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The Plio-Pleistocene Tokai Group and the Tectonic Development Around Ise Bay of Central Japan since Pliocene

By

Keiji Takemura

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Contents

Abstract

The Tokai Group, one of the representative non-marine Plio-Pleistocene sequences in Japan, is distributed around Ise Bay in the southern part of central Japan. In this paper, the litho- and tephrostratigraphy of the Group in central and northern area (Hokuse area) on the west coast of Ise Bay are first described precisely. From biostratigraphy (plant remains and fossil mammals), paleomagnetism and fission-track ages, those sediments are estimated to range from about 3.0 Ma to about 1.2 Ma, in other words, from Kaena event of the Gauss Normal Polarity Epoch to early Matuyama Reversed Polarity Epoch.

The correlation was made among sediments of Tokai Group distributed in various localities like as Hokuse, Nanse (southern area on the west coast of Ise Bay), Nagoya and Chita Peninsula.

As a conclusion, a geohistory of the sedimentary basin of Lake Tokai is divided into two stages, Stage I (ca. 6.0 Ma to 3.0 Ma) and Stage II (ca. 3.0 Ma to 1.2 Ma).

In connection with this, paleogeography of Lake Tokai and its mode of transition are explained as follows. After the time of wide alluvial plains distribution in ca. 6.0 Ma, a large water body appeared in southern area of the basin in Stage I. At ca. 3.0 Ma, the northwestward shifting of the basin came to induce an appearance of water body in northern area (the beginning of Stage II). In the last of Stage II, a large amount of gravel was supplied from the Suzuka Mountain area, and those materials filled up whole of the sedimentary basin nearly completely. In such a way, Lake Tokai became to extinct at last at ca. 1.2 Ma. In relation to basin transition, mode of tectonism may be interpreted as the results of interaction between upheaving of southern area under the tectonic stress in N-S direction and tilting of the Chubu (central) Block influenced by the stress state in E-W direction.

Comparative study of geohistory was made for Tokai, Kobiwako and Osaka Groups which are all allied sequences in the Second Setouchi Sedimentary Basin. Consequently, it becomes clear that the division between Stage I and Stage II of Lake Tokai (ca. 3.0 Ma) is fairly coincidental with that between Older I and Older II stages of Paleo-lake Biwa. Moreover, one of them is with the initial stage of Paleo-lake Osaka. Therefore, this 3.0 Ma phase seems to play an important role in geohistory of the Second Setouchi Inland Depression. It is also important that the extinction of Lake Tokai at about 1.2 Ma is able to be correlated with the time confined between Older and Actual stages of Paleo-lake Biwa, and with the first marine transgression in the area around Osaka Bay. Furthermore, similar pattern of basin migration was recognized in both Lake Tokai and Paleo-lake Biwa, but it should be noted that northwestward migration of Paleo-lake Biwa on a large scale occurred at a later date to compare with that of Lake Tokai. The causes of migration of two sedimentary basins were commonly explained as mutual interaction between upheaving of southern area and tilting of eastern area.

I. Introduction

Three sedimentary basins, Lake Tokai, Paleo-lake Biwa and Paleo-lake (bay) Osaka, are arranged from east to west latitudinally in the eastern part of Second Setouchi Inland Depression of IKEBE (1956). All of them are filled with the Plio-Pleistocene sequences, and they are named Tokai, Kobiwako and Osaka Groups, respectively (Fig. 1). Since 1977, the author has engaged in stratigraphical studies on the Tokai Group on the west coast of Ise Bay, and confirmed the relation between litho- and tephrostratigraphy, and its chronology by the methods of paleomagnetism and fission-track dating. Based on those studies, he has also tried to correlate the sediments distributed throughout areas around Ise Bay. Consequently, it becomes clear that geohistory of Lake Tokai can be divided into two stages (Stage I and Stage II) with the boundary at ca. 3.0 Ma. Furthermore, paleogeography of Lake Tokai since Pliocene will be explained on the basis of lithofacies and sedimentological data (lithologic proportion, gravel composition and paleocurrent).

On the basis of paleogeography, it is inferred that temporal changes of regional tectonic stress state reflected closely mode of basin transition. Accordingly, this article deals with transition of sedimentary basin of Lake Tokai and tectonism in the eastern part of the Setouchi Geologic Province since the Pliocene.

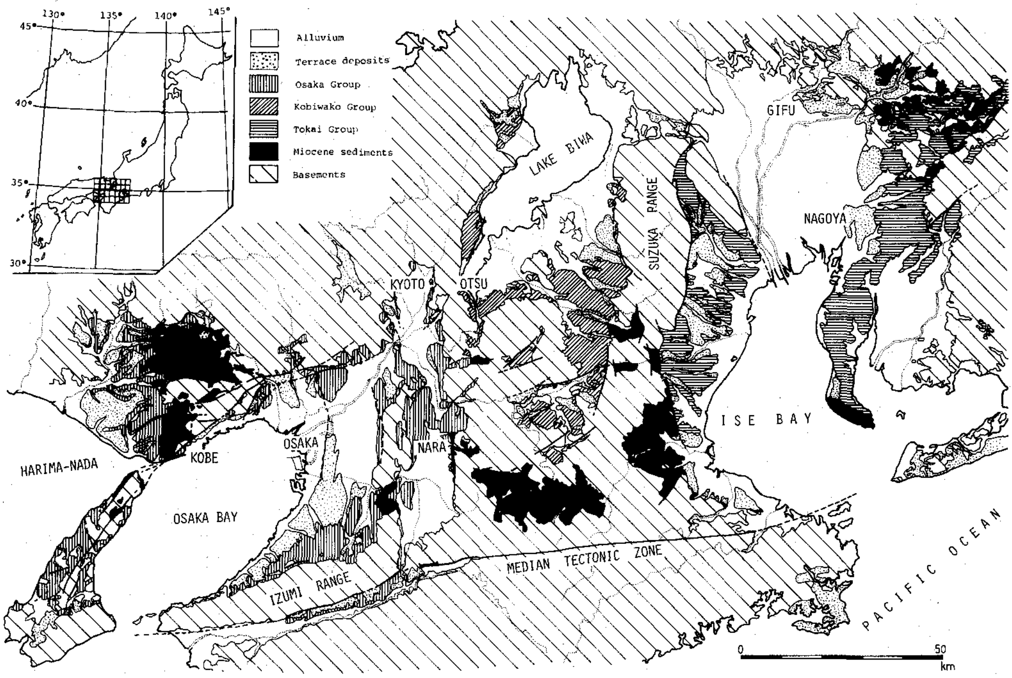

Fig. 1. Distribution of the Plio-Pleistocene series in the eastern Setouchi Geologic Province.

HUZITA (1962) distinguished two types of structural trend, that is, older latitudinal trend and younger meridional trend in the Setouchi Province since the Pliocene. Recently, he has proposed an idea that Quaternary tectonics of the Japanese Islands can be explained by two types of tectonic zone (parallel to the Nankai Trough and Japan Trench respectively) (HUZITA, 1980). In addition, regional stress state of the Japanese Islands in the present and Late Quaternary Period has been deduced from the distribution of active faults, earthquake mechanism and remeasurements of triangulation points. In this way, the distribution pattern of the regional horizontal principal stress has been determined (MATSUDA *et al.*, 1978). Moreover, the informations on tectonic stress state since Miocene have been much accumulated (NAKAMURA, 1977; TAKEUCHI, 1980; KOBAYASHI, 1979). Taking the results into consideration, change of tectonic stress state pattern in the eastern part of the Setouchi Province since Pliocene will be proposed here in relation to process of paleogeographical transition of three basins; Lake Tokai, Paleo-lake Biwa and Paleo-lake (bay) Osaka.

II. Geology of Tokai Group in Northern Ise Area

A. Historical Review

In historical review of the studies on the Plio-Pleistocene sediments in Kinki and Tokai districts, it should be described that IKEBE (1933, 1934) studied tephrostratigraphically Kobiwako Group first, and HUZITA *et al.* (1951) confirmed the presence of marine and nonmarine alternations with intercalations of volcanic ash layers in the Osaka Group. Besides them, many investigators paid much attention to volcanic ash layers intercalated in these sediments and they introduced tephrostratigraphy into the studies. Following them, the sequences of those sedimentary basins were compiled; the Osaka Group by ITIHARA (1960), Kobiwako Group by TAKAYA (1963) and Agé Group (Tokai Group on the west coast of Ise Bay) by TAKEHARA (1961). Based on those works, ISHIDA and YOKOYAMA (1969) proposed a correlation scheme throughout the areas.

Plant remains which were yielded from those sediments were described in detail by MIKI (1948), which were studied stratigraphically by HUZITA (1954). Further, ITIHARA (1960) proposed "*Metasequoia* flora flourish age" and "*Metasequoia* flora extinction age" for Plio-Pleistocene turnover on the basis of his biostratigraphical study. Furthermore, IKEBE *et al.* (1966) and KAMEI and SETOGUCHI (1970) summarized stratigraphical distribution of the fossil mammalian fauna.

As for paleogeography and tectonism, some significant concepts have been introduced such as "Foundation folding" (MAKIYAMA, 1956), "Rokko Movements" (IKEBE, 1956 and IKEBE and HUZITA, 1966) and "First and Second Setouchi Inland Sea" (IKEBE, 1956).

As for Plio-Pleistocene sediments on the west coast of Ise Bay, OGAWA (1919) studied first and called them the Agé lignite bearing formation. Thereafter, TAKIMOTO (1935) renamed them as Agé Series. Besides them, many stratigraphic studies were carried out in various areas (SUZUKI *et al.*, 1947, 1948; AKAMINE *et al.*, 1951; ARAKI, 1953; MATSUI, 1943; KATO, 1957). Fossil elephants such as *Stegodon* cf. *elephantoides* and *Stegodon akashiensis* were reported by MAKIYAMA (1938), MATSUI (1943) and KAKUTA and AKAMINE (1958), and also MIKI (1948) and YASUDA (1957) studied plant remains.

In the stratigraphic investigation for the Tokai Group on the west coast of Ise Bay (Agé Group), TAKEHARA (1961) discriminated as T_1–T_{20} volcanic ash layers intercalated in that group. By his result, the stratigraphy and geological structure of the group became to be clear, but there were some problems on volcanic ash discrimination and also on the relation between lithology and tephrostratigraphy. Stratigraphic studies on Agé Group have been carried out continuously thenceforth (TAKEHARA, 1966; HATA, 1967; YOKOYAMA, 1971). ISHIDA and YOKOYAMA (1969) called collectively the Plio-Pleistocene sediments around Ise Bay as Tokai Group, because those sediments were considered to have been deposited in a single sedimentary basin (Lake Tokai).

Recently, the integration of paleomagnetic and radiometric studies has provided accurate geochronological framework for the Late Neogene, especially for last 5 Ma. Those studies are also helpful to establish stratigraphy of the Plio-Pleistocene sequences in Kinki and Tokai districts. The informations from Kobiwako and Osaka Groups have been much accumulated now, but those from the Tokai Group have been left behind from such contemporaneous studies.

B. Geological Outline

Generally, in Southwest Japan have been recognized three Neogene geologic provinces, "Hokuriku-San'in" (Japan Sea side), "Setouchi" (Median Zone), and "Nankai" (Pacific Ocean side). Among them, the area around Ise Bay can be treated as a depression in the eastern part of the "Setouchi" geologic province, bordered meridionally by the Suzuka Mountains on the western margin of the depression. To the east of the depression, the Mikawa Highland lies, and the Mino Massif is located to the north. The Yoro Mountains runs through from northwest to southeast in the northern part of this area and divides the depression into two parts, western half "Agé subbasin", and the other half "Nagoya subbasin" to be called herein. To the west of "Agé subbasin", Suzuka Mountains runs from south to north with altitude from 800 to 1,200 m (Fig. 2). To northeast, Yoro Mountains ranges from northwest to southeast with altitude from 600 to 850 m. In foothill areas of those two Mountains, the hills composed of Miocene and Plio-Pleistocene sediments spread widely with 40 to 300 m in height. In the foot of Yoro Mountains, terraces are remarkably developed along Inabe River and are developed in direction at right angle to Mountains. Those terraces have the highest level of 250 m. Along Suzuka Mountains, terraces are also developed along main water courses of the present rivers. Suizawa Fan which develops at north of Kameyama City is remarkable in its wide-distribution, with the height from 180 to 40 m. Alluvial plains are distributed along the coast of Ise Bay and along the rivers described above.

