Journal of Geosciences, Osaka City University
Vol. 35, Art. 1, p. 1–12
March, 1992

Middle to Late Pleistocene Tephrostratigraphy of the 200-meter Core Sample from the North of Osaka Bay, Japan

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(With 3 Figures and 1 Table)

Abstract

Drilling up to 200 m in depth was carried out at Nishinomiya in the north of Osaka Bay. Middle Pleistocene to Holocene sedimentary samples were obtained by the drilling.

In the samples, seven volcanic-ash layers and seven invisible volcanic-ash horizons have been found by our investigation of the vertical variation of the content of volcanic material fractions and their petrographic properties.

In this paper we describe the lithofacies of the sediments, and clarify the lighologic and petrographic properties of the volcanic-ash layers and the invisible ash horizons. Furthermore, on the basis of the investigation and the stratigraphic position, we have correlated the KS47 volcanic-ash horizon in this core with "the middle ash horizon in the Ma12 bed under the Osaka Plain (the Ma12–M)". We have also correlated the KS108 volcanic-ash layer with "the ash horizon just below Ma11 bed under the Plain (the Ma11-L)" and with the BT58 volcanic-ash layer in Lake Biwa.

Key Words: Tephrostratigraphy, volcanic-ash layer, volcanic-ash horizon, Pleistocene, Osaka Plain

1. Introduction

The Pliocene to Holocene sediments underlying the Osaka Plain consist of unconsolidated clay, silt, sand and gravel. Geological studies on these sediments have been carried out chiefly by drilling for civil engineering works.

Stratigraphical sudy of the sediments underlying the Osaka Plain was instituted by YAMANE (1930), who gave a fundamental description through the investigation of drill-core samples. On the basis of the lithofacies and the distribution area of the sediments, he divided them into four formations, that is, the Basement Formation of Osaka (corresponding to the Osaka Group at present), the Uemachi, the Tenma and the Umeda Formations, in ascending order.

A standard stratigraphy under the Osaka Plain has been obtained by the deep drills called OD–1 and OD–2. The sediments contain 14 intercalated marine clay beds, which

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are named the Ma0, Ma1, Ma2,..., Ma12 and the Ma13 beds in ascending order, and have been divided into three stratigraphic units, namely, the Osaka Group, the Upper Pleistocene Formation, and the Alluvium Formation (IKEBE *et al.*, 1970; YOSHIKAWA *et al.*, 1987). The Osaka Group is composed of alternating beds of marine clay (*i.e.* the Ma0 to the Ma10) and fluvio-lacustrine sand; the Upper Pleistocene Formation, which ranges from the upper limit of the Ma10 to the bottom of the Alluvium Formation, contains the Ma11 and the Ma12; and the Alluvium Formation contains the Ma13.

In the hilly areas around the Osaka Plain, stratigraphic studies of the Cenozoic sediments have been made by tracing key beds, such as volcanic-ash layers and marine clay beds (*e.g.* ITIHARA, 1960). In drill core samples, however, it is difficult to locate accurately the thin volcanic-ash layers and volcanic-ash horizons, which are important as key beds.

FURUTANI (1978, 1989) described the middle Pleistocene to Holocene stratigraphy under the Osaka Plain on the basis of lithological and pollen analytical investigation. YOSHIKAWA (1981) studied the tephrostratigraphy of the Upper Pleistocene Formation (*i.e.* the Ma11, the Ma12 beds and the Tenma Formation) to the Holocene Formation (*i.e.* the Nanba Formation) under the Plain, and noted 5 widely traceable volcanic-ash horizons by the investigation of volcanic-glass shards in cores.

However, detailed information about the tephrostratigraphy below the Upper Pleistocene Formation underlying the Plain has not been obtained yet.

The recent drilling carried out on the reclaimed land at Nishinomiya in the north of

