34°41'40"N 135°30'49"E	-19.5m	OCU-14	8400±120	wood
1-6	Amishima[2]	34°41'30"N 135°31'46"E	-7.0m	OCU-24	5520±100	shell
			-7.5m	OCU-30	5460±80	shell
			-13.0m	OCU-33	7300±90	shell
1-7	Higashi-Noda 2chome[2]	34°41'39"N 135°32'02"E	-9.0m	OCU-26	5100±100	shell
			-21.0m	OCU-27	8530±90	wood
2	Doushin 1chome[1]	34°41'51"N 135°31'06"E	-19.6m	OCU-48		wood
3	Toyosaki 3chome[1]	34°42'25"N 135°30'01"E	-24.0m	OCU-47	9480±100	wood
4	Azuchimachi 2chome[4]	34°40'54"N 135°31'31"E	-1.7m	OCU-7	4290±60	shell
			-3.7m	OCU-6	3530±60	shell
			-4.7m	OCU-4	5230±100	wood
			-4.7m	OCU-5	6190±80	shell
			-9.7m	OCU-1	7460±80	wood
			-11.7m	OCU-8	7340±70	shell
			-13.6m	OCU-9	8330±90	wood
5	Minatomachi 1chome[2]	34°39'47"N 135°29'55"E	-2.9m	OCU-19	990±60	shell
			-3.5m	OCU-20	1280±60	shell
			-5.3m	OCU-28	1570±60	shell
			-7.0m	OCU-32	1560±60	shell
			-10.0m	OCU-39	5800±80	shell

1) This study 2) MITAMURA and MIKI (1992) 3) MITAMURA *et al.* (1992) 4) MITAMURA (1991)

3. Stratigraphy and geological structure of the Umeda Formation

3.1. Stratigraphy

The Umeda Formation is the Holocene deposits which are piled up in the bay under coastal sedimentary environments by the Holocene transgression. The type locality of this formation is the area from the OD-1 site (Minato-ku Tanakamotomachi) to Kita-ku Umeda and ranges less than 30 m in depth. The formation is divided into three members: the Lower alternation (the alternation of peaty clays and sands), the Middle clay bed (soft marine clay bed), and the Upper sand bed (well sorted loose sand bed), in ascending order. These typical facies extend in the western area of a line from Nishiyokobori to Umeda. In contrast to this, the Middle clay bed changes into gravels and sands in the marginal area of the Uemachi Upland. So, the formation is not able to be divided in

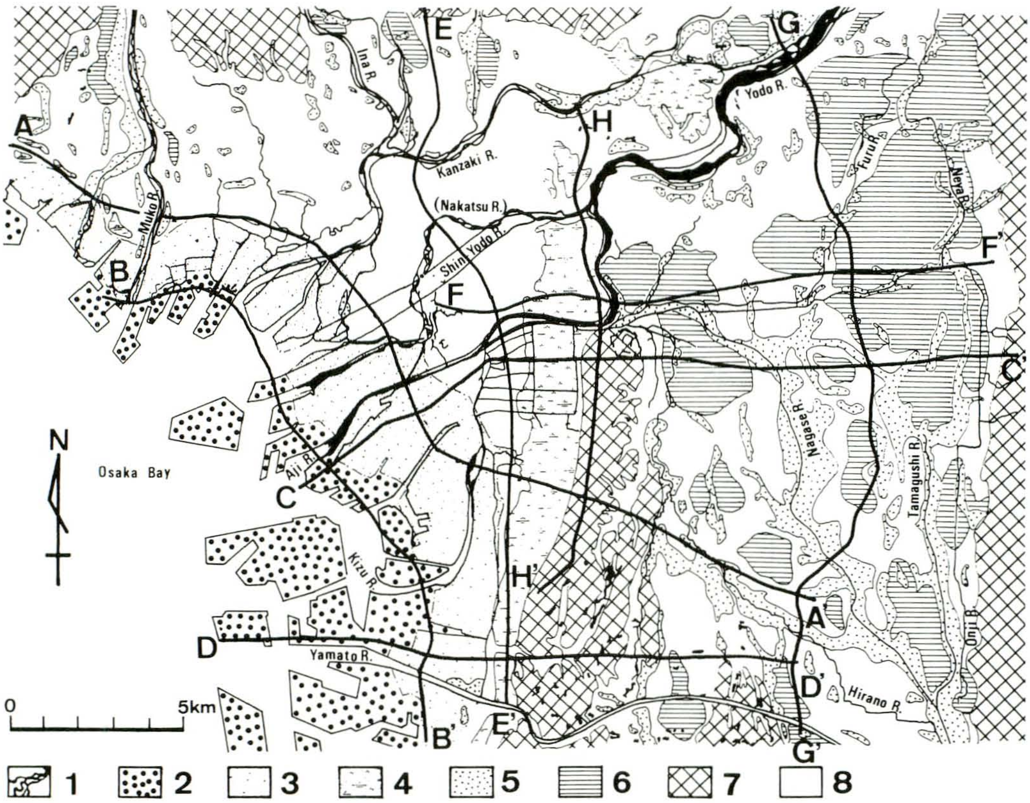


Fig. 2. Land classification map of the Osaka urban area and locality of geological profiles in Fig.5 (adapted NAKAGAWA and MITAMURA 1992).
1: abandoned river channels and irrigation ponds, **2**: lands reclaimed after 1868, **3**: lands reclaimed before 1868, **4**: bay-mouth bars, **5**: natural levees, **6**: flood basin and marsh, **7**: uplands and mountain lands, **8**: alluvial lowlands.

this area.

(1) Lower alternation

The lower alternation in the type locality ranges from OP-30 m (OP-40 m in the coastal area) to OP-20 m. It is 10000–7000 years B.P. in age and is composed of an alternation of peaty clay - silt and middle - fine sand, 3–10 m in thickness. The silt and clays are 50 cm to 2 m in thickness, with inclusions of wood fossils and plant fragments. The upper part of this member, in parts strongly bioturbated, includes molluscan fossils of *Dosinia penicillala* and *Paphia undulata*, which indicate the sedimentary environments of the muddy bottom in the bay. The clay in the lowermost part of the member include granules. The sands in the lower part of the member, include coarse sand. The member is interbeded with the Minato volcanic ash layer (YOSHIKAWA *et al.*,

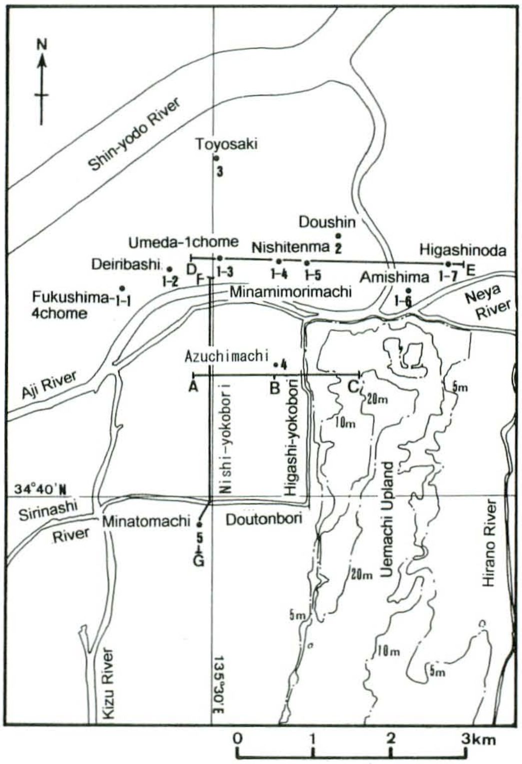


Fig. 3. Location map of ^{14}C dating site (Fig.4) and geological profile lines (Fig.7,9,10).

1986) which is correlated with the Oki volcanic ash layer (MACHIDA *et al.*, 1981).

This member overlaps the Upper Pleistocene Formation (including the Tenma Formation, Ma11, and Ma12 bed; IKEBE *et al.*, 1970) and the Osaka Group (Plio-Pleistocene; ITIHARA *et al.*, 1984) in the lowland area, and abuts the basement formation in the Uemachi Upland. Because the member becomes finer upward, the boundary with the Middle clay bed is not well defined. The lower alternation is correlated with the Nanko bed in the Osaka Bay Formation (MAEDA, 1976) and the Lower part of the Namba Formation (FURUTANI, 1978).