Geology on the west coast of Ise Bay is divided as follows: Mesozoic and Paleozoic formations, Ryoke metamorphic rocks and granites, Cretaceous granites, Miocene deposits of Ichishi, Suzuka Groups and Chigusa Formation, Plio-Pleistocene Tokai Group, Pleistocene Rengeji Formation and its equivalents, terrace and alluvial deposits (Table 1 and Fig. 2).

Mesozoic and Paleozoic formations are mainly composed of sandstone, shale, chert, limestone and green rocks, and they are exposed at Yoro Mountains and northern half of Suzuka Mountains which are northern part of the depression.

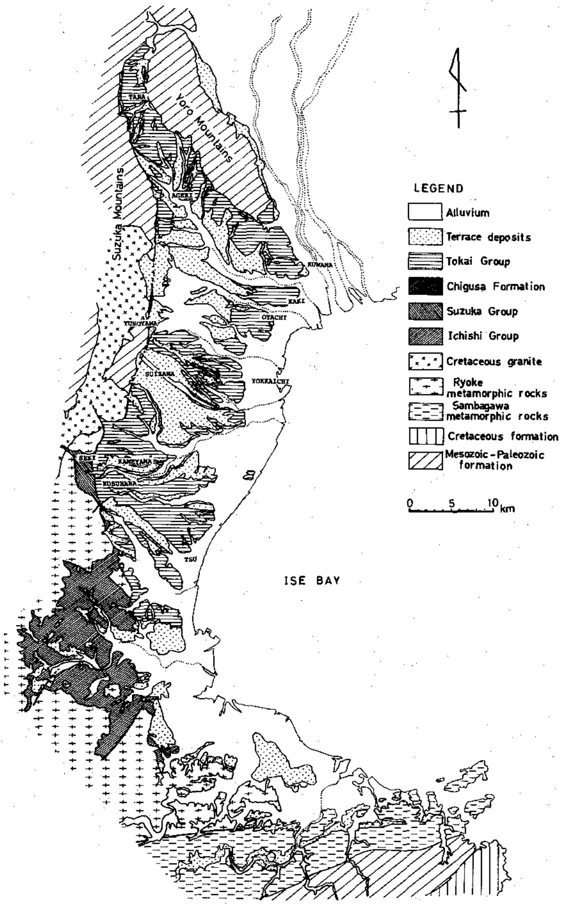

Fig. 2. Geologic map on the west coast of Ise Bay.

Table 1. Geologic system on the west coast of Ise Bay

Holocene	Alluvium
Pleistocene	Terrace deposits
	Rengeji, Kentoyama } Formation
Pliocene - Pleistocene	Tokai Group
Miocene	Ichishi, Suzuka } Group Chigusa Formation
Pre-Neogene	Granite Ryoke Metamorphic Rocks Mesozoic-Paleozoic Rocks

Ryoke metamorphic rocks and granites are distributed in southern part of Suzuka Mountains which lies at central and southern parts of the depression. Cretaceous granites are also exposed in central part of Suzuka Mountains.

Miocene Ichishi Group composed of marine sediments belonging to First Setouchi Supergroup is distributed in hilly zones in southern part of the depression. Also, Suzuka Group is distributed in Seki district (west of Kameyama) which is at central part of the depression. Its upper part consists of marine sediments, while middle and lower parts are composed of lacustrine sediments. Miocene Chigusa Formation is also marine deposits which are found in a narrow area between Cretaceous granites and Plio-Pleistocene sediments distributed along the Ichishi Fault in eastern foothill of Suzuka Mountains.

Plio-Pleistocene Tokai Group is distributed in hilly districts (40–300 m in height) extending from northern Sekigahara to southern Matsusaka City with a length of about 100 km in N–S direction. These sediments consist mainly of gravels, sands, muds in fluvial and lacustrine origin and intercalated with numerous volcanic ash layers and lignite beds. Generally speaking, in southern part (Nanse area around Tsu and Kameyama Cities), lower part of this sequence is distributed, and in northern part (Hokuse area) is upper part of it.

Middle Pleistocene sediments such as Rengeji and Kentoyama Formations overlie unconformably Tokai Group. Rengeji Formation is distributed at marginal parts of hills along Yoro Mountains, and at the top of hills to the west of Karegawa and to the north of Rengeji. It is chiefly composed of gravels, containing mostly cobble to pebble size gravels, and contains seams of silt and lignite. 95% of gravels is occupied by chert and sandstone. On the other hand, Kentoyama Formation consists of gravels, sands and muds, and is distributed around Tsu City. These formations can be correlated with Taketoyo Formation of Chita Peninsula, which is intercalated with some marine muddy layers (MAKINOUCHI, 1975b). Terrace deposits are composed mainly gravels, but marine fine-grained facies is intercalated in the Middle terrace deposists.

C. Lithostratigraphy of the Tokai Group

The surveyed areas in this study are shown in Figs. 3 and 4, and they occupy central and northern parts of the distribution of Tokai Group on the west coast of Ise Bay. As it is one of characteristics of Tokai Group that lateral variation of lithofacies is conspicuous, it is convenient at first to describe the lithology of Tokai Group in Hokusei and Inabe districts collectively as the type area (Fig. 3–A) (TAKEMURA, 1984), where the most continuous sequence and stable lithofacies can be observed. Thereafter, lithology of Tokai Group in other five areas (Fig. 3–B～F) will be described and compared with that of the type area. Stratigraphy in each area is summarized in Table 2.

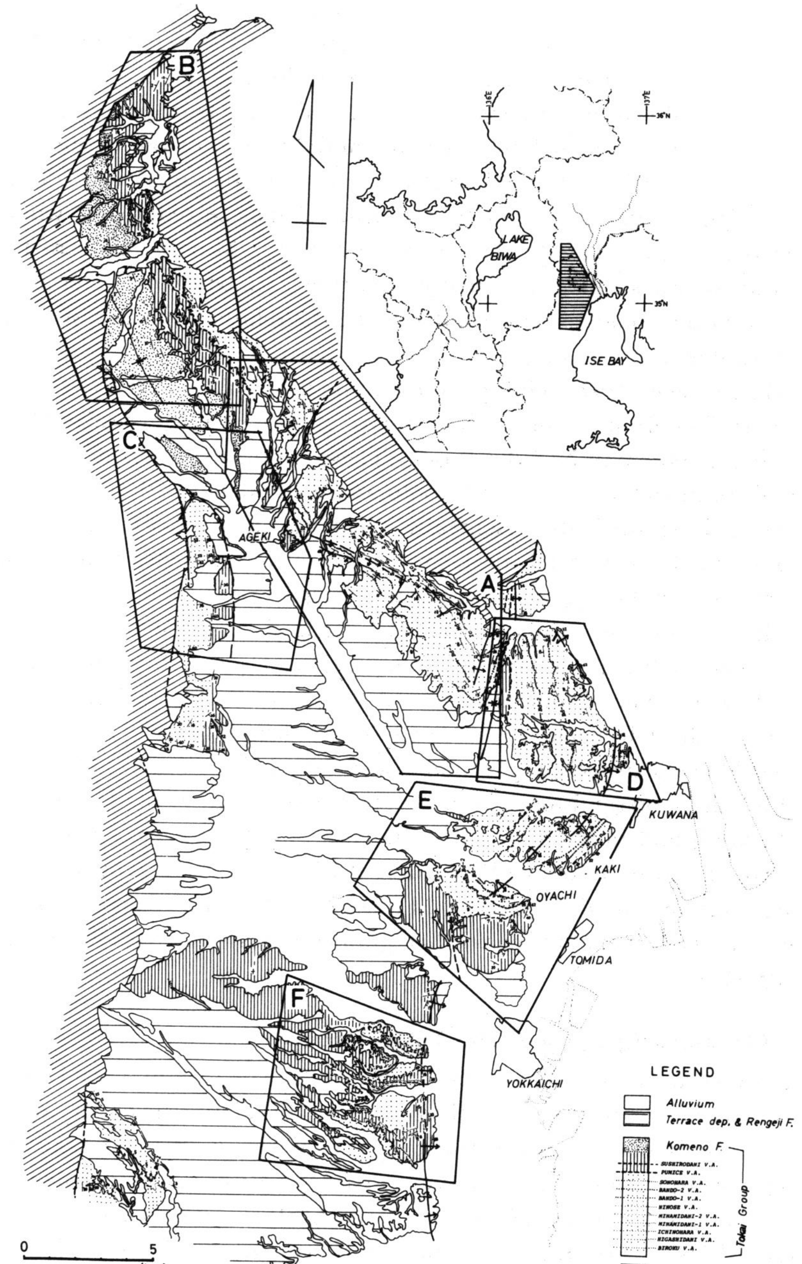

Fig. 3. Geologic map in the northern part of the west coast of Ise Bay (Hokuse area) and index map of the surveyed area.

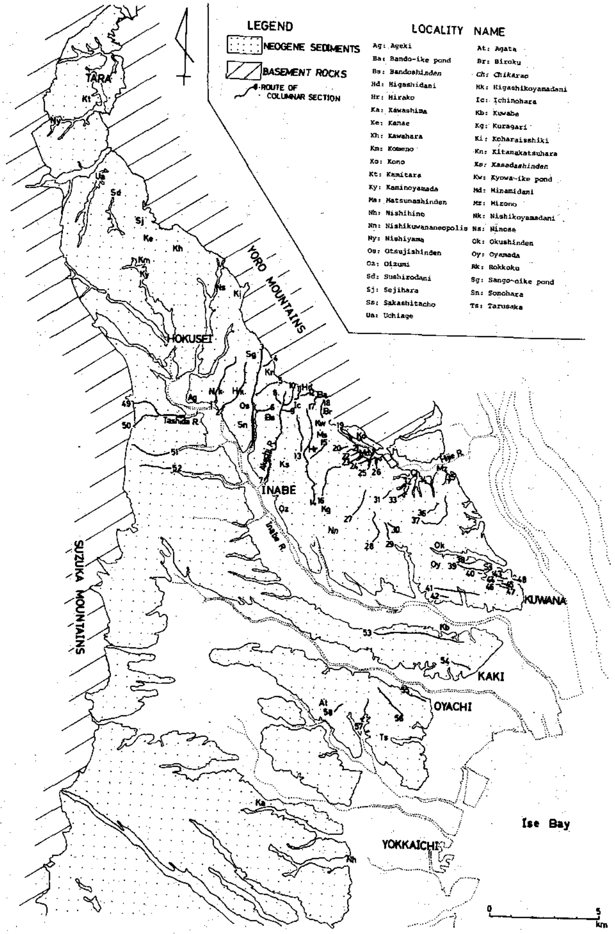

Fig. 4. Locality map in Hokuse area.

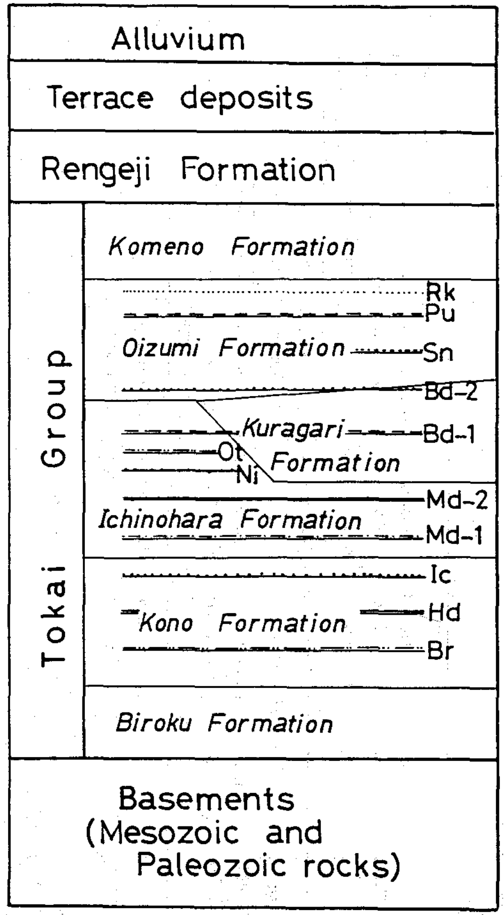

Fig. 5. Stratigraphy of the Tokai Group in Inabe and Hokusei area. Volcanic ash layers: Rk; Rokkoku, Pu; Pumice, Sn; Sonohara, Bd-2; Bando-2, Bd-1; Bando-1, Ot; Otsujishinden, Ni; Ninose, Md-2; Minamidani-2, Md-1; Minamidani-1, Ic; Ichinohara, Hd; Higashidani, Br; Biroku

Table 2. Stratigraphy of the Tokai Group in Hokuse area

FORMATION \ AREA	TARA	SUZUKA	INABE & HOKUSEI	KUWANA	KAKI & OYACHI	YOKKAICHI
KOMENO FORMATION	gravel	gravel	gravel			
OIZUMI FORMATION	alternation of mud & gravel "TARA FACIES"	alternation of mud & sand partly gravel	alternation of mud & sand "INABE FACIES"	alternation of mud & sand	sandy alternation of mud & sand partly gravel	sand & gravel sandy alternation of mud & sand partly gravel
KURAGARI-ICHINOHARA FORMATION	ICHINOHARA F.		sand & gravel	KURAGARI F. sand & gravel	sand & gravel	
	alternation of gravel & mud	alternation of gravel & mud	alternation of gravel & mud	alternation of sand & mud "KUWANA FACIES"	alternation of sand & mud	
KONO FORMATION		alternation of mud & sand	alternation of mud & sand	alternation of mud & sand		
BIROKU FORMATION		gravel	gravel			

a. Hokusei and Inabe area (Fig. 3–A)

Tokai Group in this area (about 950 meters in thickness) forms hills at southwestern foot of Yoro Mountains, and dips to southwest. It is divided into six formations such as Biroku (gravels), Kono (alternating beds of sand and mud), Ichinohara (alternating beds of gravel and mud), Kuragari (gravels with mud and sand layers), Ôizumi (alternating beds of sand and mud) and Komeno (gravels) Formations in ascending order (Fig. 5). These sediments intercalates at least twenty five volcanic ash layers. The geologic map and columnar sections are shown in Figs. 6, 7 and 8.