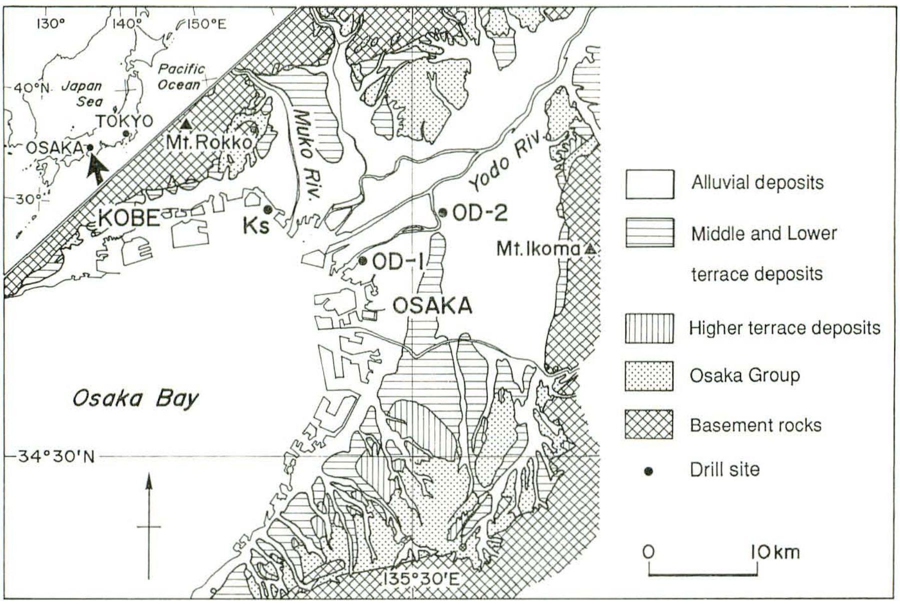

Fig. 1 Generalized geologic map showing drill sites (simplified after Itihara *et al.*, 1988). Ks, this study site (the 200-m drill); OD–1 and OD–2, the sites of Osaka Deep Drills (Ikebe *et al.*, 1970).

Osaka Bay (Fig. 1) has reached 200 m in depth; it has succeeded in collecting almost all of the fine sediments ranging from the Middle Pleistocene (the Ma9) to the Holocene. By systematic investigation of volcanic material fractions in the core sediments, we have found 7 volcanic-ash layers and 7 invisible volcanic-ash horizons.

In this paper, we describe the detailed lithofacies and the properties of the volcanic-ash layers and the volcanic-ash horizons, and we have standardized the Middle (the Ma9) to Late Pleistocene tephrostratigraphy under the Osaka Plain. Furthermore, on the basis of the similarities of lithology, petrography and stratigraphic position, we have correlated the volcanic-ash layers and the volcanic-ash horizons.

2. Method of study of the core sample

The cores were first observed with the naked eye and the lithofacies described, paying attention to inclusions. Then, 5 to 50 g of clay and silt samples, taken at 0.2 to 1 m intervals, and 8 volcanic-ash samples, both from the core, were analyzed as described below (Yoshikawa, 1981, 1984).

The samples were dried below 50°C, weighed, disaggregated, cleaned in water using an ultrasonic cleaner, wet-sieved using 63- and 250-μm mesh Tyler screen, dried, and weighed. The fine-sand size fractions, between 63 and 250 μm, were examined.

The fractions were mounted on glass slides and counted under a polarizing microscope to determine the grain percentages of volcanic material fractions, phenocrysts and detrital crystals. Volcanic material consists of volcanic glass and phenocrysts which have glass adhering to their surfaces.

Fine-sand size heavy minerals were selected using ethanol solution of Bromoform ($CHBr_3$), with specific gravity of 2.8. The heavy minerals, mounted on glass slides, were also counted under a microscope to determine the grain percentages of amphibole, orthopyroxene, clinopyroxene, biotite, zircon, apatite and opaque minerals.

The shapes and refractive indices of the volcanic-glass shards were examined. Generally, volcanic ashes contain a wide variety of glass-shard shapes, which Yoshikawa (1976) classified into three types. The first type (H-type shard) consists of the wall of a relatively large, broken bubble. The second type (T-type shard), containing numerous small bubbles in glass, is fibrous and represents pumice fragment. The third type (C-type shard) is an intermediate form between the H-type and the T-type shard. On the basis of this classification, the percentages of glass-shard types have been determined.

Refractive indices (R.I.) of the glass shards were measured by the dispersion-coloration technique, using a set of standard glass and an optical phase-microscope (Yoshikawa, 1984). The accuracy of this technique is less than ± 0.001.

3. Lithofacies and volcanic ash layers

The 200-m drill-core sample consists of unconsolidated clay, silt, sand and gravel of freshwater, brackish or marine origin. The detailed lithofacies are shown in Fig. 2.

"G.L." is an abbreviation for "ground level", and it means altitude above the surface of the earth. At this drill site, G.L. ±0 m is +0.06 m above the standard sea level in