(2) Middle clay bed

The Middle clay bed ranges from OP-20 m (OP-30 m in coastal area) to OP-8 m. It is 7000–2000 years B.P. in age, consists of pale gray marine clay, 10–15 m in thickness, and extends widely in the West Osaka area. The middle part is composed of massive clay, with *Paphia undulata*. The lower and upper part consists of silty clay, with *Dosinia penicillala* and *Paphia undulata*, in parts strongly bioturbated. Clay of the upper part grades upward into sandy silt. The lower part interbeds with the Yokooji volcanic ash

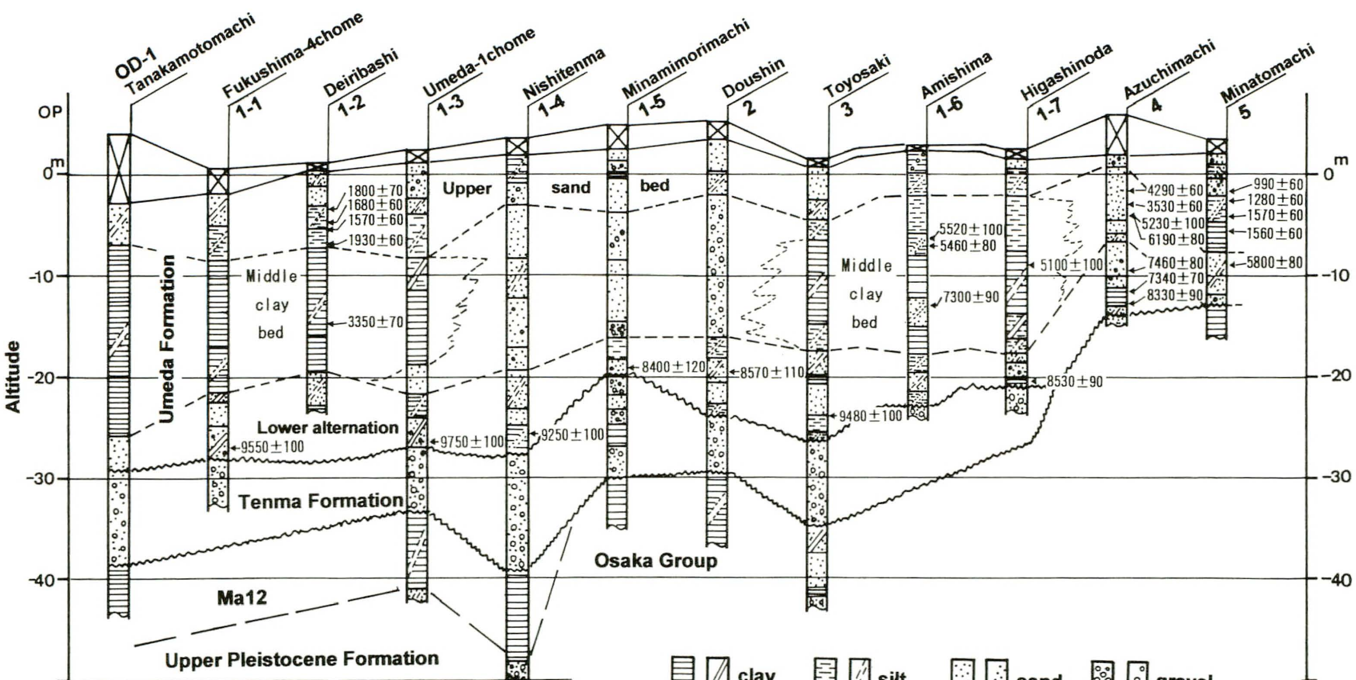


Fig. 4. Geological columns and ^{14}C ages.

layer (YOSHIKAWA *et al.*, 1986) which is correlated with the Akahoya volcanic ash layer (Machida and Arai, 1978). In the marginal area of the Uemachi Upland, this bed becomes middle-coarse grained sand, with molluscan fossils, and becomes gravel layer on the northern side of the Uemachi Upland.

(3) Upper sand bed

The Upper sand bed extends above OP-8 m under ground, It is 7000–2000 years B.P. in age, 5–10 m in thickness, and consists of gray to dark brown, loose, well sorted with cross lamination, coarse sand, including medium sand to granules, and interbedded with, in parts, thin silt layers. These beds become brackish or fresh silt beds to the east side of the Uemachi Upland.

3.2. Distribution and Facies

This study investigated the Umeda Formation with the borehole database system (HAYASHIDA *et al.*, 1987b; YAMAMOTO *et al.*, 1992) and ^{14}C dating. ^{14}C ages, facies, and N-values are regarded as important indices to the subdivision and the continuity of the formation. Fig. 5 shows the geological profiles of the Osaka Plain with the borehole database system. The typical facies of the Umeda Formation extends widely in the west Osaka Area. On the other hand, in the west and north side of the Uemachi Upland, the facies of the formation become the gravelly facies. In this paper, the facies in the type locality is defined as the main facies, the gravelly facies is the marginal facies.

3.2.1. Main Facies

The main facies of the Umeda Formation is characterized by the Middle clay bed which is more than 10 m in thickness. The profiles of A-A' and B-B' in Fig. 5 show the typical distribution of the main facies of the Formation in west Osaka and the coastal area. The east to west profile in the Osaka Plain (Fig. 5 C-C') shows that the main facies extends in the east side of the Uemachi Upland. These geological profiles show that the main facies of the Umeda Formation unconformably overlies the Tenma Formation.

The Lower alternation of Umeda Formation fills up the channel which eroded Ma12 at the Samondo River in the A-A' profile. Because the Lower alternation of the Umeda Formation unconformably overlies a gently rolling upper plane of the Tenma Formation, the alternation varies markedly in thickness. On the other hand, the boundary between the Lower alternation and the Middle clay bed is a flat plane, which forms OP-20 m in height and dips to the coastal area. The distribution of the Lower alternation and its peaty facies shows the brackish and coastal sedimentary environments at 7000 years B.P.

The Middle clay bed horizontally overlies the Lower alternation and ranges from OP-20 m to OP-8 m. The clay bed thickens to the coastal area, but thins towards the marginal area of the Uemachi Upland and interfingers with gravels and sands of the marginal facies.

The Upper sand bed conformably overlies the Middle clay bed and is 10 m in thick. Along the Muko River, the Kanzaki River, the Aji River, and the Okawa River, this bed shows an increase in grain size. In the Tenma area, especially, the Upper sand bed becomes a gravelly bed (the F-F' profile in Fig. 5). The profile E-E' in Fig. 5 shows the stratigraphical relations between the Umeda Formation and the underlying formations. In the northern area of the Osaka Plain, Ma11 and Ma12 beds dip to the south. the Ma12 bed is slightly folded in at the Doutonbori River, and dips steeply northeast at Sakuragawa. The Pleistocene formation underlying Ma12 is folded and tilted by faults of the basement rocks. The Tenma Formation overlying Ma12 and the lower Pleistocene dip southward, resulting in a clino-unconformity to the Umeda Formation.

Fig. 6, which is compiled from borehole data at 13000 sites in the Osaka Plain, shows the contour map and the isopach map of the Umeda Formation. The contour map of the basal plane of the Umeda Formation (Fig. 6a) signifies the paleotopography before the deposition of the Umeda Formation. The paleotopography shows a broad, southwest-trending valley of the Paleo-Yodo River, the broad north-trending Uemachi Upland, and valleys of the Neya River, Nagase River, and Hirano River in the eastern part of the Osaka Plain. The contour map of the basal plane of the Middle clay bed shows the Paleo-Yodo valley across the northern area of the Uemachi Upland, a broad, gently undulating valley in the east area. The valley of the Paleo-Yodo River is shifted to the north by a bank running north and south at the stage of the deposition of the Upper sand bed (Fig. 6c). In this stage, the valley in the east area is reduced.

Fig. 6e shows the distribution of the Middle clay bed. This distribution is in accord with the isopach contour of the Umeda Formation's 10 m in thickness (Fig. 6d). Hence, the distribution of the marginal facies, which is the coarse facies of the Umeda Formation less than 10 m in thick, is consistent with the outside of the middle clay distribution.

3.2.2. Marginal Facies

The Umeda formation, which is composed of three facies, is modified at the marginal zone near the Uemachi Upland. In the marginal zone, the middle clay begins to inter-finger with sand and gravel layers, and finally fades out. This can be seen in the borehole data sections of A-A', B-B', C-C', D-D', E-E', F-F', G-G', and H-H'. The following three sections are selected to demonstrate the process of inter-fingering deposits in the merginal zone based upon ^{14}C datings. The depositional sedimentary environment is also shown as intertidal to the sandy shore-face zone, based upon fossil considerations.