1. Biroku Formation (MATSUI, 1943)

Type locality: the area around Bandoike pond to northwest of Biroku village

This formation is composed mainly of gravels of bluish green sandstone which were derived from the basement of Mesozoic and Paleozoic formations. Gravels are subround and subangular in shape, and are cobble, pebble to small boulder in size. Most gravels are heavily weathered, and the matrix is composed of bluish green colored sands. Distributions are restricted in foothill zone of Yoro Mountains.

At the type locality, the gravel bed attains 50 m thick.

2. Kono Formation (MATSUI, 1943)

Type locality: Northwest of Biroku

This formation is distributed mainly from Koharaisshiki to Chikarao in the area of southern foothills of Yoro Mountains. It is composed of alternating beds of

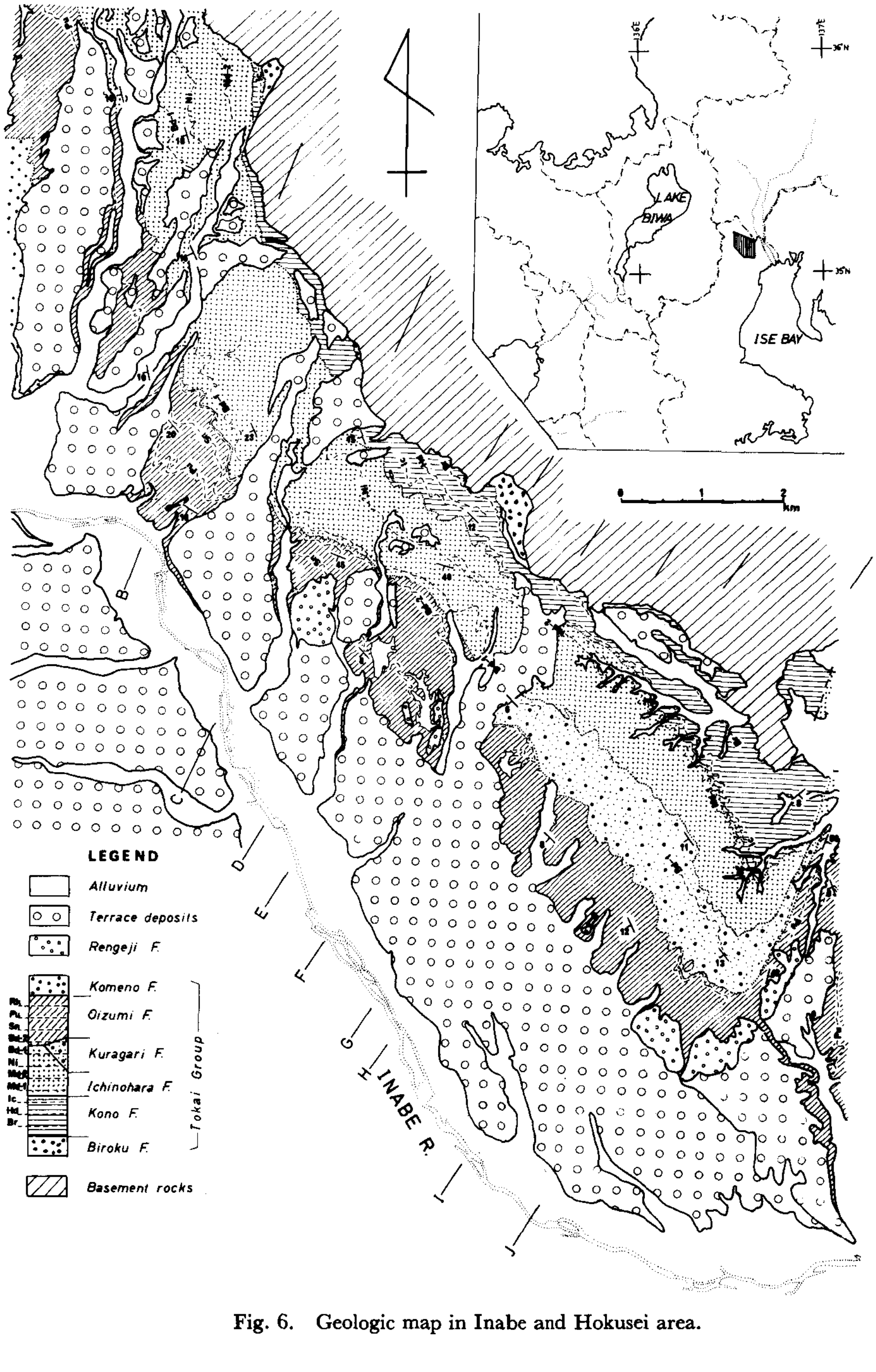

Fig. 6. Geologic map in Inabe and Hokusei area.

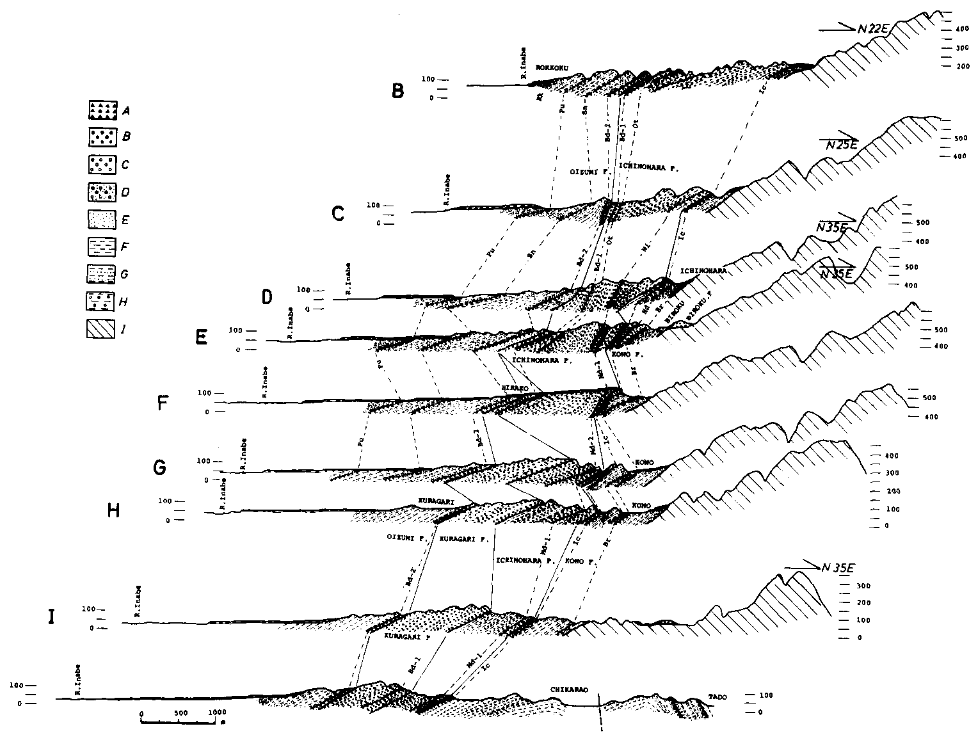

Fig. 7. Geologic profiles in Inabe and Hokusei area. Profiling lines are shown in Fig. 6.
A: Terrace deposits, *B*: Rengeji Formation, *C*: gravel, *D*: sand and gravel, *E*: sand, *F*: mud, *G*: alternating beds of sand and mud, *H*: alternating beds of mud and gravel, *I*: basement rocks

massive bluish green mud and sand with lignites and volcanic ash layers. At least five volcanic ash layers are intercalated in this formation, and three of them, the Biroku, Higashidani and Ichinohara volcanic ash layers in ascending order are effective as marker beds. The thickness of this formation decreases westward: about 110 m in Kono, but about 25 m in Kitanakatsuhara. Generally, Kono Formation abuts on basement of Mesozoic and Paleozoic rocks and overlies Biroku Formation conformably.

3. Ichinohara Formation (MATSUI, 1943)

Type locality: At the valley to west of Matsunashinden

This formation is composed mainly of alternating beds of mud and gravel, and overlies Kono Formation conformably. In the area to north of Kawahara, however, it abuts directly on Mesozoic and Paleozoic basement rocks. The thickness of this formation attains to 220 m near Ichinohara, and to 350 m along Yamada river. In the area to west of Hirako, the upper part of Ichinohara Formation grades into

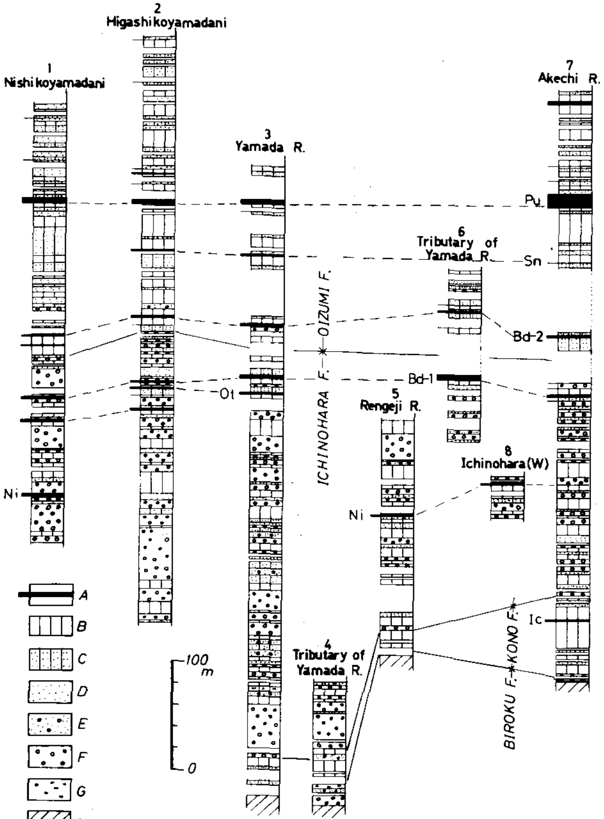

Fig. 8–a. Columnar sections in Inabe and Hokusei area. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

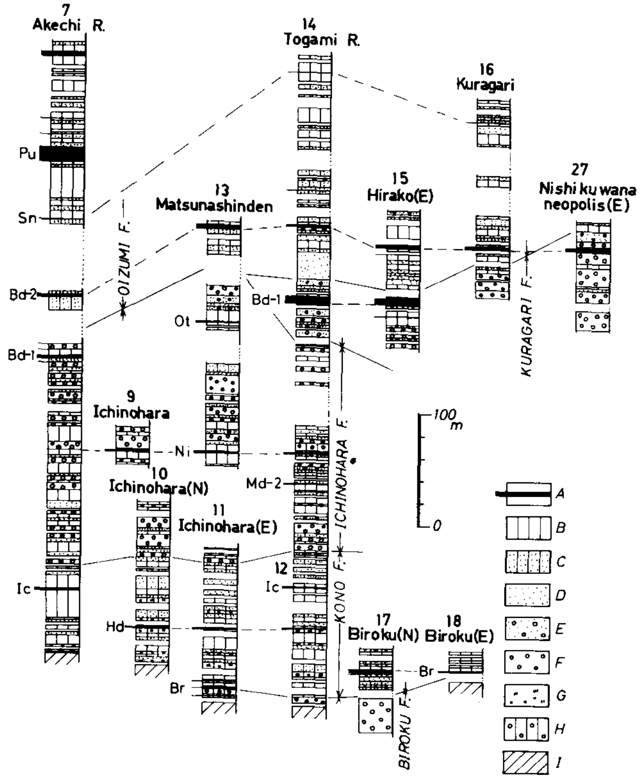

Fig. 8–b. Columnar sections in Inabe area. *A*: volcanic ash layer, *B*: mud, *C*: alternating beds of sand and mud, *D*: sand, *E*: sand and gravel, *F*: gravel, *G*: lignite, *H*: alternating beds of mud and gravel, *I*: basement rocks. (Symbols of volcanic ash layer are shown in Fig. 5. Route Nos are shown in Fig. 4.)