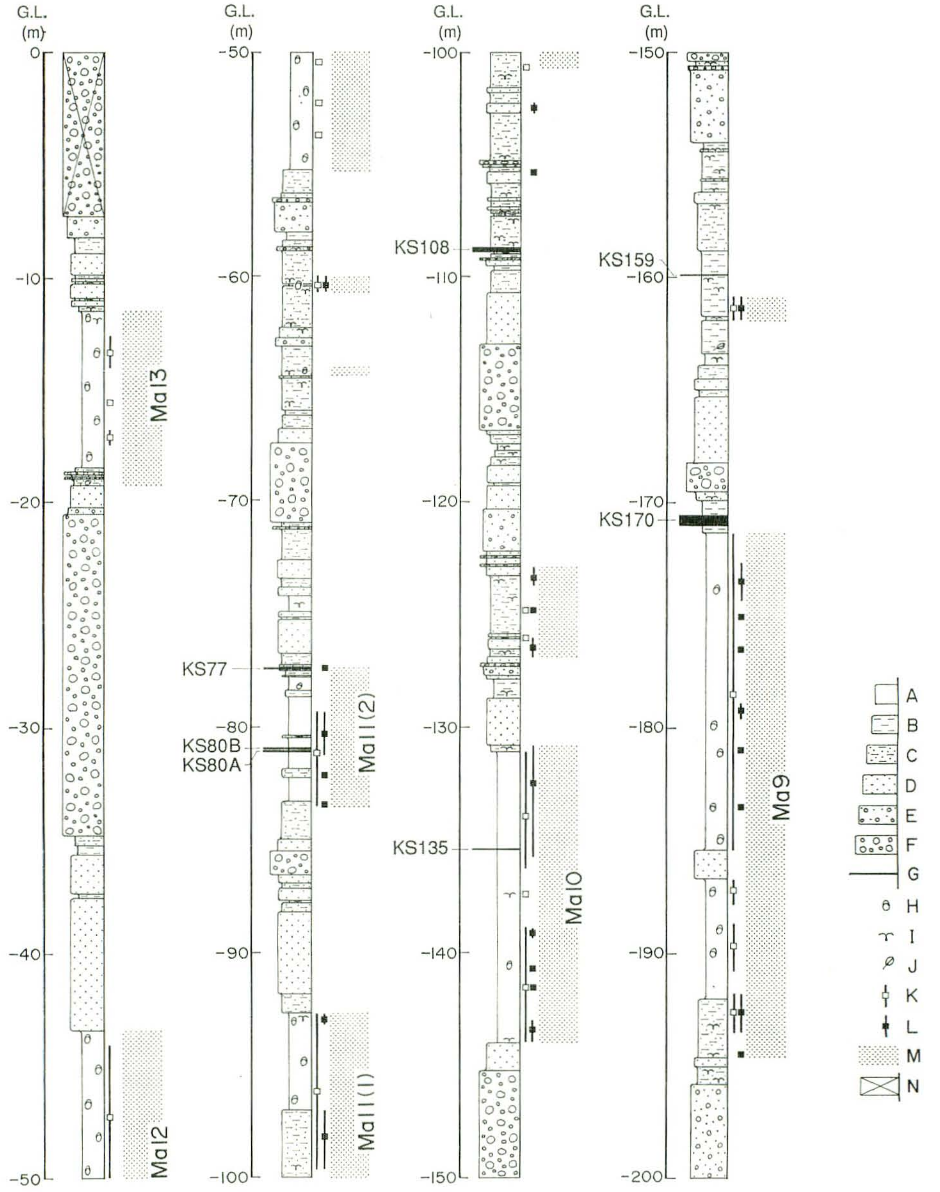

Fig. 2 Lithofacies of the 200-m core sample. A, clay; B, silt; C, silt and sand; E, sand and pebble gravel; F, gravel; G, volcanic-ash layer; H, shells; I, plant fragments; J, broadleaf remains; K, gypsum crystals; L, sulfides; M, marine facies; N, artificially piled materials. The Ma9 to the Ma13 are correlated with those of Ikebe *et al.* (1970).

Tokyo Bay. The lithofacies have been described in descending order as follows.

G.L. ±0 to −7.25 m: artificially piled materials.

G.L. −7. 25 to −11.30 m: alternating sands and gravels with silty sands.

G.L. −11.30 to −18.55 m: mainly clay (the Ma13) containing many shell fragments; gypsum crystals are present between −12.50 and −17.45 m.

G.L. −18.55 to −18.95 m: mainly pebble gravels.

G.L. −18.95 to −19.20 m: sands and the silts containing shell fragments between −19.10 and −19.20 m.

G.L. −19.20 to −34.15 m: gravel with 80 cm maximum size.

G.L. −34.15 to −43.30 m: sands with silts.

G.L. −43.30 to −55.20 m: marine clay (the Ma12) containing gypsum crystals and many shell fragments of *Turritella kurosio*.

G.L. −55.20 to −67.45 m: alternating sands and silts, both containing plant fragments, interbedded with pebble gravels. Gypsum crystals, sulfides and trace fossils are present between −58.95 and −60.70 m, and plant and shell fragments are present between −64.05 and −64.45 m.

G.L. −67.45 to −71.30 m: cobble gravels and sands.

G.L. −71.30 to −77.25 m: alternating sands and silts.

G.L. −77.25 to −83.50 m: mainly silts and clays (the Ma11(2)), both containing gypsum crystals, sulfides and shell fragments. Three volcanic-ash layers are intercalated within this interval. The first one is the KS77 volcanic-ash layer at −77.45 m, the second is the KS80B volcanic-ash layer at −80.90 m, and the third is the KS80A volcanic-ash layer at −80.93 m.

The KS77 volcanic-ash layer consists of 10 cm of gray, fine-grained volcanic ash containing pale-yellow pumice fragments with a maximum size of 3 mm.

The KS80B volcanic-ash layer consists of 3 cm of light-gray, medium-grained volcanic ash containing pumice fragments.