(1) Tenma area E-W section

The Tenma Area, located at the north of the Uemachi Upland, and several

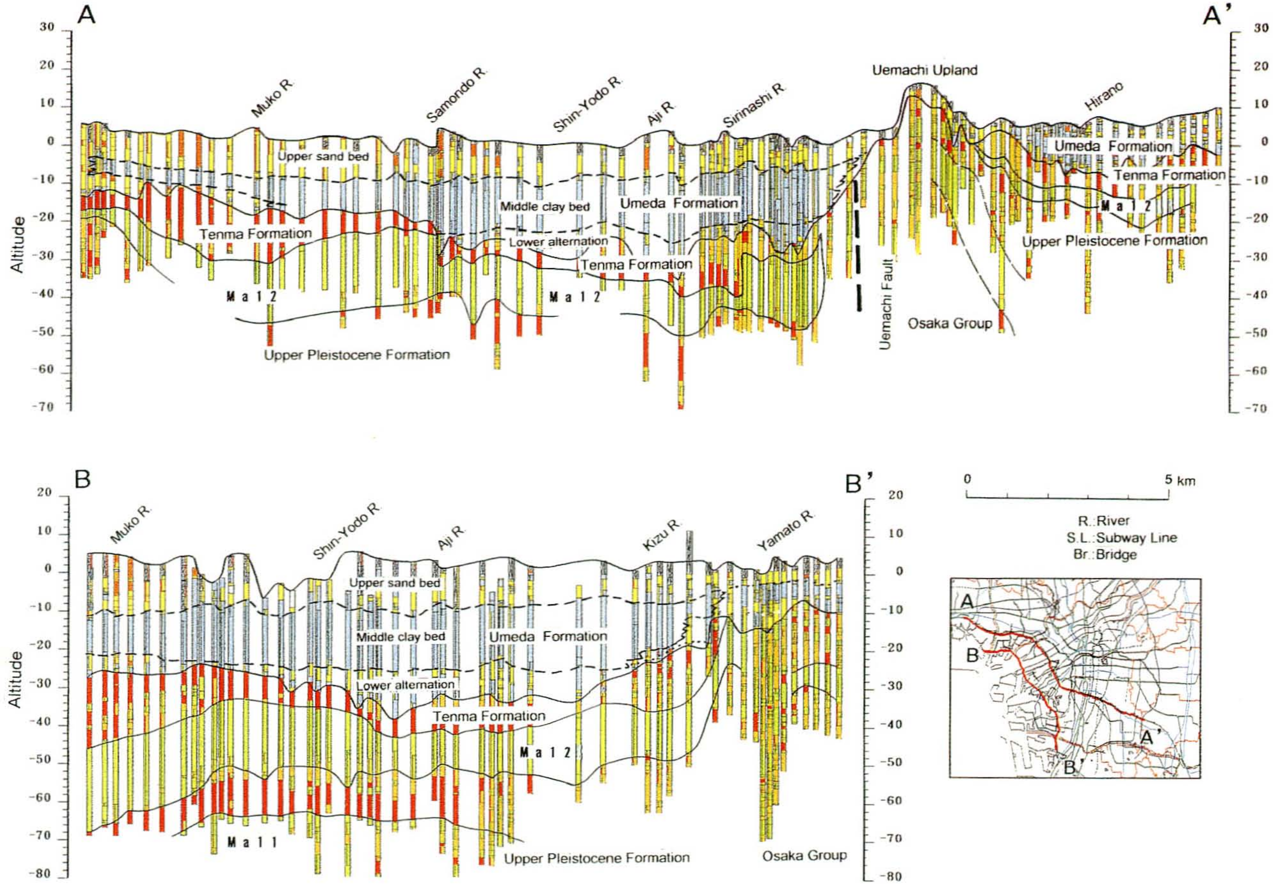


Fig. 5a. Geological profile of the Osaka Plain (adapted from MATSUYAMA *et al.*, 1992).
Colors in geological columns and facies: Umeda Formation (orange: gravel, yellow: sand, light blue: clay), Pleistocene formation (red: gravel, orange: sand, light green: clay).

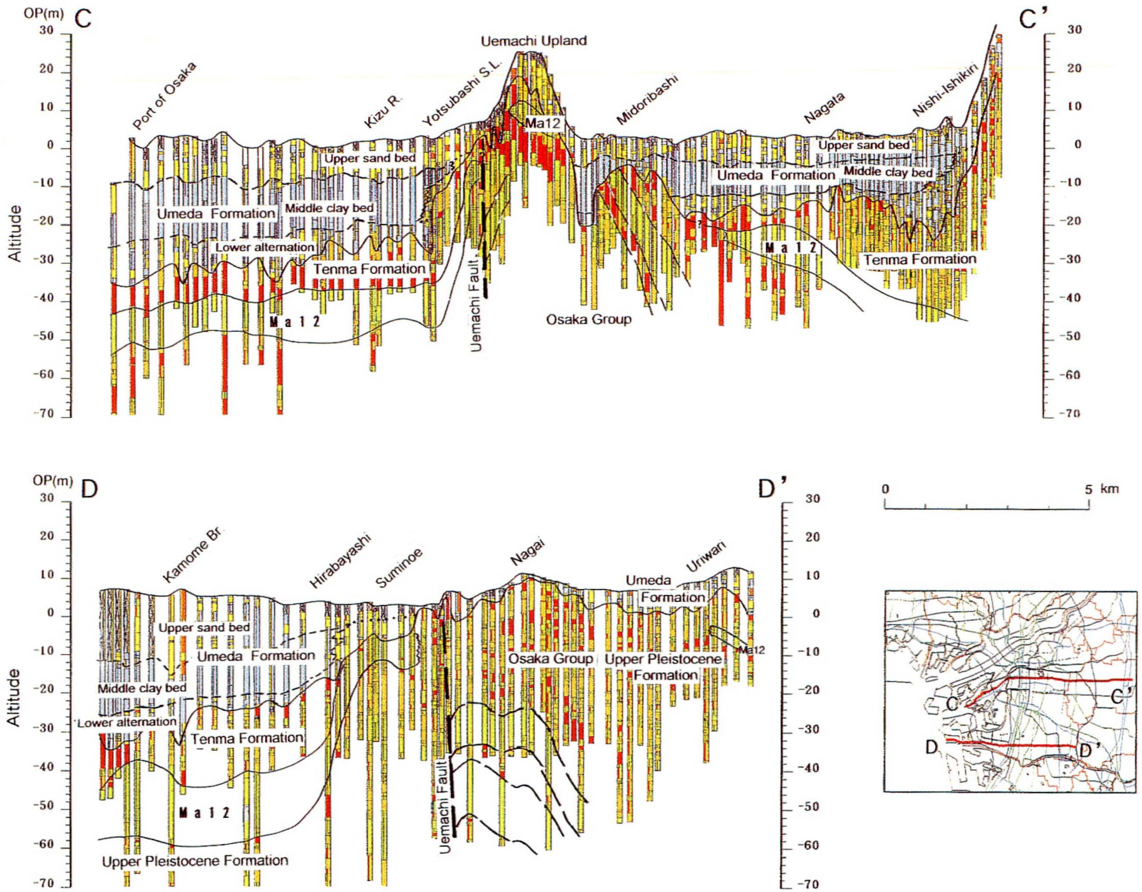


Fig. 5b. Geological profile of the Osaka Plain (adapted from MATSUYAMA *et al.*, 1992).

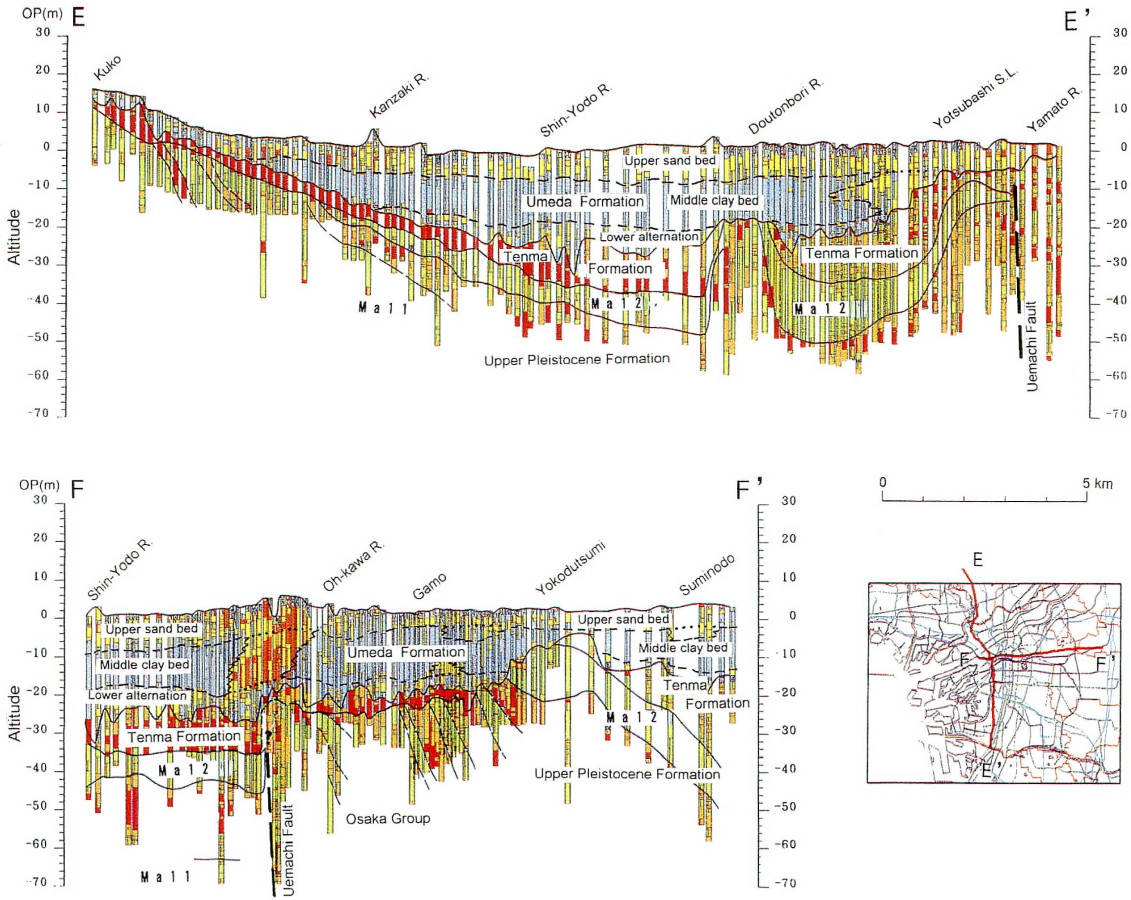


Fig. 5c. Geological profile of the Osaka Plain (adapted from MATSUYAMA *et al.*, 1992).