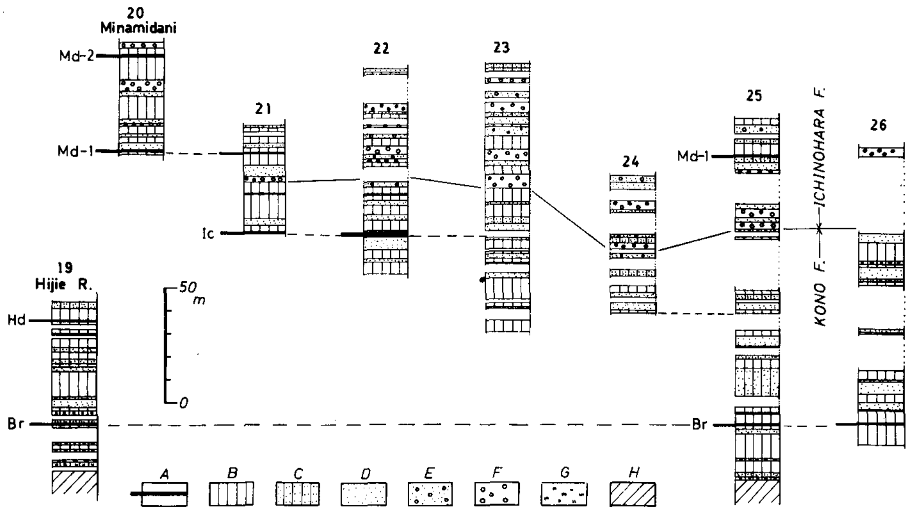

Fig. 8–c. Columnar sections in Kono area. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

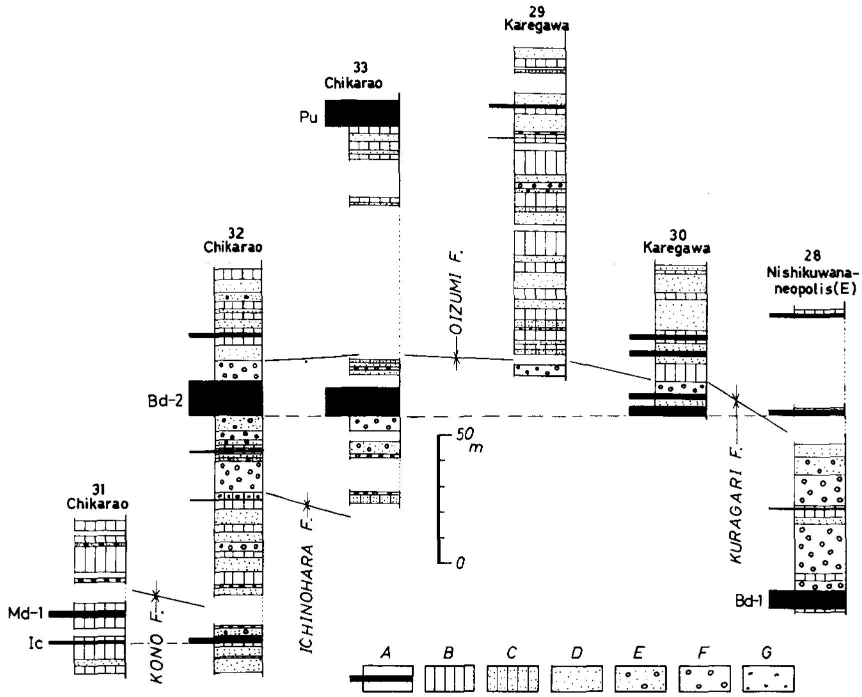

Fig. 8–d. Columnar sections in Karegawa and Chikarao area. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

overlying Kuragari Formation. At least nine volcanic ash layers are intercalated in this formation, and five of them are effective as marker beds. They are called Minamidani-1, Minamidani-2, Ninose, Otsujishinden, and Bando-1 volcanic ash layers in ascending order.

4. Kuragari Formation (Matsui, 1943)

Type locality: hills to north of Kuragari village

This formation is composed mainly of gravels with a small amount of mud and sand layers. At least five volcanic ash layers are intercalated within this formation, and among them, the Bando-1 volcanic ash layer is useful as a key bed. Gravels are pebble to cobble in size, and are dominated by chert, sandstone and quartz porphyry, with matrix of coarse to medium sand. In total, the amount of chert is about 50–70% and that of quartz porphyry is about 20–30%. The Bando-1 volcanic ash layer is also commonly found in upper part of Ichinohara Formation in northern part of Hokusei area. This formation is distributed only in the area to east of Hirako. Thickness of the deposits increases eastward and northward.

5. Ôizumi Formation (Matsui, 1943)

Type locality: at the valley in western area of Kasadashinden (the Akechi river)

This formation is composed mainly of alternations of sand and mud with some lignites and volcanic ash layers, and is about 360 m thick. At least ten volcanic ash layers are intercalated in this formation, and four of them, Bando-2, Sonohara, Pumice and Rokkoku volcanic ash layers in ascending order, are available as good marker beds.

6. Komeno Formation (Yasuda, 1950)

Type locality: a cliff in the west of Komeno

This formation occupies the uppermost part of Tokai Group. This is composed mainly of gravels which are made of sandstone, shale, siliceous shale and chert. The lower part is commonly composed of granule, pebble and cobble gravels, while the upper part is represented by cobble with boulder gravels. This formation is distributed mainly in Tara area (Fig. 3–B).

b. Tara area (Fig. 3–B)

The Tokai Group in this area was reported by Yokoyama (1971) and Miyamura *et al.* (1976) as shown in Figs. 9 and 10. According to them, the deposit in this area is 650 m in thickness and was divided into Ichinohara, Ôizumi and Komeno Formations in ascending order. At least fifteen volcanic ash layers are commonly found throughout this area (Fig. 11).

Ichinohara Formation overlies unconformably basement Mesozoic and Paleozoic rocks of the Yoro Mountains. In the neighborhood of Sejihara, there are several good outcrops, and the formation is measured as 50–70 m thick. The sediments are

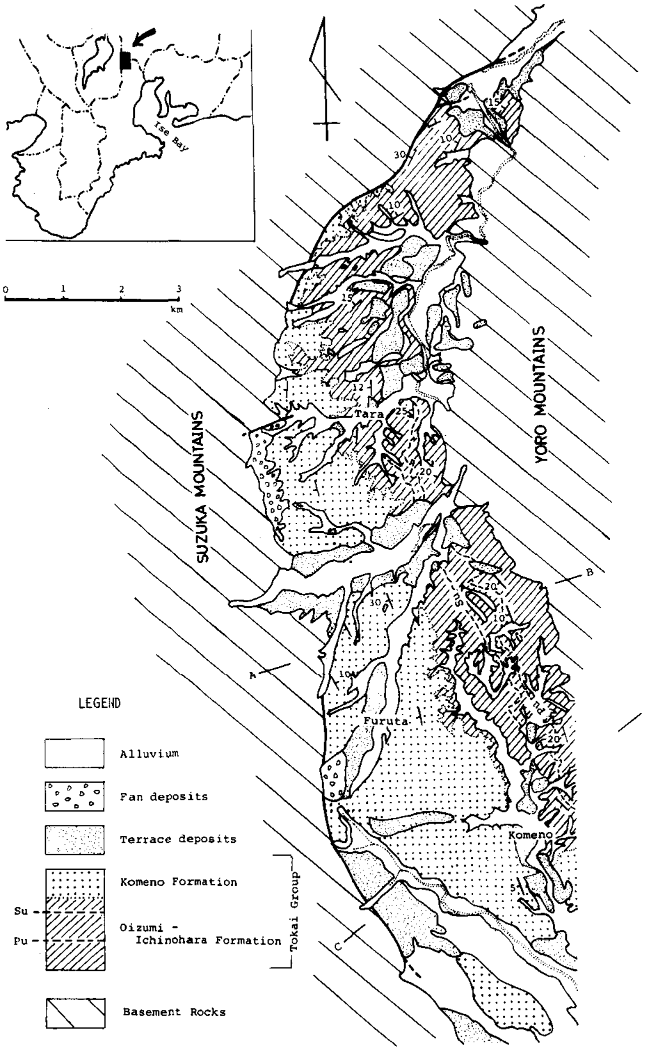

Fig. 9. Geologic map in Tara area (after MIYAMURA *et al.*, 1976).

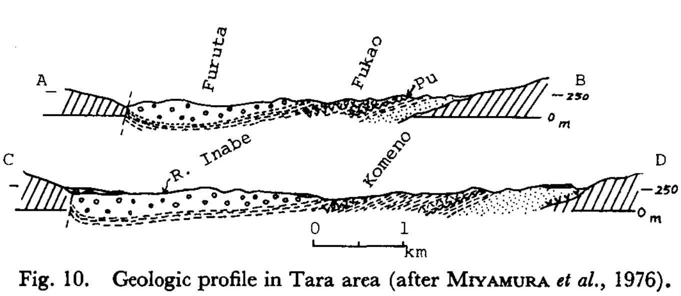

Fig. 10. Geologic profile in Tara area (after MIYAMURA *et al.*, 1976).

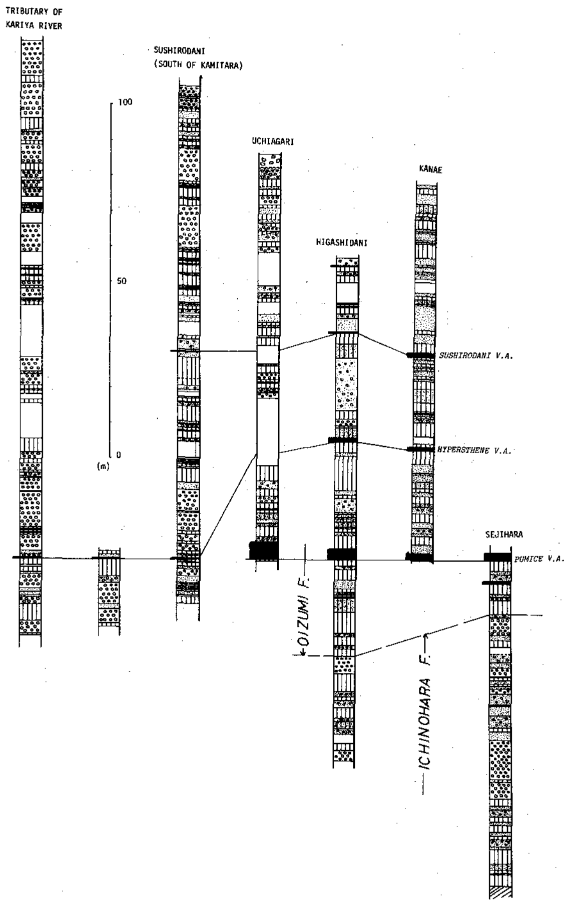

Fig. 11–a. Columnar sections in Tara area (after MIYAMURA *et al.*, 1976).