The KS80A volcanic-ash layer consists of 0.5 cm of light-gray, medium-grained volcanic ash.

G.L. −83.50 to −88.25 m: alternating sands and silts, with interbedded gravel between −85.50 and −86.60 m.

G.L. −88.25 to −92.60 m: sands with silts.

G.L. −92.60 to −96.90 m: clay (the Ma11(1)) containing gypsum crystals, sulfides and shell fragments.

G.L. −96.90 to −100.70 m: alternating sands and silts, both containing gypsum crystals, sulfides and shell fragments.

G.L. −100.70 to −113.00 m: silts with sands, containing plant fragments, interbedded with pebble gravels. A volcanic-ash layer (the KS108 volcanic-ash layer) is intercalated between −108.69 and −108.90 m.

The KS108 volcanic-ash layer is 21 cm thick in all and consists of three parts. The lower part consists of 2 cm of light yellowish-orange, coarse-grained ash containing 1 mm sized pumice fragments. The middle part consists of 15 cm of light yellowish-brown, medium- to fine-grained glassy ash containing 3 mm sized pisolites. The upper part consists of 4 cm of light yellowish-brown, fine- to medium-grained ash with parallel lamination.

G.L. −113.00 to −116.80 m: pebble gravels.

G.L. −116.80 to −122.85 m: alternating sands and silts containing plant fragments, interbedded with pebble gravels.

G.L. −122.85 to −126.90 m: alternating sands and silts containing gypsum crystals, sulfides and plant fragments.

G.L. −126.90 to 131.10 m: alternating sands and silts containing plant fragments, interbedded with pebble gravel.

G.L. −131.10 to −144.00 m: clay (the Ma10) containing gypsum crystals, sulfides, shell fragments and a small amount of plant fragments. A volcanic ash layer (the KS135 volcanic-ash layer) is intercalated at −135.36 m.

The KS135 volcanic-ash layer consists of 1 cm of pale-yellow, fine- or medium-grained ash.

G.L. −144.00 to −154.00 m: pebble and cobble gravels, and coarse sands.

G.L. −154.00 to −158.80 m: alternations of sand beds and silt beds containing plant fragments.

G.L. −158.80 to −163.90 m: silts and clays; gypsum crystals, sulfides and a small amount of plant fragments are present between −160.80 and 161.90 m; broadleaves, cones and other plant fragments are contained between −161.90 to −163.90 m. A volcanic-ash layer (the KS159 volcanic-ash layer) is intercalated at −159.90 m.

The KS159 volcanic-ash layer consists of 5 cm of light bluish-gray, fine-grained ash.

G.L. −163.90 to −171.35 m: alternating sands and silts interbedded with pebble gravels between −168.20 and −169.50 m. A volcanic-ash layer (the KS170 volcanic-ash layer) is intercalated between G.L. −170.50 and −170.95 m.

The KS170 volcanic-ash layer attains a total thickness of 45 cm and consits of five parts. These are, from bottom upwards: 1 cm of light-gray, fine- or medium-grained ash (the lowermost part); 16 cm of light-gray, fine-grained ash (the lower part); 13 cm of light brownish-gray, very fine- or fine-grained ash (the middle part); 10 cm thick of light-gray, medium-grained ash (the upper part); and 5 cm of light-gray, silty, fine-grained ash (the uppermost part).

G.L. −171.35 to −192.00 m: clay (the Ma9) containing gypsum crystals, sulfides and shell fragments, interbedded with sand between −185.40 and −186.70 m.

G.L. −192.00 to −195.80 m: alternating sands and silts, both containing gypsum crystals, sulfides, a small amount of plant fragments between −192.00 and −194.60 m, trace fossils about −192.45 m, and plant fragments between −194.60 and −195.80 m.

G.L. −195.80 to −200.00 m: sand and pebble gravels.

Besides our description, SAKAGAMI *et al.* (1990) described the marine clay beds as follows. The Ma13 bed occurs between G.L. −12 and −19 m, the Ma12 between

−42 and −55 m, the Ma11 between −78 and −97 m, the Ma10 between −131 and −144 m, and the Ma9 between −170 and −186 m.

4. Determination of volcanic-ash horizons

KENNETT and WATKINS (1970), and HUANG *et al.* (1973) investigated the relative abundance of volcanic material fractions in deep-sea sedimentary cores and found many volcanic-ash horizons containing abundant glass shards.

In sedimentary cores from the Osaka Plain, YOSHIKAWA (1981) investigated the vertical variation of the content, the shape and the refractive index of volcanic-glass shards, and used these parameters to determine volcanic-ash horizons. According to YOSHIKAWA (1981), the vertical variation of the content of glass shards in sediments and the petrographic properties of the shards are controlled mainly by the fall of volcanic ash. Therefore, a horizon that corresponds to a peak of volcanic material percentage and/or an abrupt change in the petrographic properties of volcanic materials is identified as a volcanic-ash horizon.