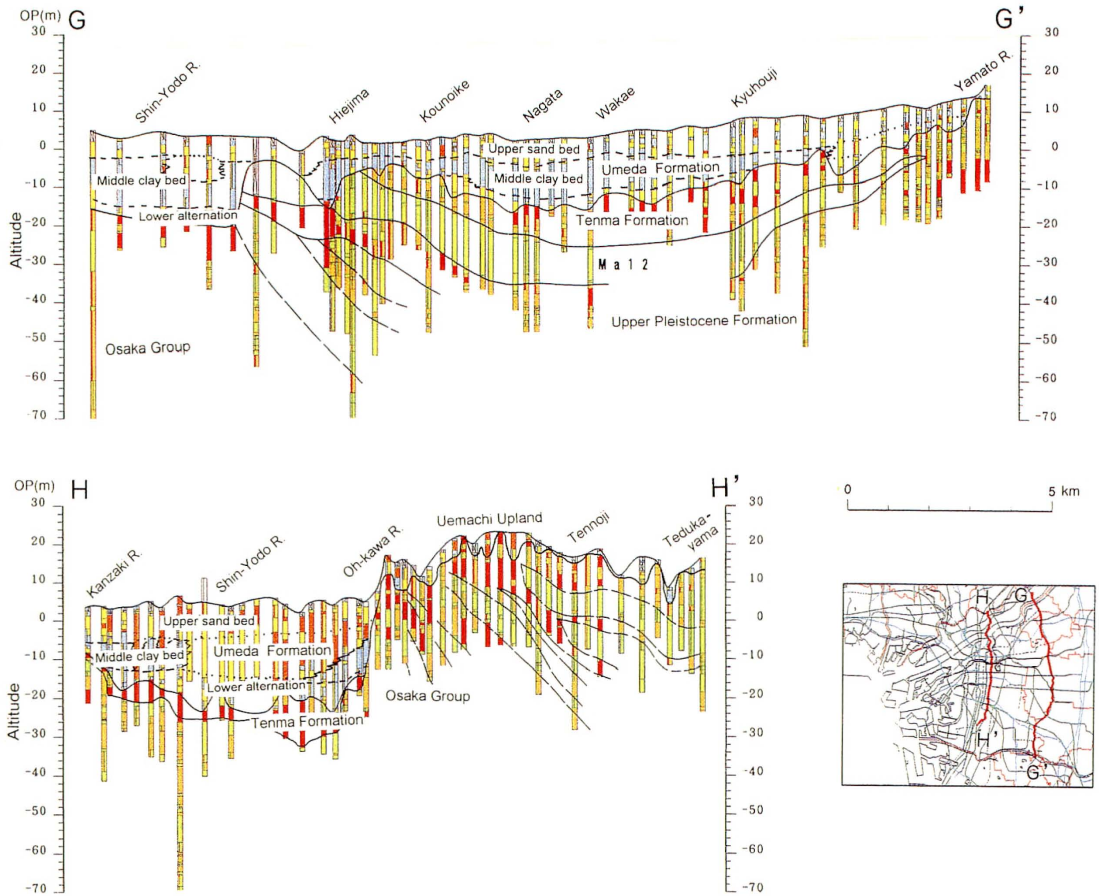


Fig. 5d. Geological profile of the Osaka Plain (adapted from MATSUYAMA *et al.*, 1992).

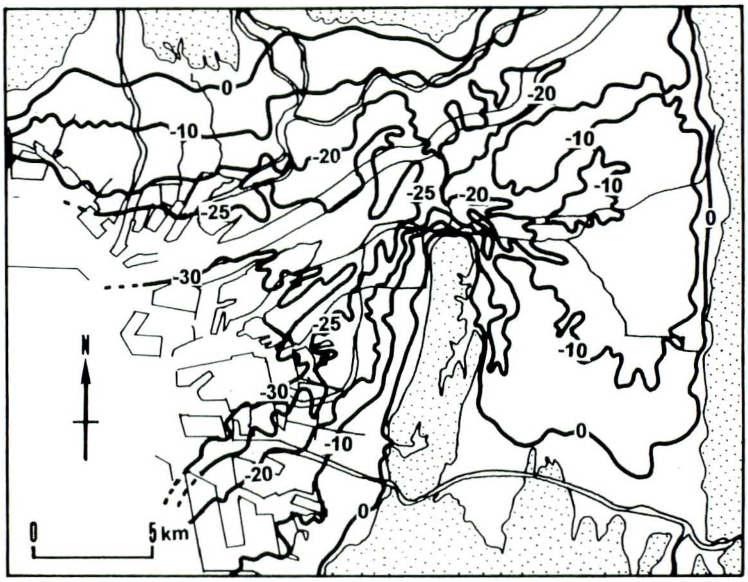


Fig. 6a. Contour map of the base of the Umeda Formation (altitude from OP in meters, adapted from MATSUYAMA *et al.*, 1992).

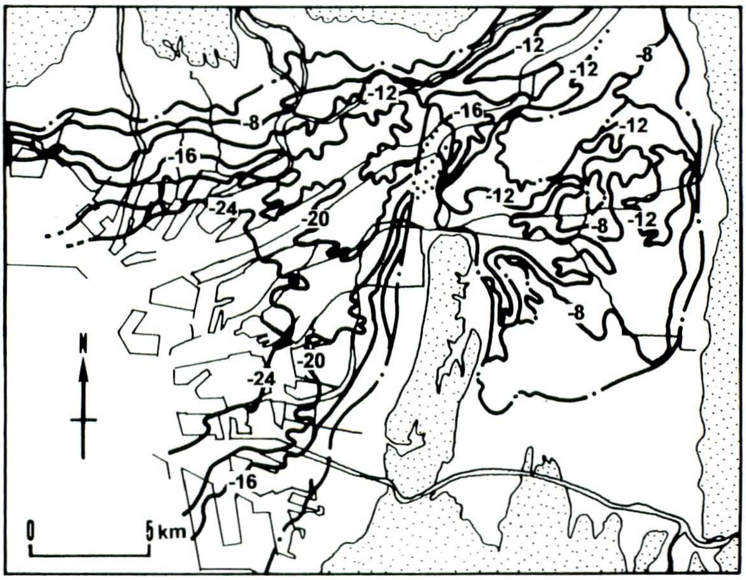


Fig. 6b. Contour map of the base of the Middle clay bed (altitude from OP in meters, chain line: marginal line of the Middle clay bed, adapted from MATSUYAMA *et al.*, 1992).

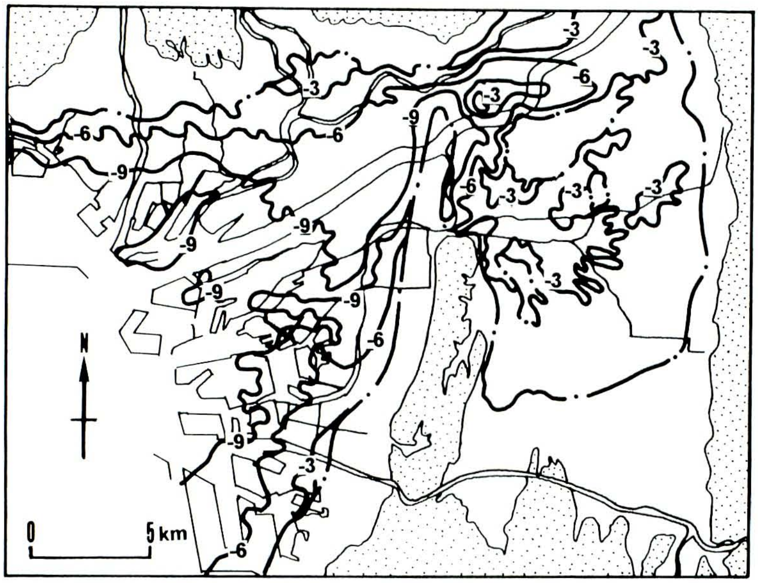


Fig. 6c. Contour map of the base of the Upper sand bed (altitude from OP in meters, chain line: marginal line of the middle clay bed, adapted from MATSUYAMA *et al.*, 1992).

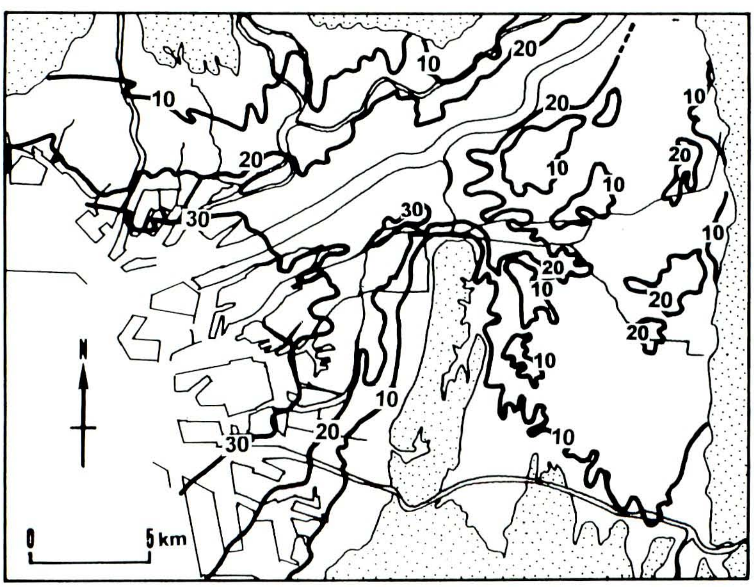


Fig. 6d. Isopach map of the Umeda Formation (thickness in meter, adapted from MATSUYAMA *et al.*, 1992).

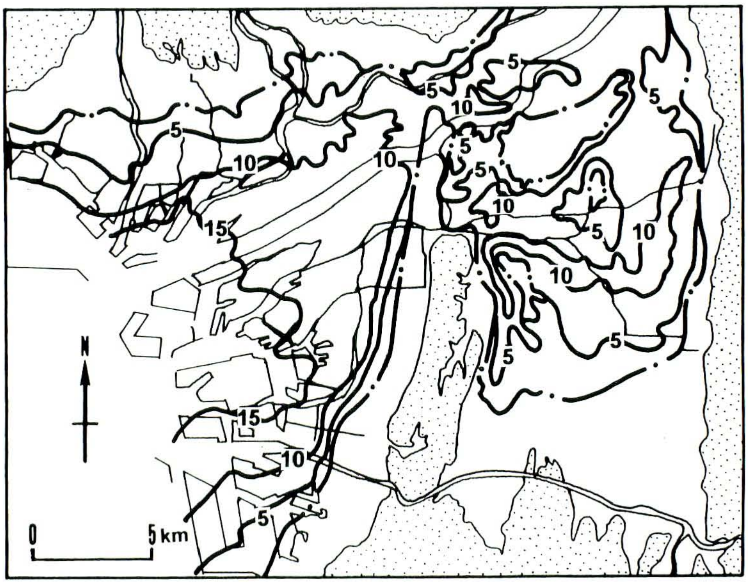


Fig. 6e. Isopach map of the Middle clay bed (thickness in meters, chain line: marginal line of the middle clay bed, adapted from MATSUYAMA *et al.*, 1992).