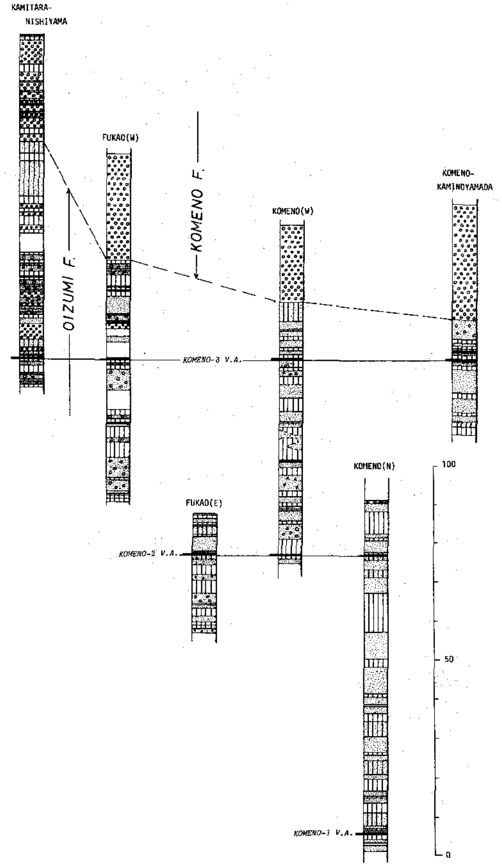

Fig. 11–b. Columnar sections in Tara area (after MIYAMURA *et al.*, 1976).

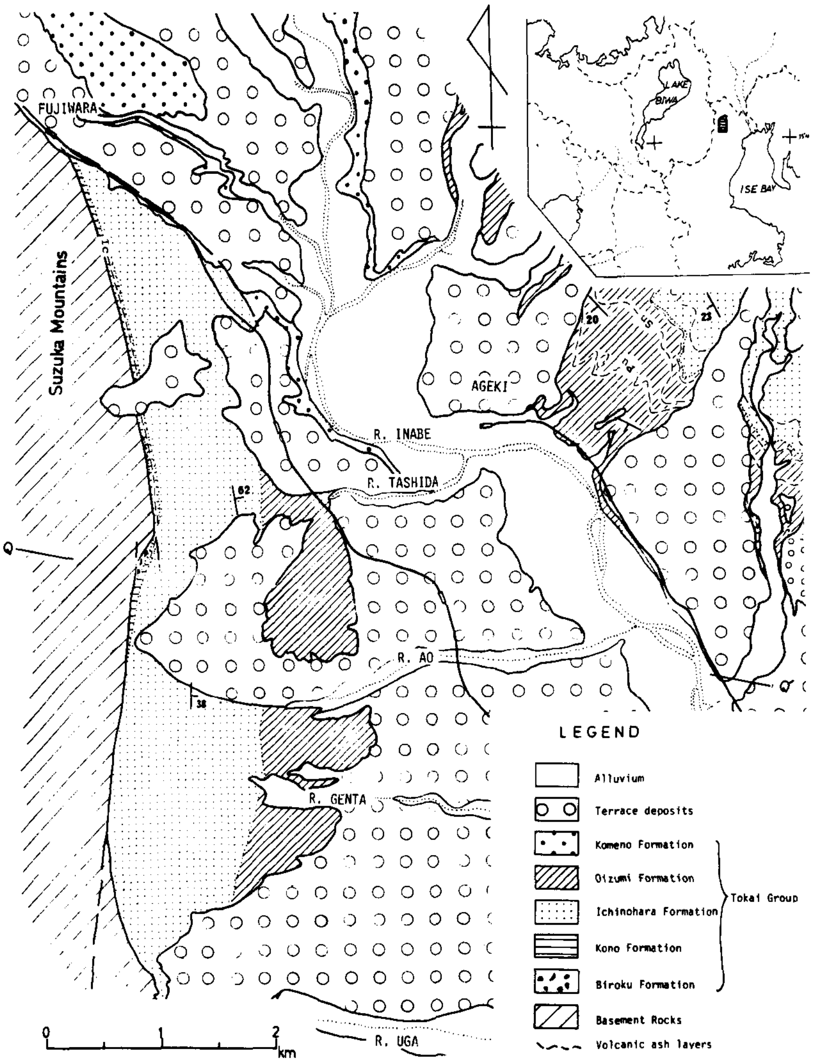

Fig. 12. Geologic map in the foot of the Suzuka Mountains.

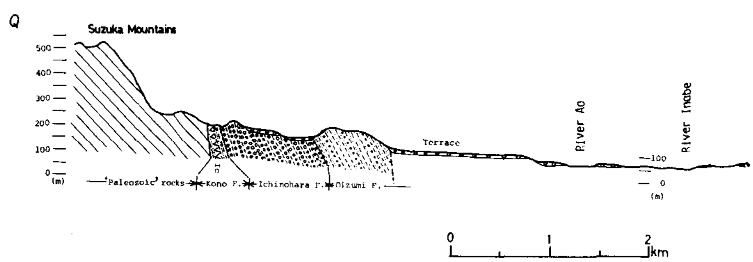

Fig. 13. Geologic profile in the foot of the Suzuka Mountains. Profiling line is shown in Fig. 12.

composed mainly of alternating beds of gravel and mud with some sandy layers. The thickness and sedimentary facies are variable laterally. Gravels are cobble to pebble in size, subangular to subround in shape, and are composed mostly of sandstone with subordinate shale and chert.

The Ôizumi Formation reaches to 300 m in thickness, and its sedimentary facies are also variable laterally. At Tara, along Makita river and Sushirodani valley, the sedimentary facies is very similar to those of Ichinohara Formation at Inabe area. The author calls this facies "Tara Facies" of Ôizumi Formation. This facies is characterized by alternating beds of gravel and mud. On the other hand, along Aibagawa river and around Komeno, it is composed of alternating beds of sand and mud with small amount of granule to pebble gravels. The Pumice and Sushirodani volcanic ash layers are intercalated.

The Komeno Formation, the uppermost formation of Tokai Group, exceeds 300 m thick and thins northward. It is composed mainly of cobble to pebble gravels, with matrix of very coarse sand. Gravels are composed of sandstone (50%), and subordination of siliceous shale, shale and chert, and with small amount of quartz porphyry. Type locality of Komeno Formation is the cliff of Aibagawa river, to west of Komeno of this area.

c. **Suzuka area** (Fig. 3–C)

At east foot of Suzuka Mountains, Tokai Group exceeds 800 m in thickness and dips to east (Figs. 12 and 13). Tokai Group is divided into Biroku, Kono, Ichinohara, and Ôizumi Formations, and at least seven volcanic ash layers are intercalated (Fig. 14). In the upper course of tributary of Tashida river, Biroku Formation is well exposed. It is 30 m thick and two lignite beds are intercalated in the upper part. It is conformably covered with Kono Formation. Kono Formation crops out in the upper course of Tashida river and its tributaries. It consists of muddy alternating beds of sand and mud with lignite beds. It is about 40 m thick. The thickness of mud layer ranges from 2

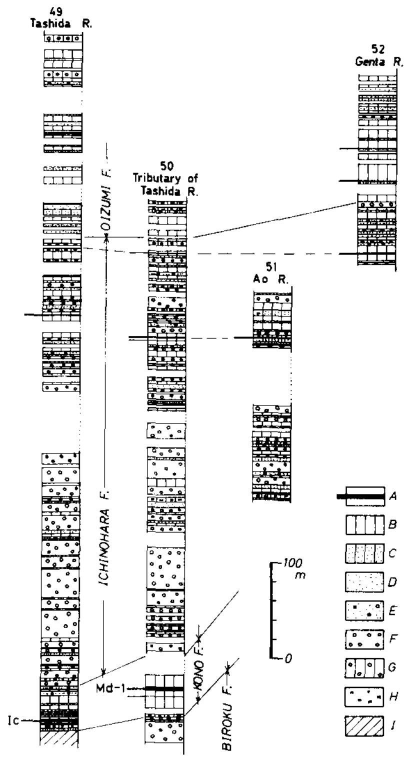

Fig. 14. Columnar sections in the foot of the Suzuka Mountains. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

to 5 m thick, and that of sand layer is about 2 m thick. A coarse grained crystalline volcanic ash layer named Ichinohara volcanic ash layer, lies 10 m upper than the unconformity just above the basement rocks.

Also, Ichinohara Formation is well exposed at the river bed of Tashida river. In this district, this formation is about 470 m thick, and is divided into two parts. The lower part is composed mainly of cobble gravels with thin mud layers, and the upper part is composed of alternating beds of gravel and mud.

The Ôizumi Formation is also exposed at the cliffs along Tashida river. It exceeds 220 m in thickness and is composed of alternating beds of sand and mud with some gravel layers.

d. **Kuwana area** (Fig. 3–D)

In west of Kuwana City, Tokai Group forms the hills of 50–200 m in height, and makes an asymmetric anticline in N–S trend, called Kuwana Anticline (Figs. 15 and 16). At east wing of this anticline, the strata are steeply inclined to Ise Bay. Around the axis of the anticline, Kono Formation is exposed. To the upper horizon, Ichinohara, Kuragari and Ôizumi Formations are successively arranged in ascending order. The total thickness of the strata is about 420 m (Fig. 17). At least eight volcanic ash layers are found in east wing of the anticline and fourteen layers in its west wing.

Kono Formation is exposed at Nishibessho of Kuwana City, and is composed of alternating beds of sand and mud. It is about 30 m thick. At the axis of Kuwana anticline, a light gray hard volcanic ash layer (Higashidani volcanic ash layer) is observed, and it contains fragments of plant remains.

Ichinohara Formation exceeds about 100 m thick and is represented by sandy alternation of sands and muds with some pebbly gravel layers. This facies is called "Kuwana facies" of Ichinohara Formation, and is different from that of alternating beds of gravels and mud at the Inabe and Hokusei area.

Kuragari Formation is composed mainly of gravels with a small amount of mud and sand layers, and is well exposed at a pilotfarm to south of Mizono. The sediment is about 140 m in thickness, which is the thickest part of Kuragari Formation.

Ôizumi Formation in this area, is composed of sandy alternation of sands and muds, and is about 120 m thick. Together with very thick (about 10 m) bed of Pumice volcanic ash layer at Nishibessho and the valley to east of Karegawa, at least six volcanic ash layers are intercalated in this formation.

e. **Kaki and Oyachi Hills** (Fig. 3–E)

Along the west coast of Ise Bay, from Kuwana to Yokkaichi City, there are two hilly regions of about 50–100 m in height, which are composed of Tokai Group. Among them, the northern hill is called "Kaki Hill" and the southern one is called

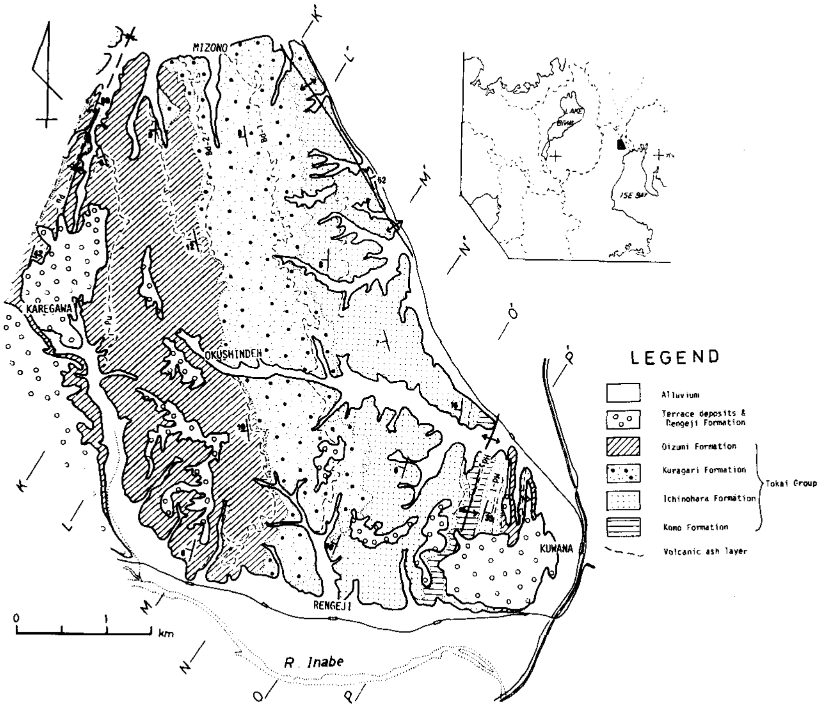

Fig. 15. Geologic map in Kuwana area.