However, if a horizon that is abundant in volcanic materials occurs at a point where lithofacies change takes place, the horizon cannot be identified as a volcanic-ash horizon. For example, the KS18 sample, picked up at G.L. −18.50 m, contains many volcanic material fractions; but there is a lithofacies change just below that point, so the point G. L. −18.50 m cannot be identified as a volcanic-ash horizon. In this instance, the actual volcanic-ash horizon should exist below G.L. −18.50 m, and the volcanic materials without a conspicuous peak of the percentage are the materials derived from underlying volcanic-ash layers.

In this paper, the vertical variation of the content of volcanic material fractions and fine-sand size fractions in the sediments is shown in Fig. 3. Volcanic material fractions can be found in almost all the samples examined in this study, and the relative abundance of volcanic material fractions ranges widely from complete dominance to complete absence.

Using the above-mentioned method, we noted 7 volcanic-ash horizons besides 7 volcanic-ash layers in the 200-m core. These volcanic-ash horizons are at G.L. −47.78 m (the KS47 volcanic-ash horizon), −78.89 m (the KS78), −80.70 m (the KS80C), −81.15 m (the KS81), −137.40 m (the KS137), −174.75 m (the KS174), and −183.75 m (the KS183).

5. Petrographic properties of the volcanic ashes

As mentioned above, 7 volcanic-ash layers and 7 volcanic-ash horizons have been found in the 200-m core. The petrographic properties of these volcanic ashes are given below (Table 1).

The KS47 volcanic ash is composed of feldspar and glass shards, with quartz and a small amount of heavy minerals. The glass particles consist mainly of T-type shards with refractive index (R.I.) of 1.515 to 1.526; they contain 9 percent brown shards. Of the