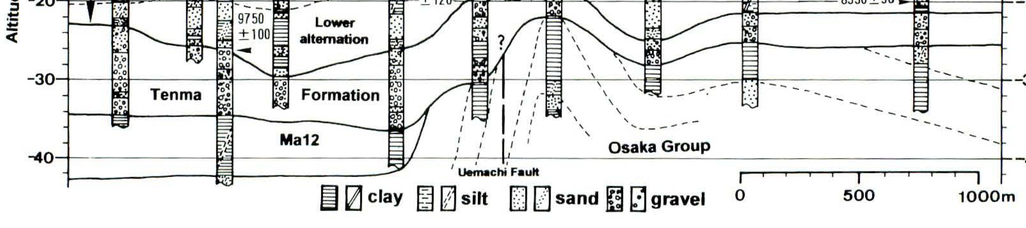


Fig. 7. Geological profile in the Tenma area (the location is shown in Fig.3).

borehole logs in an E-W direction, are shown in Fig. 7.

The Upper sand bed and the lower alternation layer are found continuously. From the point D to 1–3, however, the Middle clay bed of the Umeda formation fades out and the sand and gravel formation prevails. This sand and gravel layers were considered as of Pleistocene before 10000 years based upon dense character of the deposites (the Publication Committee of the Ground of Osaka, 1966). A piece of fossil wood was found at the depth OP-19.5 m during boring study at point 1–5 for a subway construction. The ^{14}C age was determined as 8400 ± 120 years B.P., which means that the sand and gravel layer above OP-19.5 m is the same deposit in the Holocene age as the main facies of the Middle clay bed of the Umeda Formation. The clay and sand-gravel layers in the Tenma area are inter-fingering each other, and are also considered as characteristic of marginal facies.

(2) Azuchimachi area E-W section

Fig. 8 shows the E-W geological profile at the marginal zone near the Uemachi Upland. In the profile, the marginal facies unconformably overlies the Pleistocene deposits which are steeply tilted to west by the Uemachi Fault. The terrace-wise plane of unconformity was made by the rise of the coastal line with the Holocene transgression. The ^{14}C dating was made for the several fossils at Azuchimachi excavation site No.4 (see Fig. 3), which is about 100 m north of the point B in Fig. 8. As the Umeda Formation increases its thickness northwards in this area, the clay layer in the alternation at the point B in Fig. 8 corresponds with the clay layer at about OP-12 to OP-14 m of the log in Fig. 9. At this site, a medium-sized sand layer from OP 0 to OP-7 m includes molluscan fossils and sand pipes, which indicate that the sedimentary environment was from the intertidal to sandy shore-face zone. Datings of ^{14}C of this sand layer were from 4000 to 6000 years B.P., and correlate with the Middle clay bed of the main facies. Under this sand layer, datings of ^{14}C indicate 7000 to 8000 years B.P. for the lower alternation layer in the Umeda Formation.

(3) Nishiyokobori N-S section

Fig. 10 shows geological profile of the N-S section along the Nishiyokobori Creek. The Midddle Clay bed grades southward into a sand layer with molluscan fossils. The ^{14}C ages of these molluscan fossils in the layer are younger than 6000 years B.P. The results of ^{14}C dating for the fossils at the point 5 is shown in Fig. 11. Fossils found in the upper part of this sand layer indicate the coastal brackish environments; those in the lower part indicate the environments of the intertidal to sandy shore-face zones.

3.3. Geological Structure

The investigation about the distribution and facies of the underlying formations in the Osaka Plain with the boring database system has revealed the geological structure in detail, so that the two flexures which accompany the Uemachi Fault were

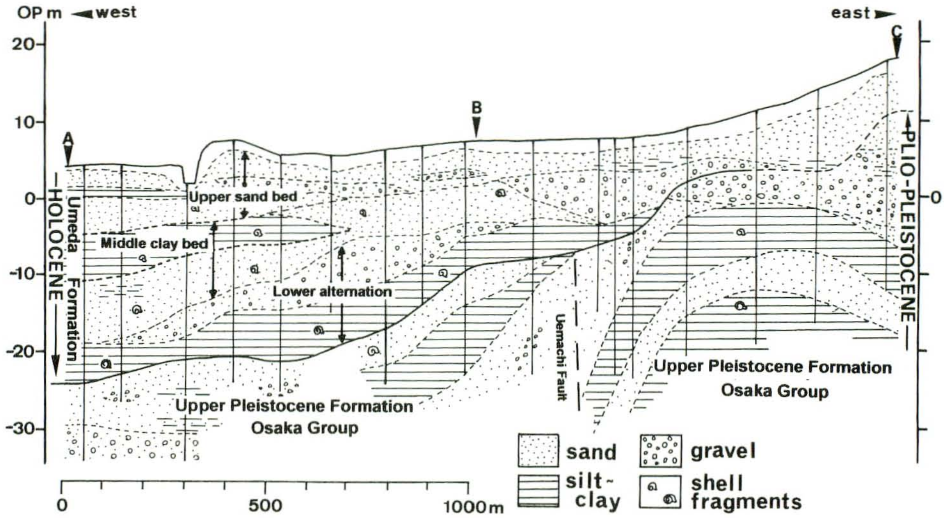
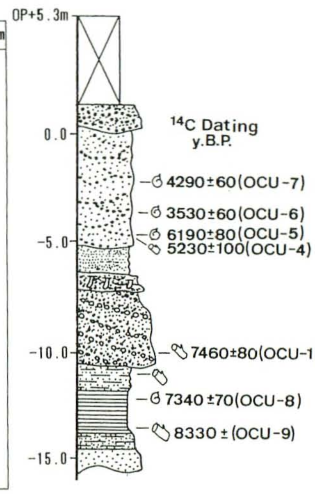


Fig. 8. Geological profile along the Chuou-ohdori street (the location is shown in Fig.3, adapted from MITAMURA 1991).

Species	Habitat Zone	OP-2.7m	OP-3.7m	OP-4.7m	OP-11.7m
MOLLUSCA					
Umbonium moniliferum	T-S	○	○		
Serpulorbis imbricatus	T		○		
Batillaria multiformis	T		○		
Cerithideopsilla djadjariensis	T		○		○
Ochetoclava kochi	T-S	○	○		
Doxander vittatus japonicus	S		○		
Neverita didyma	T-S	○.	○		
Zeuxis succincitus	S				○
Pecten albicans	S	○	○		
Chlamys aspelata pelseneeri	S	○			
Crassostrea gigas	T-S		○		
Ostrea denselamellosa	T-S			○	
Anodontia stearnsiana	M		○		
Callista chinensis	T-S	○			
Dosinia japonicus	S	○			
penicillala	M				○
Paphia undulata	M				○
Protothaca jedoensis	T-S	○			
Mactra chinensis	S-M	○	○		
Venatomya truncata	T-M	○			
Soletellina boeddinghausi	T-S	○			
Arcopagia diaphana	S	○			
Macoma sectior	S	○	○		
Lutrarina maxima	S	○			
Anomina chinensis	T	○	○		
ECHINODERMATA					
Scaphechinus mirabilis			○		
ARTHROPODA					
Macrophthalmus latreillei	M				○



T:Inter Tidal Zone S:Sandy Shoreface Zone
M:Muddy Offshore Zone

Fig. 9. Molluscan fossils and ^{14}C age in Azuchimachi site (adapted from MITAMURA 1991).

confirmed. Fig. 13 summarizes the recognized geological structure in this study.

Uemachi Fault The Uemachi Fault runs north and south under the ground. The east side of the Uemachi Fault is elevated. So, along this fault, the Pleistocene formations steeply dip west and are cut by the fault. The deep boring investigation (OD series)

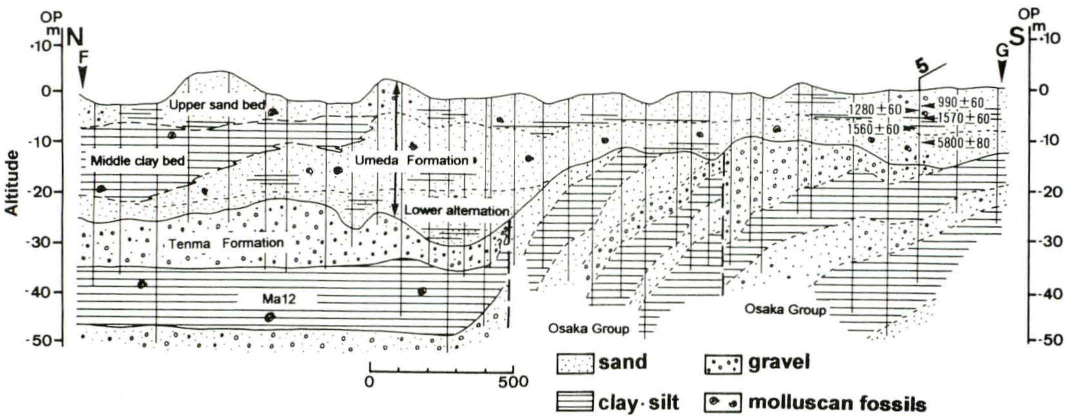


Fig. 10. Geological profile along Nishiyokobori (the location is shown in Fig.3).