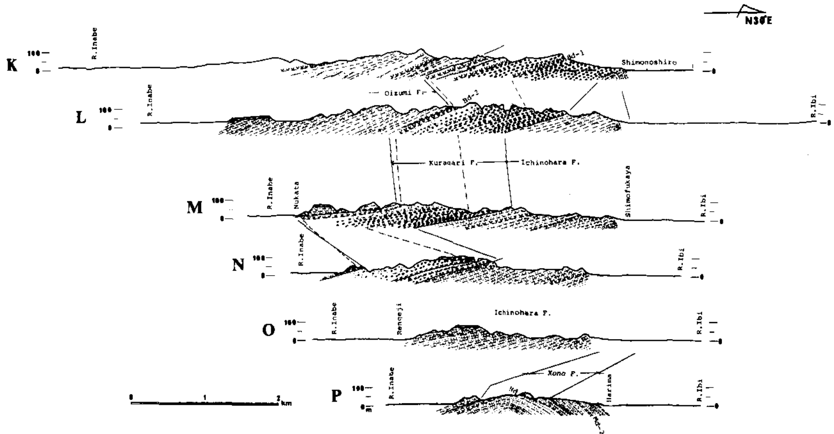

Fig. 16. Geologic profiles in Kuwana area. Legend is shown in Fig. 7. Profiling lines are shown in Fig. 15.

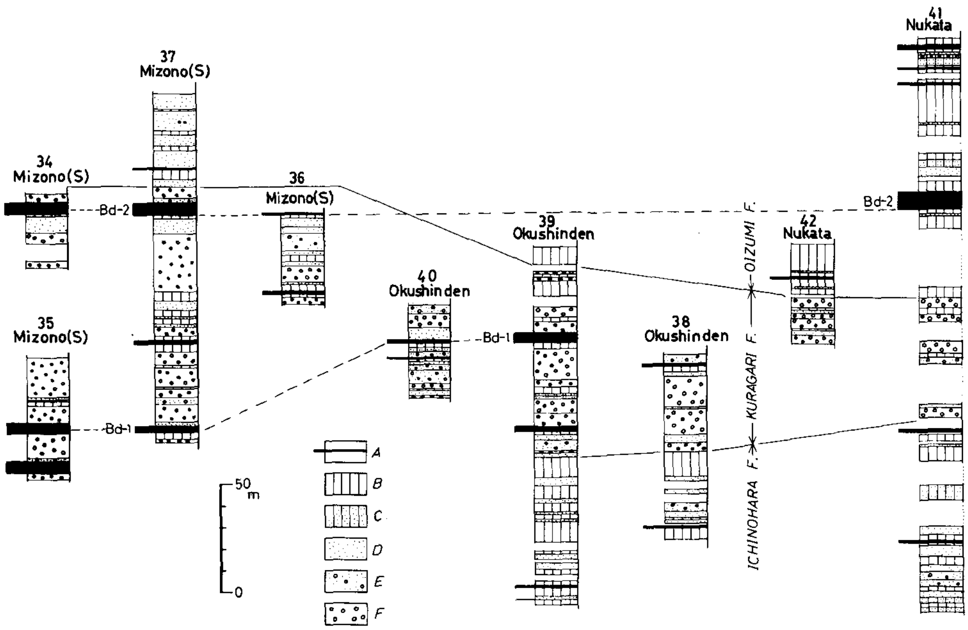

Fig. 17–a. Columnar sections in Kuwana area. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

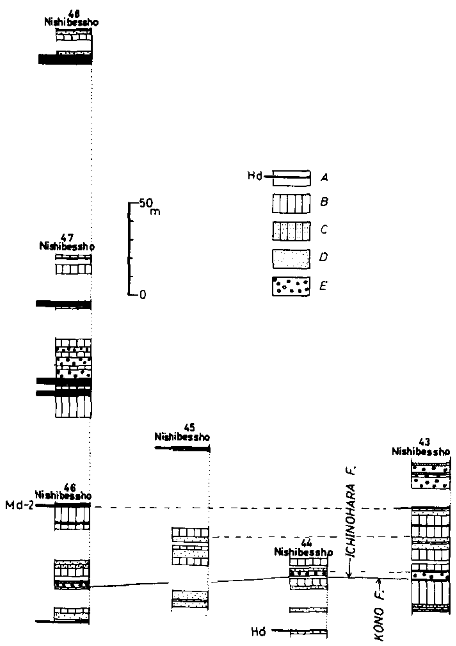

Fig. 17–b. Columnar sections in Kuwana area. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

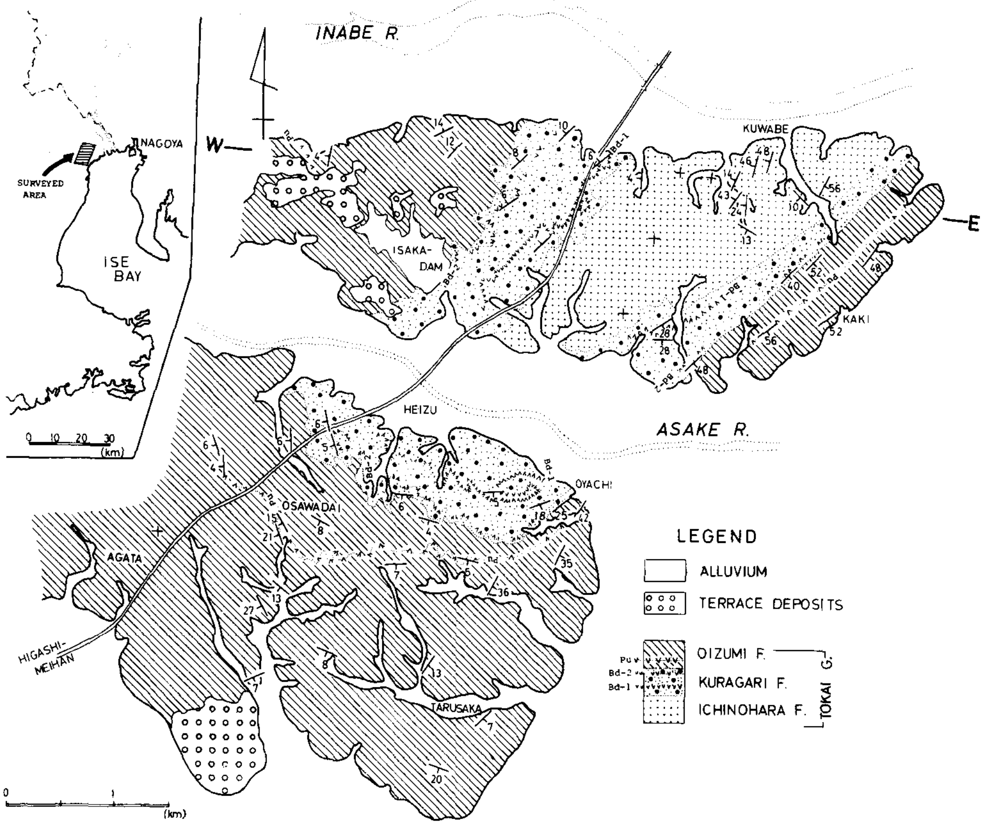

Fig. 18. Geologic map in Kaki and Oyachi area.

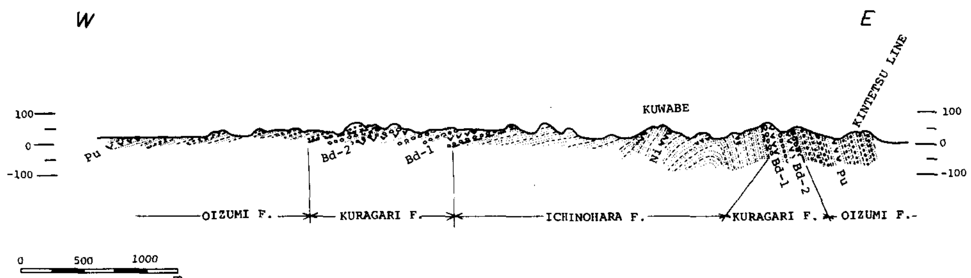

Fig. 19. Geologic profiles in Kaki and Oyachi area. Legend is shown in Fig. 7. Profiling lines are shown in Fig. 18.

"Oyachi Hill". As the axis of anticline running from Kuwana hill (Kuwana anticline) plunges to south, the upper horizon appeared in southern part alongside anticline axis (Figs. 18 and 19).

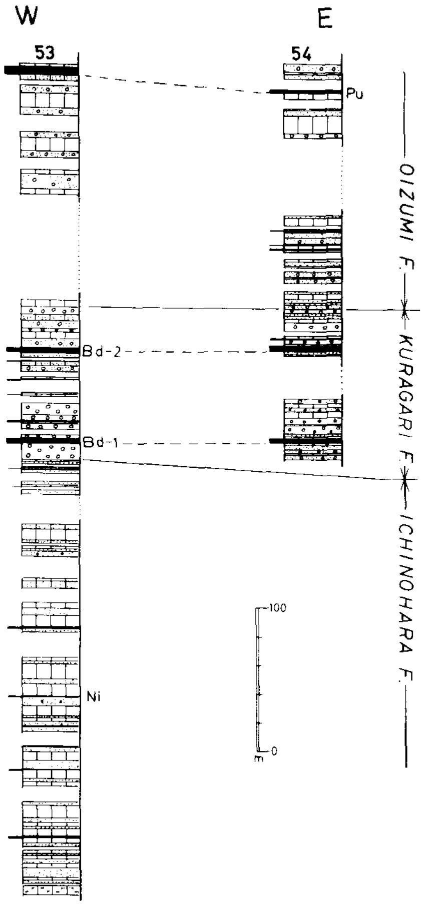

Fig. 20–a. Columnar sections in Kaki and Oyachi area. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

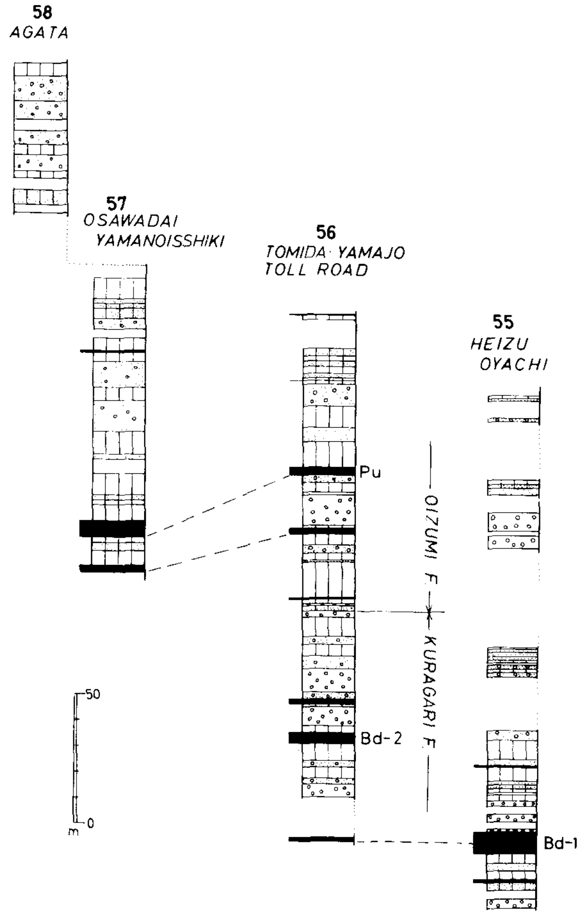

Fig. 20–b. Columnar sections in Kaki and Oyachi area. Legend is shown in Fig. 8–b. Route Nos are shown in Fig. 4.

In Kaki hill, Tokai Group is divided into Ichinohara (340 m thick), Kuragari (110 m thick) and Ôizumi (260 m thick) Formations in ascending order. Throughout these sequences, at least sixteen volcanic ash layers are identified. In the area around Kuwabe, Ichinohara Formation is composed mainly of alternating beds of sand and mud with small amount of pebble gravel layers, and it belongs to Kuwana Facies(Fig. 20). Kuragari Formation is well exposed along Higashi Meihan Highway. It is composed mainly of sandy gravel deposits and is similar to the facies around Kuwana City. It contains some volcanic ash and mud layers. Ôizumi Formation is composed of alternating beds of sand and mud with some gravel layers. This facies is slightly different from that in the Kuwana area, because of the presence of large amount of sandy materials and abundant gravel layers (Fig. 20).