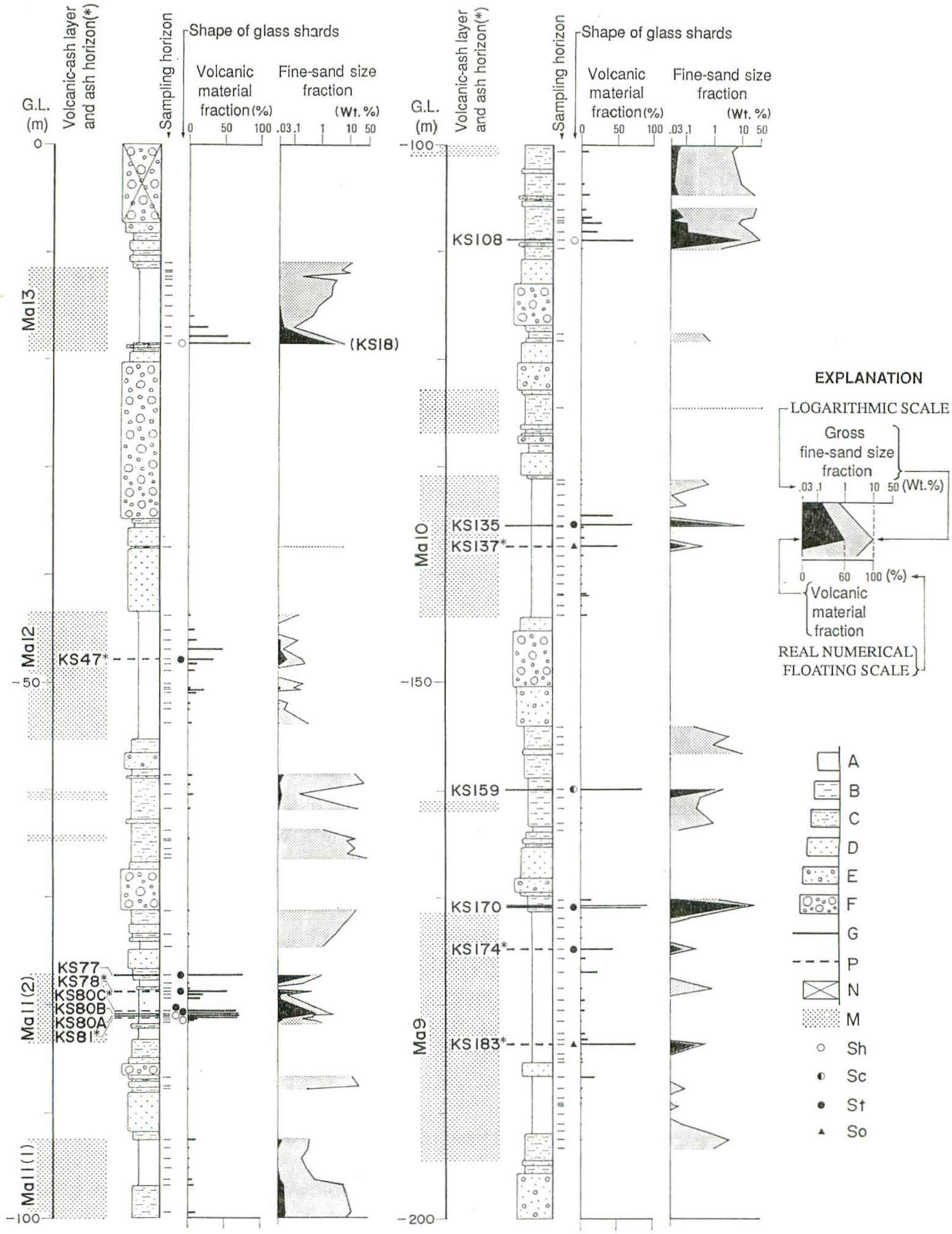

Fig. 3 Vertical variation of the content of volcanic material fractions and fine-sand size fractions. Fine-sand size fractions are 63 to 250 μm in size. The EXPLANATION illustrates the case where the fine-sand size fraction forms 10 percent in weight of a sample, and the volcanic material fraction forms 60 percent in the number of these fine-sand size fractions. A to N, the same as in Fig. 2; P, volcanic-ash horizon: Sh, H-type glass shard; Sc, C-type glass shard; St, T-type glass shard; So, other type glass shard.

Table 1 Petrographic properties of the volcanic ashes in the core samples.

Volcanic ash	Mineral composition Gl.	Fl.	Qz.	Hm. (%)	Glass Shape H.	C.	T.	O. (%)	Refractive Index (mode)	Heavy mineral composition Bi.	Am.	Op.	Cp.	Zr.	Ap.	Oq. (%)
KS47	32	49	16	3	2	13	84	1	1.515-1.526	*	++	+++	+++			+
KS77	16	51	2	31	15	21	64	0	1.503-1.508 (1.505-1.507)	*	73	20	0	*	2	4
KS78	11	48	4	38	17	22	61	0	1.502-1.506 (1.504-1.505)	*	67	15	0	1	*	16
KS80C	13	46	*	40	13	14	73	0	1.502-1.509 (1.505-1.506)	*	76	14	0	0	2	8
KS80B	15	44	3	38	3	13	84	0	1.502-1.507 (1.505)	2	75	16	0	0	1	7
KS80A	16	63	*	21	+++	++	+		1.501-1.506 (1.502-1.505)	0	76	18	0	0	1	6
KS81	65	25	7	3	71	29	0	0	1.499-1.506 (1.503-1.506)	1	18	31	13	0	1	35
KS108	67	27	2	4	++	+	+		1.499-1.501 (1.499-1.500)	1	51	24	5	0	*	18
KS135	57	35	0	9	0	1	99	0	1.502-1.508 (1.506-1.507)	1	85	7	0	0	0	7
KS137	41	49	2	9		++	++	++	1.500-1.504 (1.503)	0	81	13	*	0	0	7
KS159	86	13	0	2	35	60	5	0	1.498-1.505	*	23	28	5	0	0	43
KS170 (upper)	83	15	0	2	2	6	91	0	1.499-1.510 (1.505-1.506)	2	72	10	2	0	1	13
KS170 (lowermost)	65	29	0	6	1	3	96	0	1.500-1.507 (1.504-1.506)	0	54	12	5	0	3	25
KS174	37	55	3	6	1	24	70	5	1.499-1.505	*	64	14	2	0	*	19
KS183	++	++		*			+	+++		0	46	45	+	0	2	7

Mineral composition: Gl, Glass; Fl, Feldspar; Qz, Quartz; Hm, Heavy minerals.
Shape of glass: H, H-type shards; C, C-type shards; T, T-type shards; O, Others.
Heavy mineral composition: Bi, Biotite; Am, Amphibole; Op, Orthopyroxene; Cp, Clinopyroxene; Zr, Zircon; Ap, Apatite; Oq, Opaque minerals.
+++, Abundant; ++, Common; +, Uncommon; *, Rare.

heavy minerals, clinopyroxene and orthopyroxene are abundant, amphibole is common, opaque minerals and biotite are rate.

The KS77 volcanic ash is composed of feldspar and heavy minerals, with a subordinate amount of glass and a small amount of quartz. Glass particles consist chiefly of colorless T-type shards with R.I. of 1.503 to 1.508 (mode: 1.505 to 1.507). Amphibole is abundant, orthopyroxine is common, and opaque minerals, apatite and zircon are rare.

The KS78 volcanic ash is composed of feldspar and heavy minerals, with a subordinate amount of glass and a minor amount of quartz. Glass particles consist cheiefly of colorless T-type shards with R.I. of 1.502 to 1.506 (1.504 to 1.505). Amphibole is abundant, opaque minerals and orthopyroxene are common, and zircon, apatite and biotite are rare.

The KS80C volcanic ash is composed of feldspar, heavy minerals and a subordinate amount of glass. Glass particles consist cheifly of colorless T-type shards with R.I. of 1.502 to 1.509 (1.505 to 1.506). Amphibole is abundant, orthopyroxene and heavy minerals are common, and apatite and biotite are rare.