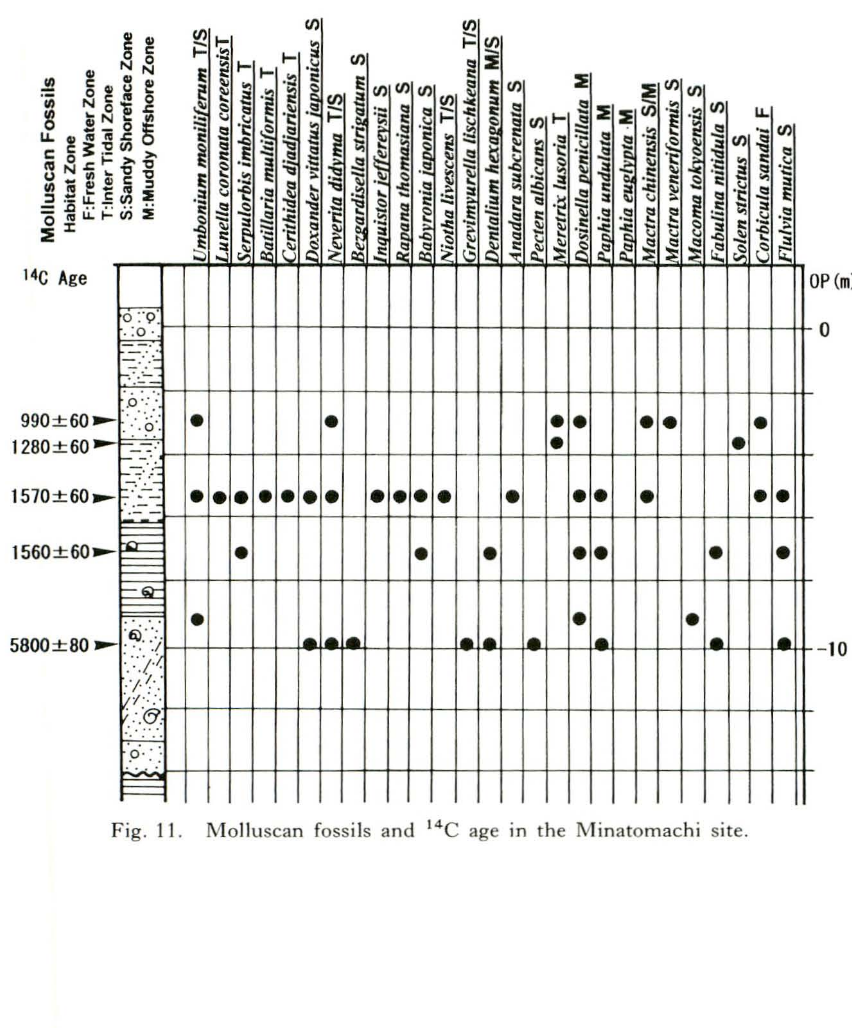


Fig. 11. Molluscan fossils and ^{14}C age in the Minatomachi site.

revealed the vertical displacement of the Azuki volcanic ash layer in the Osaka Group by the fault to be about 400 m (IKEBE *et al.*, 1970). The recent investigation with the seismic reflection prospecting and the data of the deep well revealed that the vertical displacement of the basement rocks is about 800 m (NAKAGAWA and MITAMURA, 1992). This fault tilted the Ma12 in this area (Fig. 5b C-C'). In the northern part of the Uemachi Upland, the clay bed correlated with the Ma12 is interbedded by the Uemachi Formation (FURUTANI,1978). The vertical displacement between this bed and Ma12 is about 50 m. These facts indicate the continuous activity of the Uemachi Fault from the Pliocene to the Upper Pleistocene.

The recognized location of the Uemachi Fault with the database system shows that it runs along the Sakaisuji street in the central area of Osaka City, and trends south-southwest from southern part of the Osaka City to the Sakai City. In the northern area of the Osaka City this fault runs north-northwest and is connected to the Butsunenjiyama Fault.

Sakuragawa Flexure This flexure runs northeastward from Sakuragawa to Sakaisujihonmachi. Along this flexure, the Ma12 bed dips northwest, and the main facies of the Umeda Formation becomes the marginal facies. In the Tenjinbashi area, this flexure joins the Uemachi Fault. In Sakuragawa, the vertical displacement of the Ma12 by the flexure is about 20 m. In this area, Ma12 and the underling Pleistocene dip into a poorly delineated northeast trending anticline. The displacement appears to diminish southwestward, and it may die out in this direction.

Suminoe Flexure This flexure runs NE-SW, from Tamade to Hirabayashi. Along the flexure, the Ma12 bed dips northwest. The vertical displacement of the Ma12 is more than 25 m in the northern part, and increase southwestward; in the Hirabayashi area it is about 50 m. The northeastern part of the flexure joins the Uemachi Fault in the Tamade area.

4. Paleotopography

The marginal facies of the Umeda Formation occurs along the Uemachi Fault and the two flexures. The authors think that the tectonic landscape resulting from the activities of these faults and flexures affected the sedimentary environment of the Umeda Formation. On the other hand, the Holocene transgression was the direct factor of the deposition of the Umeda Formation. The relative sea-level change in Holocene times (from 10000 to 6000 years B.P.), was a rapid rise, which came to the peak at 6000 years B.P. (OTA *et al.*, 1990). In the Osaka Plain, the sea level in Holocene times was at a peak from 6000 to 5500 years B.P. (MAEDA, 1976). The result of the investigation about the distribution and lithofacies of the Umeda Formation, using ^{14}C ages and many geological profiles, is the paleotopographic map of the Umeda Formation (Fig. 12). The paleotopography at the each stage of the Umeda Formation is summarized as follows.

Stage I (10000 years B.P.): In this stage, the sea level was lower than OP-20 m, so that the paleo-Osaka Plain extended to the eastern part of the recent Osaka Bay. The paleo-Yodo River ran straight southwestward through the paleo-Osaka Plain. Alluvial fans and gently undulating terraces, which were eroded by the paleo-Neya, -Nagase, -Hirano Rivers, extended to the east side of the Uemachi Upland. The western slope of the Uemachi Upland ran along the Uemachi Fault and the flexures.

Stage II (7000–8000 years B.P.): The sea level rose by about OP-20 m, so that the bay area extended to the north side of the Uemachi Upland. The coastal line ran along the marginal slope of the west side of Uemachi Upland. The lowland, which was formed by the deposits from the rivers developed on the northeast side of Uemachi Upland.

Stage III (5000–6000 years B.P.): The sea level rose to a little higher level than the recent sea level. The bay area spread to the east area of the Uemachi Upland. In the inner bay of the east side, banks which are composed of Pleistocene

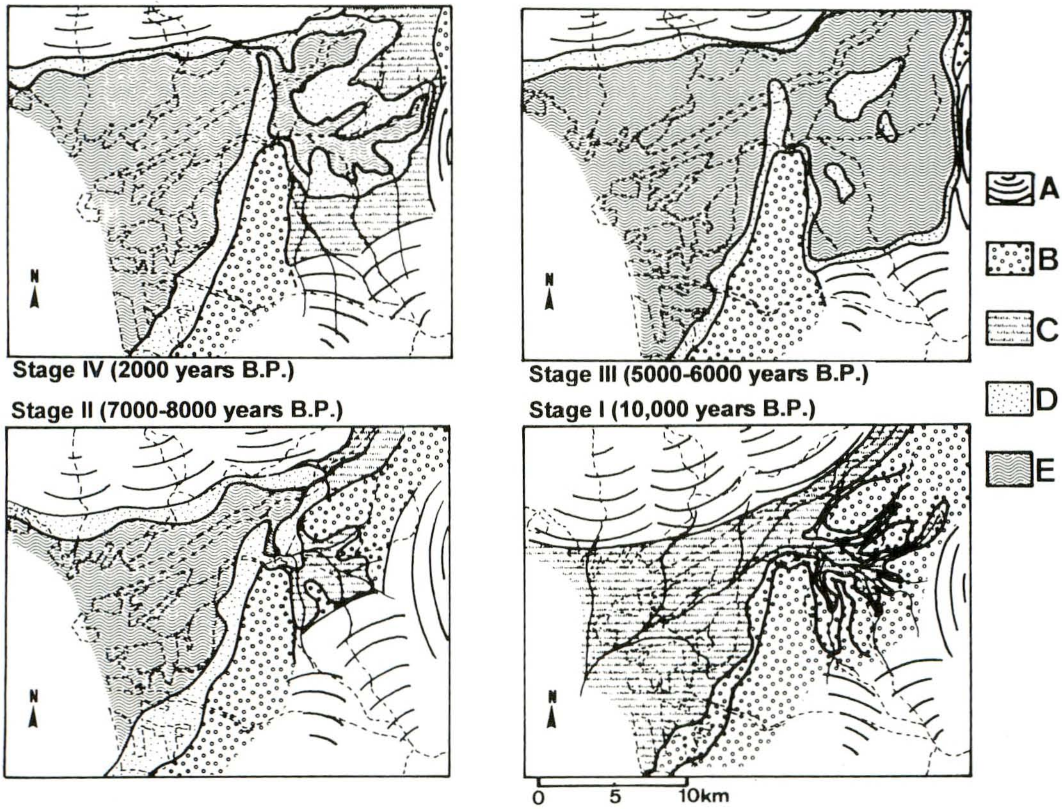


Fig. 12. Paleotopographic map of the Umeda Formation.
A: alluvial fan, **B:** upland and undulating terrace, **C:** alluvial plain, **D:** coastal area, **E:** sea area.

formation, are sporadically distributed. A bay-mouth bar extended northward from the Uemachi Upland.

Stage IV (2000 years B.P.): The sea level descended to the recent sea level. The bay mouth bar of the north side of the Uemachi Upland closed the inner bay, so that the inner bay area changed gradually to a lacustrine environment. This stage is correlated with the stage of the Kawachi Lagoon (KAJIYAMA and ITIHARA, 1972).

5. Geotechnical Characteristics as Urban Ground

The Umeda Formation, which forms the alluvial plain, is composed of soft clays and loose sands, which are recognized as weak materials. The flat ground formed by the deposition of the Umeda Formation is used by man. The ground water, for example, which is present in the sandy aquifers, is used as drinking water and industrial water. Buildings of less than four stories are supported by direct foundations in the Umeda Formation.