In Oyachi hill, Tokai Group consists of Kuragari and Ôizumi Formations in ascending order. The former is composed of sandy gravel layers and is about 110 m thick. Kuragari Formation is exposed at Heizu, west of Oyachi, and in the lowest part, a peculiar volcanic ash layer containing many pumice grains is intercalated. Muddy sediments are more dominant than in Kuwana area. Ôizumi Formation is about 240 m thick and can be divided into two facies vertically. The upper half is exposed at Tarusaka of southeastern part of the hill and at Agata of western part of the hill. It is composed mainly of sand and gravel layers in which cross laminations are well developed. The lower half which is composed of alternating beds of sand and mud with some gravel layers is observed along Tomida-Yamajo Toll Road.

f. Yokkaichi area (Fig. 3–F)

Tokai Group distributed at west of Yokkaichi City corresponds to Ôizumi Formation in Hokuse area. It is about 150 m thick and is divided into two parts as shown in geologic map and columnar section of Figs. 21 and 22.

The lower half is about 50 m thick and is composed of alternating beds of bluish gray colored clay and sand with some pebble gravel layers, and is called "Kawashima Member". Those deposists are distributed mainly around Kawashima of Yokkaichi City. In this member, a prominant volcanic ash layer of about 10 m in thickness is intercalated. This layer treated as very useful key bed in this hill region (Fig. 23) is composed of coarse grained pumiceous ash, and is designated to Pumice volcanic ash layer. The upper half of about 100 m thick is composed mainly of sand layers with many gravels, and is called "Nishihino Member". Those deposits are distributed at the top of hill and in eastern end of hill.

Lithology and relationship between lithofacies and volcanic ash layers in Hokuse area are summarized in Fig. 24 and Table 2.

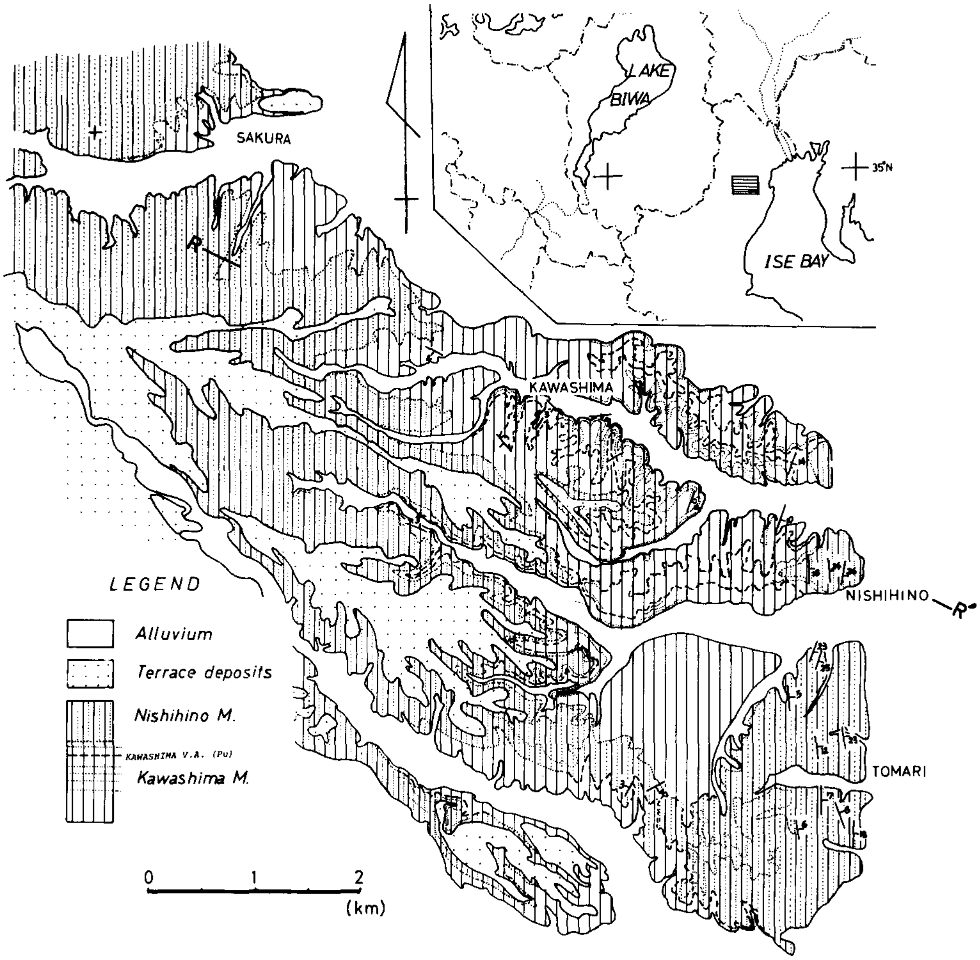

Fig. 21. Geologic map in Yokkaichi area.

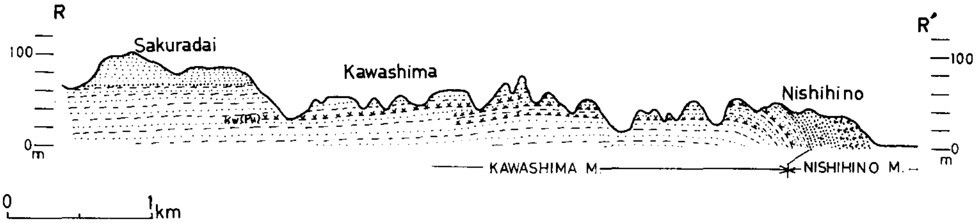

Fig. 22. Geologic profile in Yokkaichi area. Legend is shown in Fig. 7. Profiling line is shown in Fig. 21.

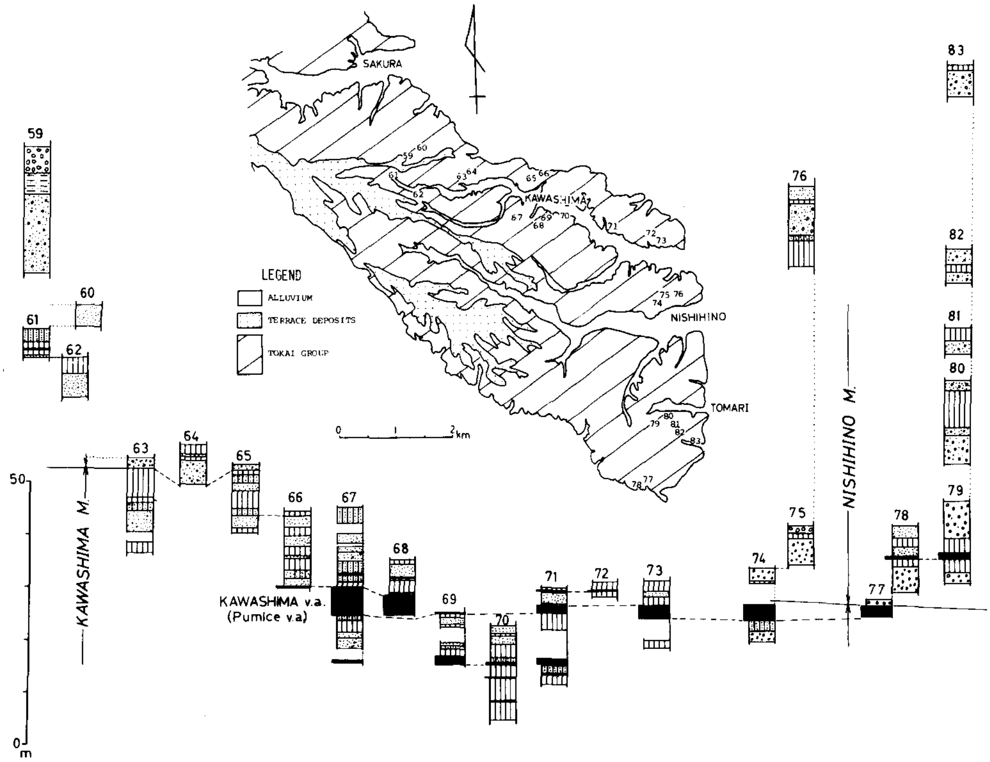

Fig. 23. Columnar sections in Yokkaichi area. Legend is shown in Fig. 8–b.

D. Description of Volcanic Ash Layers

At least thirty volcanic ash layers intercalated in the Tokai Group are discriminated each other in the surveyed area. Among them thirteen ones are usable as key beds for chronostratigraphical and biostratigraphical correlation on the basis of their characteristics and wide distribution, and they will be described in ascending order as follows.

1. Biroku volcanic ash layer (Mori and Kimura, 1973)

   Type locality: northwest of Biroku, Tado-cho

This volcanic ash layer of 30 cm in thickness is intercalated in the lower part of Kono Formation and is composed of massive medium-grained ashes. The color is yellowish green when weathered and gray when fresh, and heavy minerals like as hornblende, biotite and apatite are contained. NRM (natural remanent magnetization) of it has reversed polarity. Although other two volcanic ash layers are observed below this at the type locality, those NRMs are also with reversed polarity.

2. Higashidani volcanic ash layer

   Type locality: Higashidani in the east of Ichinohara, Inabe-cho

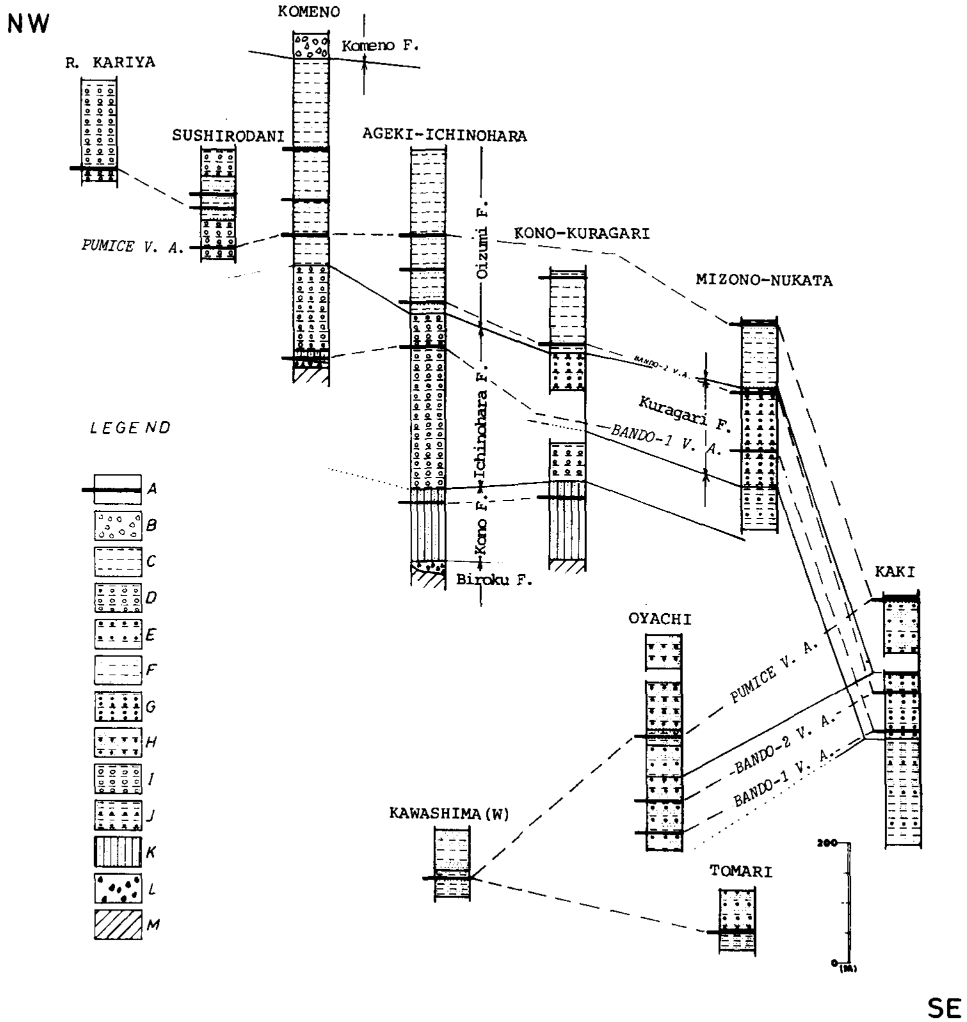

Fig. 24. Lateral lithologic variations of the Tokai Group in Hokuse area.