The KS80B volcanic ash is composed of feldspar, heavy minerals and a subordinate amount of glass. Glass particles consist chiefly of colorless T-type shards with R.I. of 1.502 to 1.507 (1.505). Amphibole is abundant, orthopyroxene and opaque minerals are common, and apatite and biotite are rare.

The KS80A volcanic ash is composed of feldspar and a subordinate amount of heavy minerals and glass. Glass particles consist mainly of colorless H-type shards with a subordinate amount of C-type, both with R.I. of 1.501 to 1.506 (1.502 to 1.505). Amphibole is abundant, orthopyroxene and opaque minerals are common, and apatite is rare.

The KS81 volcanic ash is composed mainly of glass, with a subordinate amount of feldspar, quartz and heavy minerals. Glass particles consist chiefly of colorless H-type shards with R.I. of 1.499 to 1.506 (1.503 to 1.506). Opaque minerals and orthopyroxene are abundant, amphibole and clinopyroxene are common, and apatite and biotite are rare.

The KS108 volcanic ash is composed mainly of glass, with a subordinate amount of feldspar and a minor amount of quartz and heavy minerals. Glass particles consist chiefly of colorless C-type shards, containing a small amount of pale-brown ones, with R.I. of 1.499 to 1.501. Amphibole is abundant, orthopyroxene, opaque minerals and clinopyroxene are common, and apatite and biotite are rare.

The KS135 volcanic ash is composed of glass and feldspar, with a subordinate amount of heavy minerals. Glass particles consist mostly of colorless T-type shards with R.I. of 1.502 to 1.508 (1.506 to 1.507). Amphibole is dominant, opaque minerals and orthopyroxene are common, and biotite is rare.

The KS137 volcanic ash is composed of fledspar and glass, with a minor amount of heavy minerals and quartz. Glass particles consist mainly of colorless T-type shards with R.I. of 1.500 to 1.504 (1.503). Amphibole is dominant, and orthopyroxine and opaque minerals are common.

The KS159 volcanic ash is composed mainly of glass, with a subordinate amount of feldspar and a small amount of heavy minerals. Glass particles consist chiefly of colorless C-type shards with R.I. of 1.498 to 1.505. Opaque minerals is abundant, orthopyroxene and amphibole are common, clinopyroxene is a little, and biotite is rare.

The KS170 volcanic ash is composed mainly of glass, with a subordinate amount of feldspar and a minor amount of heavy minerals. Glass particles consist chiefly of colorless T-type shards with R.I. of 1.500 to 1.507 (1.504 to 1.506) in the lowermost part, and 1.499 to 1.510 (1.505 to 1.506) in the upper part. Amphibole is abundant, opaque minerals and orthopyroxene are common, and clinopyroxene and apatite are scarce.

The KS174 volcanic ash is composed of feldspar and glass, with a small amount of heavy minerals and quartz. Glass particles consist chiefly of colorless T-type shards with R.I. of 1.499 to 1.505. Amphibole is abundant, opaque minerals and orthopyroxene are common, and clinopyroxene, apatite and biotite are rare.

The KS183 volcanic ash is composed of volcanic-rock fragments, glass and feldspar, with a small amount of heavy minerals. The volcanic-rock fragments consist of a lot of microphenocrysts of feldspar with glass. Glass particles are chiefly colorless shards. Many of the glass shards are thick and grain-like, with pitted surfaces. Amphibole and orthopyroxene are abundant, opaque minerals are common, and apatite and clinopyroxene are rare.

6. Correlation

Correlation of the volcanic-ash layers and the volcanic-ash horizons has been determined on the basis of the similarities of lithology, petrography and stratigraphic position. Using these parameters, the correlations described below were obtained.

KS67 and the middle ash horizon in the Ma12 bed (Ma12-M). The KS47 volcanic-ash horizon is correlated with "the middle ash horizon in the Ma12 bed under the Osaka Plain" (YOSHIKAWA, 1981; the Ma12–M, YOSHIKAWA and TARUNO, 1992). Both ash horizons display almost complete similarity in their petrographic feature, namely, in heavy mineral composition (mainly two pyroxenes and subordinate amphibole), in shape of glass shards (T-type), in color of glass shards (containing brown ones) and in refractive index of glass shards (1.515 to 1.526; 1.513 to 1.525, YOSHIKAWA and TARUNO, 1992). Furthermore, both volcanic-ash horizons occur in the middle part of the Ma12 bed intercalated within the Upper Pleistocene Formation (IKEBE *et al.*, 1970).