However, the Umeda Formation is a normally consolidated clay bed, so that this layer easily contracts in volume by dehydration. Hence, the excessive use of ground water has caused ground subsidence. The loose sand in the Upper sand bed of the Umeda Formation, which has received limited overburden pressure and is not cemented, has a potential for liquefaction by the unusual pore water pressure during earthquakes. The geotechnical properties of the Umeda Formation such as the ground subsidence, the aquifer and the consistency, are discussed below.

5.1. Ground subsidence

In the early 1930's, ground subsidence was recognized in the western part of Osaka City. Since then, the level of the ground-water table has gradually been lowered and the ground-subsidence area has expanded to cover the entire urban district of the Osaka Plain. In the early stage of the subsidence, the excessive use of the ground water from the shallow aquifers such as the Tenma Formation induced the shrinkage of the Middle clay bed in the Umeda Formation. Later, the use of the deep aquifers by the high-performance pumps produced the shrinkage of the Pleistocene clayey formations, so that the ground subsidence area was expanded (IKEBE *et al.*, 1969). The cumulative subsidence of the ground surface for 50 years, from 1935 to 1985, reached about 3 m. Fig. 13 shows the distribution of this cumulative subsidence and tectonic lines in Osaka City.

The subsidence in the western area of Osaka City is larger than that on the east side of the Uemachi Upland. These areas correspond to the distribution of the middle clay bed of the Umeda Formation. In the Uemachi Upland, a relative small shrinkage zone extends north and south. The sudden dip zone of the contour map on the west side of the Uemachi Upland runs along the Uemachi Fault and the flexures.

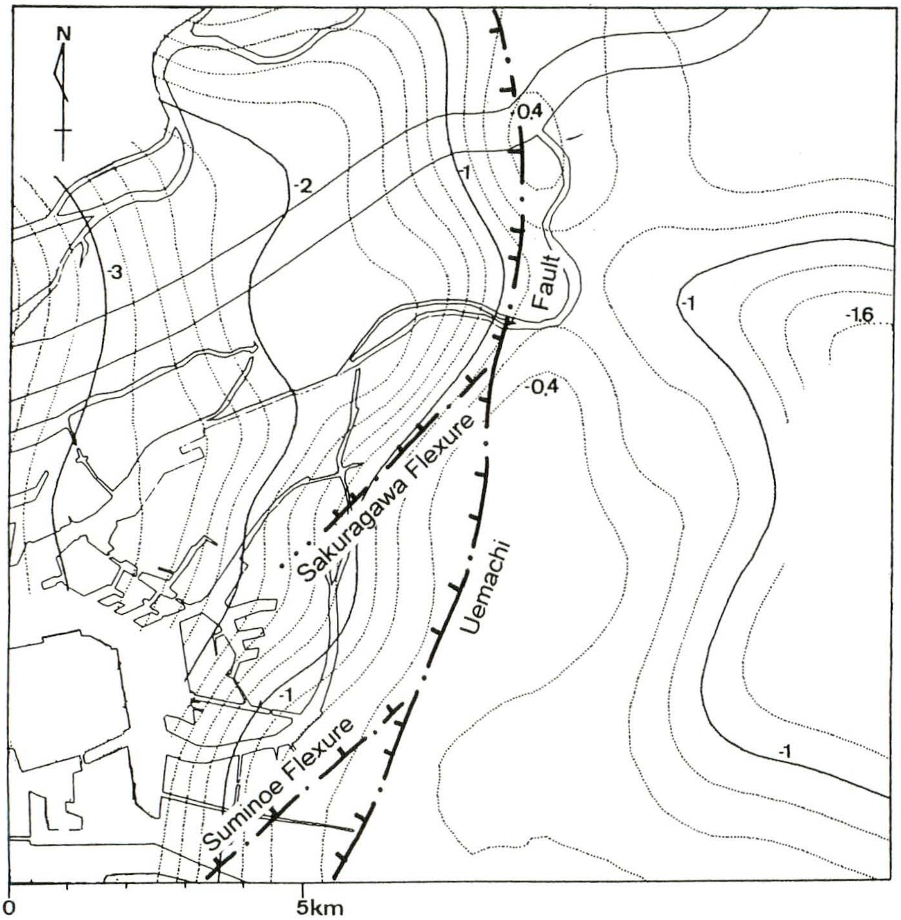


Fig. 13. Tectonic lines and contour map of the cumulative ground subsidence since 1935 in the central Osaka area (contour interval: 0.2 m, adapted from HAYASHIDA *et al.*, 1987b).

The distribution of the subsidence is affected by the distribution of the Middle clay bed and the Pleistocene clayey formation, the deposition of which was regulated by the geological structure.

5.2. Potential for liquefaction

The potential for liquefaction during an earthquake is influenced by the ground materials, the overburden pressure, the shear stress induced by earthquake motions and ground-water level. NAKAGAWA and MITAMURA (1991) compared the seismic intensity distribution of two earthquakes (in 1854 and 1946) which had similar epicenters. In the Osaka Plain, an unusual intensity area, with reverse zoning, which had a higher intensity than the surrounding area, appeared in the distribution

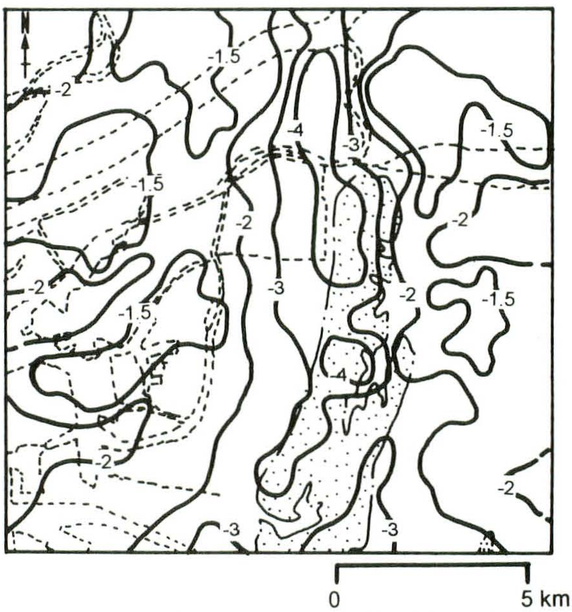


Fig. 14. Depth contour map of the ground water table of boreholes in Osaka City (depth in meter).

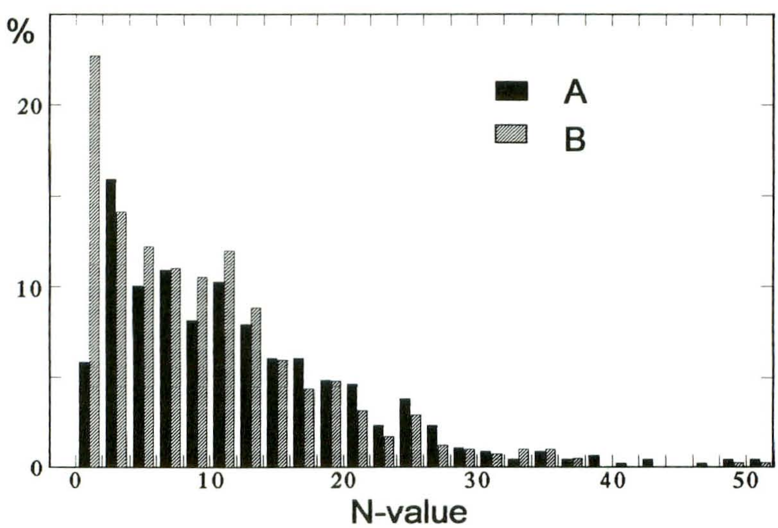


Fig. 15. Histogram of N-values of the Upper sand bed at the Nishi-ku area in Osaka City.
A: 1955-1962 in age, 94 sites, 477 data (after the Publication Committee of the Ground of Osaka, 1966).
B: 1970-1982 in age, 66 sites, 418 data (after Kansai Branch of JSSMFE and KCTK, 1987).

of the intensity in 1854. In 1854 when ground water was drawn from shallow wells by human power, the ground water table level was shallower than that in 1946, when a large quantity of ground water has been was pumped out. It seems reasonable to suppose that liquefaction caused the appearance of the unusual intensity area in 1854.

The ground-water table has now returned to a position close to sea-level, as prevention of the ground water was stopped by regulations since 1962, for the prevention of ground subsidence. Fig. 14 shows the depth distribution of the ground-water table in boreholes in Osaka City. Although the water table of a borehole is an index of a complex level of different aquifers, it may safely be assumed that these distributions indicate the level of the phreatic surface. In the area of the main facies of the Umeda Formation, this ground water table is located at shallow depth (1 – 2 m). Most of the upper sand layer of the Umeda Formation is located in zone of saturation. Fig. 15 shows the distribution of N-values of the Upper sand layer in two periods, before and after the regulations. Although the N-values of the layer are less than 10 in number and are not resolved in detail, the distribution after the regulation was introduced is a little lower. This fact indicates a decrease in the stiffness and the shear strength. Hence, the potential for liquefaction during an earthquake is high at the present time.

5.3. Grain size and consistency properties

The alterations of water content influence the properties of sediments. The Atterberg limits, given by the consistency tests such as the liquid limit, plastic limit and shrinkage limit, are the indices which indicate clayey sediments. These factors are closely related to the grain-size distributions of the sediments.

Fig. 16 shows the vertical distribution of the clay contents and the consistency limits in the Middle clay bed of the Umeda Formation. The tendency of clay contents, water contents, and liquid limits increase in common to the middle part of the clay bed. Fig. 17 shows the distributions of these factors in four horizontal levels (OP-10 m, OP-12 m, OP-15 m, and OP-17 m). The distribution of the over 60 percent clay contents extends the maximum area in the OP-15 m level. The clay contents in the Middle clay bed increase westward in the Osaka Plain. The distribution of water contents and liquid limits in the Middle clay bed are similar to that of the clay contents.

These distributions were influenced by the sedimentary environments of the Middle clay bed. The middle part of this clay bed, ranging from 5000 to 6000 years B.P., was formed during the stage of the maximum expansion of the Osaka Bay, in connection with the Holocene transgression. During this stage, the sedimentary environments for the deposition of the clay size clasts were extended by the increase of the water depth and the sea area. The increase of clay content influenced void ratios and activities of the sediments. The similar distributions of these factors suggest the above relations between the sedimentary environments and consistency properties. On the northeast side of the Uemachi Upland, the upper part of the Middle clay bed has

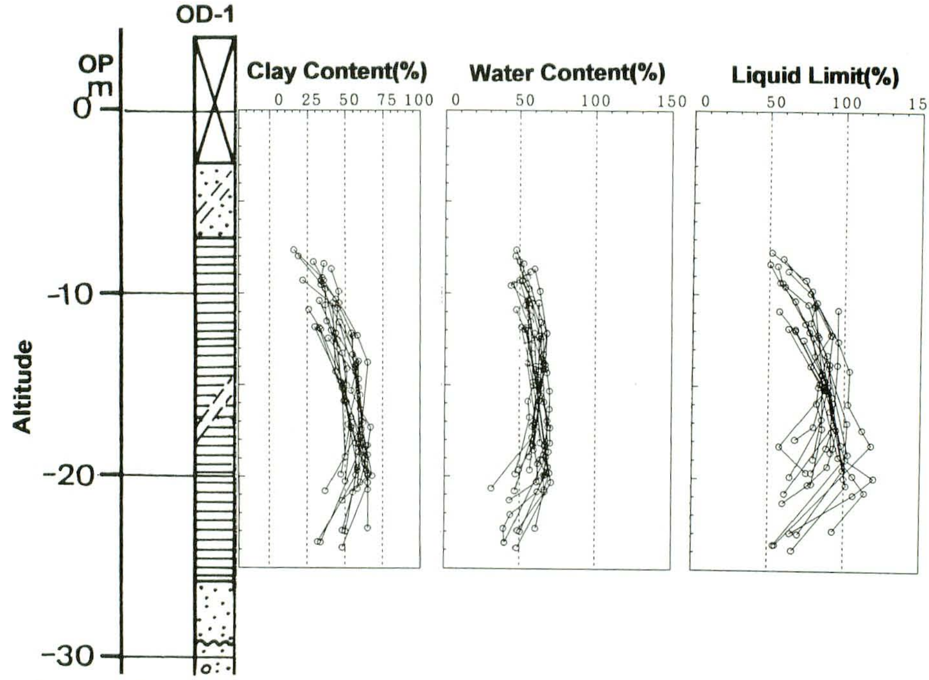


Fig. 16. Vertical disribution of clay contents, water contents and liquid limits of the Middle clay bed around the OD-1 site (adapted from Suwa et al., 1992).

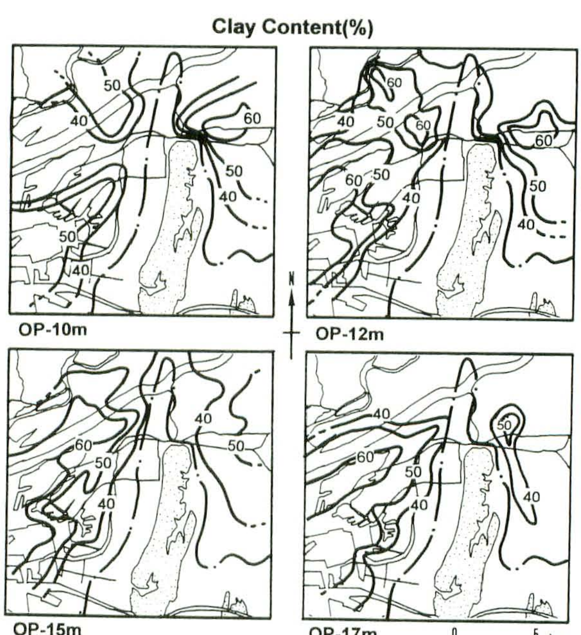


Fig. 17a. Contour map of clay content of the Middle clay bed (chain line: marginal line of the Middle clay bed)

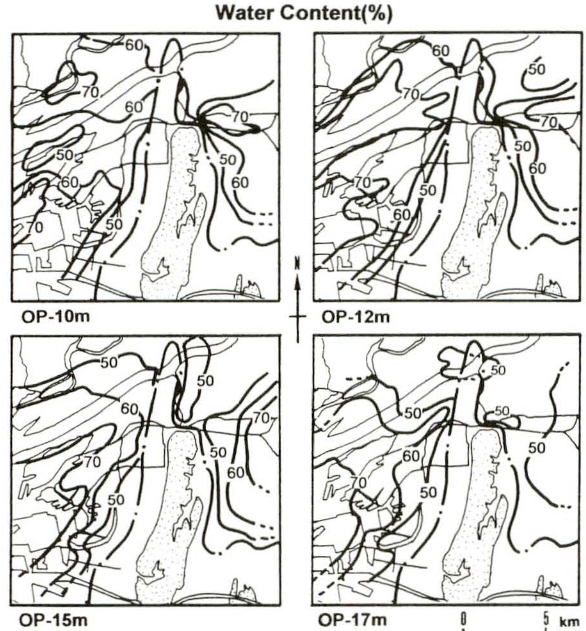


Fig. 17b. Contour map of water content of the Middle clay bed (chain line: marginal line of the Middle clay bed).

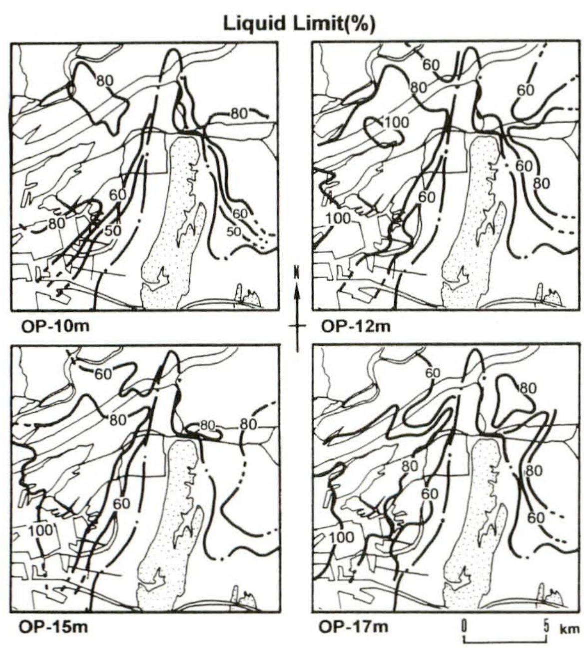


Fig. 17c. Contour map of liquid limit of the Middle clay bed (chain line: marginal line of the Middle clay bed).

higher clay contents and higher activities than the middle part. We think that this part was deposited in lagoonal environments which were made by blockage of the area by the extension of the bay-mouth bar; the clay contents thus increased to the middle part.

6. Conclusion

Based upon ^{14}C dating and subsurface structure from borehole database, several results on the Umeda Formation of the Holocene deposits around Uemachi Upland in central Osaka Plain were obtained, described below.

Stratigraphy: The Umeda formation was formed by the Holocene transgression and is represented by bay mud and littoral sandy deposits. The total thickness of the Umeda Formation is about 30 m in this zone, which can be divided into three parts, based upon geological facies. The lowest member, about 3 m thick, is composed of sand and clay with organic matter; its ^{14}C age is 7000 to 10000 years B.P. The middle member is marine clay, 10–15 m thick with its ^{14}C age of 2000 to 7000 years B.P. The uppermost member is loose and coase sand, 5–10 m thick, with its ^{14}C age of less than 2000 years B.P.

The Umeda Formation becomes shallower in the marginal zones around the Uemachi Upland area. In the marginal area, sand and gravel layers were deposited at the surface. The main facies of clay was shown to inter-finger with sand and gravel layers in these marginal zones. The fossils in the marginal zones of the Umeda Formation indicate that the sedimentary environment was intertidal to sandy shoreface. The sand and gravel layers in the marginal zones were deposited during the Holocene transgression and belong to the Umeda Formation.

Geological Structure and Paleotopography: Along the western margin of the Uemachi Upland, the Uemachi Fault extends north to south; but its location was not identified in detail. In this study, many geological profiles were investigated with the urban ground database system.

The Uemachi Fault extends northwards to the Butunenji-yama Fault in the Senri Hills and southwords to the western area of Sakai City. In addition to this, two NE-SW flexures were identified in the at Suminoe and Sakuragawa areas. Along these flexures, the Ma12 bed dips steeply west to northwest, and the marginal facies of the Umeda Formation abuts on the tilted Pleistocene formation.

By the detailed investigations using many geological profiles and ^{14}C dating, the paleotopographical maps ranging from the lower part to the upper part of the Umeda Formation were constructed. The paleotopographical maps of the lower part (stage I to II in Fig. 12) were described for the first time. Tectonic lines have affected the paleotopography at the preceding stage of the Umeda Formation (10000 years B.P.). At the stage of the middle clay member of this formation, a coastal zone was formed along this zone.

Geotechnical Characteristics as Urban Ground: In the main urbanized area of the Osaka Plain, the ground surface had subsided 1–3 m, in 30 years (between 1930's and 1960's) by the excessive pumping of ground water. Using the database system about the ground subsidence in Osaka City, the distribution of the cumulative displacement was arranged on a map. This distribution is in harmony with the distribution of the middle clay member. The inflection zone of the cumulative displacement extends along the above tectonic lines.

The consistency properties and the clay content of the middle clay member decrease eastward. These distributions show the effects of the sedimentary environments in this area during the Holocene transgression.

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