KS108, the ash horizon just below the Ma11 bed (Ma11-L) and the BT58 volcanic-ash layers. The KS108 volcanic ash layer is correlated with "the ash horizon just below the Ma11 bed under the Osaka Plain" (YOSHIKAWA, 1981; the Ma11-L, YOSHIKAWA and TARUNO, 1992), and with the BT58 volcanic-ash layer in Lake Biwa (YOSHIKAWA, 1991). These volcanic ashes are similar in gross mineral composition (glass$\gg$feldspar), in heavy mineral composition (amphibole$>$orthopyroxene), in shape of glass shards (H-type$>$C-type) and in refractive index of glass shards (1.499 to 1.501; 1.498 to 1.501; 1.497 to 1.502). Moreover, the KS108 and the Ma11-L occur few meters below the Ma11 in the Upper Pleistocene Formation. With regard to lithofacies, both the KS108 and the BT58 are similar in color (light yellowish-orange to light yellowish-brown; yellowish brown) and grain size (the lowemost part, 1 to 2 cm thick, conisits of coarse grains, containing pumice fragments; the middle part, 11 to 15 cm thick, consists of more fine grains).

Acknowledgements

We are grateful to Mr. Y. Iwasaki, the head of Geo-Research Institute Osaka Soil Test Laboratory, for his offer of core samples, and also to Mr. H. Ishii of Osaka Museum of Natural History for his identification of species of shells.

References

FURUTANI, M. (1978): Upper Pleistocene Series of the western Osaka Plain (in Japanese with English abstract). *J. Geol. Soc. Japan.* **84**, 341–358.

FURUTANI, M. (1989): Stratigraphical subdivision and pollen zonation of the Middle and Upper Pleistocene in the Coastal Area of Osaka Bay, Japan. *J. Geosci., Osaka City Univ.*, **32**, 91–121.

HUANG, T.C., WATKINS, N.D., SHAW, D.M. and KENNETT, J.P. (1973): Atmospherically transported volcanic dust in South Pacific deep sea sedimentary cores at distances over 3000 Km from the eruptive source. *Earth and Planetary Sci. Letters*, **20**, 119–124.

IKEBE, N., IWATSU, J. and TAKENAKA, J. (1970): Quaternary geology of Osaka with special reference to land subsidence. *J. Geosci., Osaka City Univ.*, **13**, 39–98.

ITIHARA, M. (1960): Some problems of the Quaternary sedimentaries, Osaka and Akashi areas (in Japanese with English abstract). *Earth Sci.* (*Chikyu-Kagaku*), No. 49, 15–25.

ITIHARA, M., YOSHIKAWA, S., KAMEI, T. and NASU, T. (1988): Stratigraphic subdivision of Quaternary deposits in Kinki district, Japan (in Japanese with English abstract). *Mem. Geol. Soc. Japan* (*Chishitsugaku Ronshu*), **30**, 111–125.

KENNETT, J.P. and WATKINS, N.D. (1970): Geomagnetic polarity change, volcanic maxima and faunal extinction in the South Pacific. *Nature*, **227**, 930–934.

SAKAGAMI, T., SUGANO, K., NAKASEKO, K., FURUTANI, M., SUWA, S., and YAMAMOTO, K. (1990): *Osaka-wan kaitei-jiban no chishitsu-tokusei* (Gelogic properties of the foundation of the bottom of Osaka Bay) (in Japanese). in *Osaka-wan kaitei-jiban* (Japanese Society of Soil Mechanics and Foundation Engineering Kansai Branch, and Osaka-wan kaitei no jiban kenkyu-iinkai ed.), 37–78.

YAMANE, S. (1930): *Osaka-shi chishitsu gaikan* (Outline of geology of Osaka City) (in Japanese). *Chigaku Ronso* (Nakamura, S. ed.), *Comm., Vol., Prof. T. Ogawa's 60th Birthday*, 187–203.

YOSHIKAWA, S. (1976): The volcanic ash layer of the Osaka Group (in Japanese with English abstract). *J. Geol. Soc. Japan.*, **82**, 479–515.

YOSHIKAWA, S. (1981): Volcanic glass in the Pleistocene to Holocene sediments in the Osaka Plain (in Japanese with English abstract). *The Quat. Res.* (*Daiyonki-Kenkyu*), **20**, 75–87.

YOSHIKAWA, S. (1984): Volcanic ash layers in the Osaka and Kobiwako Groups, Kinki District, Japan. *J. Geosci., Osaka City Univ.*, **27**, 1–40.

YOSHIKAWA, S. (1991): Tephrostratigraphy of the Takashima-oki boring core samples from Lake Biwa, Central Japan (in Japanese with English abstract). *Earth Sci.* (*Chikyu-Kagaku*), **45**, 81–100.

YOSHIKAWA, S., NAKAGAWA, K., KAWABE, T., FURUTANI, M. and DAISHI, M. (1987): Reconsideration of the OD–2 and OD–1 core samples in Osaka City, central Japan (in Japanese with English abstract). *J. Geol. Soc. Japan.* **93**, 653–665.

YOSHIKAWA, S. and TARUNO, H. (1992): Volcanic ash layers of the Middle terrace deposits in the Osaka Plain (in Japanese). *Daishiki*, 24, 61–67.