A: volcanic ash layer, *B*: gravels of the Komeno Formation, *C*: alternating beds of sand and mud of the Oizumi Formation, *D*: alternating beds of mud and gravel of the Oizumi Formation, *E*: sand and gravels of the Oizumi Formation, *F*: sand dominant alternating beds of sand and mud of the Oizumi Formation, *G*: sand and gravel of the Kuragari Formation, *H*: sand dominant alternating beds of sand and gravel of the Kuragari Formation, *I*: alternating beds of mud and gravel of the Ichinohara Formation, *J*: alternating beds of mud and sand of the Ichinohara Formation, *K*: alternating beds of mud and sand of the Kono Formation, *L*: gravels of the Biroku Formation, *M*: Mesozoic and Paleozoic formation.

This volcanic ash layer is intercalated in the middle part of Kono Formation. It is situated at the horizon about 40 m high above Biroku volcanic ash layer. Thickness is 50 cm at the type locality. It is pale in color in fresh and is yellow-greenish gray in weathered. NRM of it reveals normal polarity. This layer is also exposed at riverbed of the Hijie river and at Nishibessho, with well-preserved fossil leaves. Once it was correlated with Biroku volcanic ash layer (Mori and Kimura, 1973), but it is clear that this volcanic ash layer is different from Biroku volcanic ash layer from the stratigraphic position and magnetic polarity.

3. Ichinohara volcanic ash layer

Type locality: At the pass along the road from Ichinohara to Biroku, Inabe-cho

This volcanic ash layer is intercalated in the upper part of Kono Formation. The thickness is 86 cm at the type locality. Within it, three different parts are observed as shown in Fig. 25. The lowest part is dark gray in color, and is composed of coarse-grained volcanic glasses acompanied by biotite and quartz crystals with small pumice grains. The middle part is greenish yellow in color, and is composed of coarse-grained volcanic glasses with biotite crystals. The upper part is composed mainly of glass flakes, and is light gray in color. It contains heavy minerals such as biotite, hornblende, orthorhombic pyroxene and zircon. NRM of it shows normal

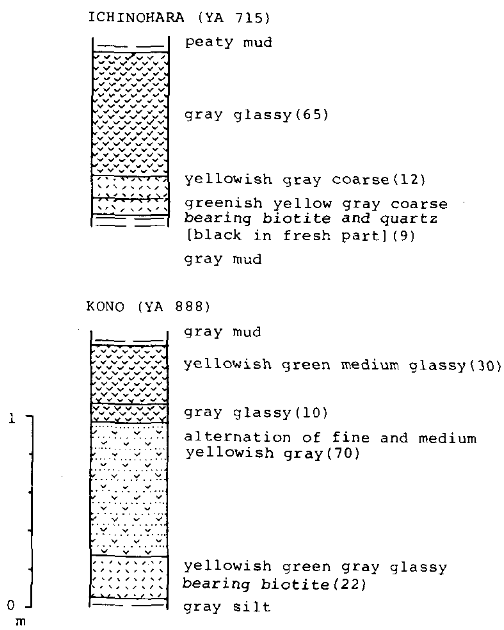

Fig. 25. Columnar sections of the Ichinohara volcanic ash layer.

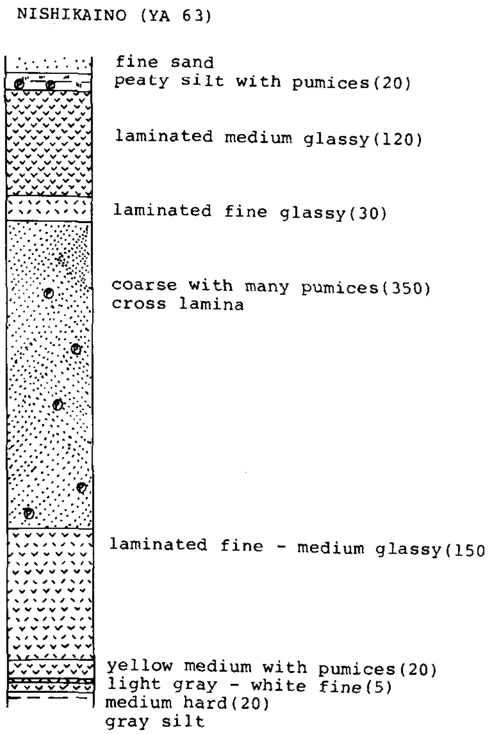

Fig. 26. Columnar section of the Pumice volcanic ash layer.

polarity. The fission-track ages were measured at two localities respectively; 2.8 Ma for the sample at Kono-minamidani and 2.9 Ma at the Tashida river (YOKOYAMA *et al.*, 1980b).

4. Minamidani-1 volcanic ash layer

Type locality: Minamidani in the south of Kono, Tado-cho

This volcanic ash layer is intercalated in the lower part of Ichinohara Formation. Its thickness is about 80 cm at the type locality. Within it, two different parts can be observed. The lower part is composed of fine glassy volcanic ash, and is yellow in color. It contains heavy minerals such as hornblende, orthorhombic pyroxene, clinopyroxene, biotite and apatite. NRM of it reveals normal polarity.

5. Minamidani-2 volcanic ash layer

Type locality: Minamidani in the south of Kono, Tado-cho

This volcanic ash layer is intercalated in the horizon 40 m above the Minamidani-1 volcanic ash layer. The thickness is 90 cm at the type locality. The lower part is greenish yellow in color, and is composed of medium-grained glass flakes. On the other hand, the upper part is composed of alternating fine- and medium-grained glassy layers. It contains heavy minerals such as hornblende, orthorhombic pyroxene and biotite. NRM of it reveals normal polarity.

6. Ninose volcanic ash layer

Type locality: at Ninose, Hokusei-cho

This volcanic ash layer is intercalated in the middle part of Ichinohara Formation. This massive glassy volcanic ash layer is light gray in color. At the type locality, it is 40 cm thick and is intercalated in gray muds. NRM of it reveals reversed polarity.

7. Otsujishinden volcanic ash layer

Type locality: at riverbed of the Yamada river in the east of Otsujishinden, Hokusei-cho

This volcanic ash layer is situated in the upper part of Ichinohara Formation, about 110 m above the Ninose volcanic ash layer. The thickness is 95 cm at the type locality, and is divided into three parts. The lower part is 2–5 cm thick, coarse-grained glassy volcanic ash, and white in color. The middle part, about 35 cm thick, consists of laminated fine volcanic ash with small pumice grains, and is very hard. The upper part, about 55 cm thick, is massive and pale gray in color. In this part, small pumice grains and plant fragment are contained.

8. Bando-1 volcanic ash layer

Type locality: North of Bandoshinden, Inabe-cho

This volcanic ash layer is generally intercalated in the upper part of Ichinohara Formation. It is also in Kuragari Formation in the eastern part of Hokusei and Inabe area, and Kuwana area. Its thickness is 200 cm at the type locality, and it reaches to 400 cm east of Ichinohara. This volcanic ash layer is divided into two parts. The lower part is medium-grained pumiceous ashes and pale yellow in color.

The upper part is composed of alternating fine-and medium-grained ashes. It contains many pumice grains. NRM of it shows reversed polarity. At the type locality, this volcanic ash layer is coincidental with T_8 tuff of TAKEHARA (1961).

9. Bando-2 volcanic ash layer

Type locality: Higashikoyamadani, Hokusei-cho

This volcanic ash layer is intercalated in the lowermost part of Oizumi Formation. The thickness is 160 cm at the type locality, but it reaches up to 10 m at Nukata in Kuwana City. This ash layer is massive and pale gray in color, and contains abundant pumice grains. This is composed mainly of glass flakes with heavy minerals such as orthorhombic pyroxene, hornblende, biotite, apatite and zircon. NRM of it reveals reversed polarity.

10. Sonohara volcanic ash layer

Type locality: at riverbed of the Yamada river in the east of Sonohara, Hokusei-cho

This volcanic ash layer is intercalated in the lower part of Oizumi Formation, and about 50 m below the horizon of Pumice volcanic ash layer. The thickness is 60 cm at the type locality. The middle part is composed of coarse-grained volcanic ash layer with abundant pumice grains. The color is dark gray. Heavy minerals as hornblende, orthorhombic pyroxene, clinopyroxene, biotite and apatite are contained, but glass flakes are very rare.

11. Pumice volcanic ash layer (YOKOYAMA, 1971)

Type locality: Nishikaino, Hokusei-cho

This volcanic ash layer is intercalated in the middle part of Oizumi Formation. This layer can be traced continuously from Kamitara in Gifu Prefecture, and through Kamikasada and Karegawa, to Yokkaich City. The thickness is 7 m at the type locality, but it reaches to 13 m at riverbed of the Akechi river. This layer is divided into three parts as shown in Fig. 26. The lower part is very hard and massive with laminated part. The middle part is composed of coarse-grained volcanic sand with many pumice grains, and is white in color. In addition, cross-laminations are observed in this part. The maximum size of pumice grain is generally 5–6 cm in diameter. The upper part is fine-grained, laminated and white in color. It contains heavy minerals such as hornblende, orthorhombic pyroxene, clinopyroxene and apatite. NRM of it reveals reversed polarity. The Pumice volcanic ash layer has been treated as an useful key bed, and it is correlated with Mushono volcanic ash layer of the Kobiwako Group (YOKOYAMA, 1969; ISHIDA and YOKOYAMA, 1969).

12. Sushirodani volcanic ash layer (MIYAMURA *et al.*, 1976)

Type locality: Sushirodani valley at the east of Kanae, Fujiwara-cho

This volcanic ash layer is intercalated in the middle part of Oizumi Formation. It is 20–80 cm thick. The lower part is 5–7 cm thick and is yellowish gray in color. It is composed of small pumice grains (diameter; less than 1 mm) and hornblende crystals, in which the latters are usually visible even by naked eyes. The upper part is composed of fine grained volcanic glass flakes and is yellowish white and pinkish white in color.

13. Rokkoku volcanic ash layer (MORI and KIMURA, 1973)

Type locality: West of Rokkoku, Hokusei-cho

This volcanic ash layer is intercalated in the upper part of Oizumi Formation. The thickness is 55 cm at the type locality. It is composed of medium-grained glassy volcanic ash and is white to pale yellow in color. NRM of it shows reversed polarity. The fission-track age of this ash layer at the type locality is measured 1.4 Ma (YOKOYAMA *et al.*, 1980b).

Although this was recently confirmed to be same to the Komeno II volcanic ash layer of YOKOYAMA (1971), so the name of Rokkoku volcanic ash layer is used in this paper conveniently.

E. Biostratigraphy, Magnetostratigraphy and Fission-track Ages

In the Plio-Pleistocene sediments of the Kinki and Tokai districts, MIKI (1948) first recognized six fossil plant beds; *Pinus trifolia* bed, *Metasequoia* bed, *Paliurus* bed, *Larix* bed, *Sapium* bed and *Aphanante* bed in ascending order. Later, HUZITA (1954) confirmed the stratigraphical position of those plant beds. Based on those results, ITIHARA (1960) discussed the distinction between "the age of *Metasequoia* flora flourish" and "the age of *Metasequoia* flora extinction".

MAKIYAMA (1938) studied fossil elephants from those districts, and IKEBE *et al.* (1966) made check list of their stratigraphical positions and localities. Then, KAMEI and SETOGUCHI (1970) recognized fossil zones of Pliocene-Pleistocene mammals. Those are Zone 1 of *Stegodon* cf. *elephantoides*, Zone 2 of *Stegodon insignis sugiyamai*, Zone 3 of *Stegodon shodoensis akashiensis*, Zone 4 of *Elephas shigensis* and Zone 5 of *Stegodon orientalis*.

In Pliocene-Pleistocene Tokai Group, many fossils such as plants, vertebrates, molluscs are also yielded. The horizon of those fossils in Hokuse area are given in Fig. 27. *Metasequoia* was discovered throughout this group, with typical Tertiary flora including *Nyssa* and *Liquidambar* in the lower half. Fossil materials of *Stegodon* cf. *elephantoides* were found in Kameyama Formation in Nanse area, and those of *Stegodon akashiensis* were reported from Oizumi Formation in Hokuse area. Consequently, it is able to say that Tokai Group is allocated to *Metasequoia* bed of MIKI (1948), and ranges from *Stegodon* cf. *elephantoides* Zone to *Stegodon akashiensis* Zone biostratigraphically.

The pioneer work on paleomagnetism of Tokai Group was carried out by ISHIDA *et al.* (1969). MAENAKA *et al.* (1977) summarized magnetostratigraphy of Pliocene-Pleistocene sequences in Kinki and Tokai districts, together with other geological and paleontological data, but as for Tokai Group those data seemed to

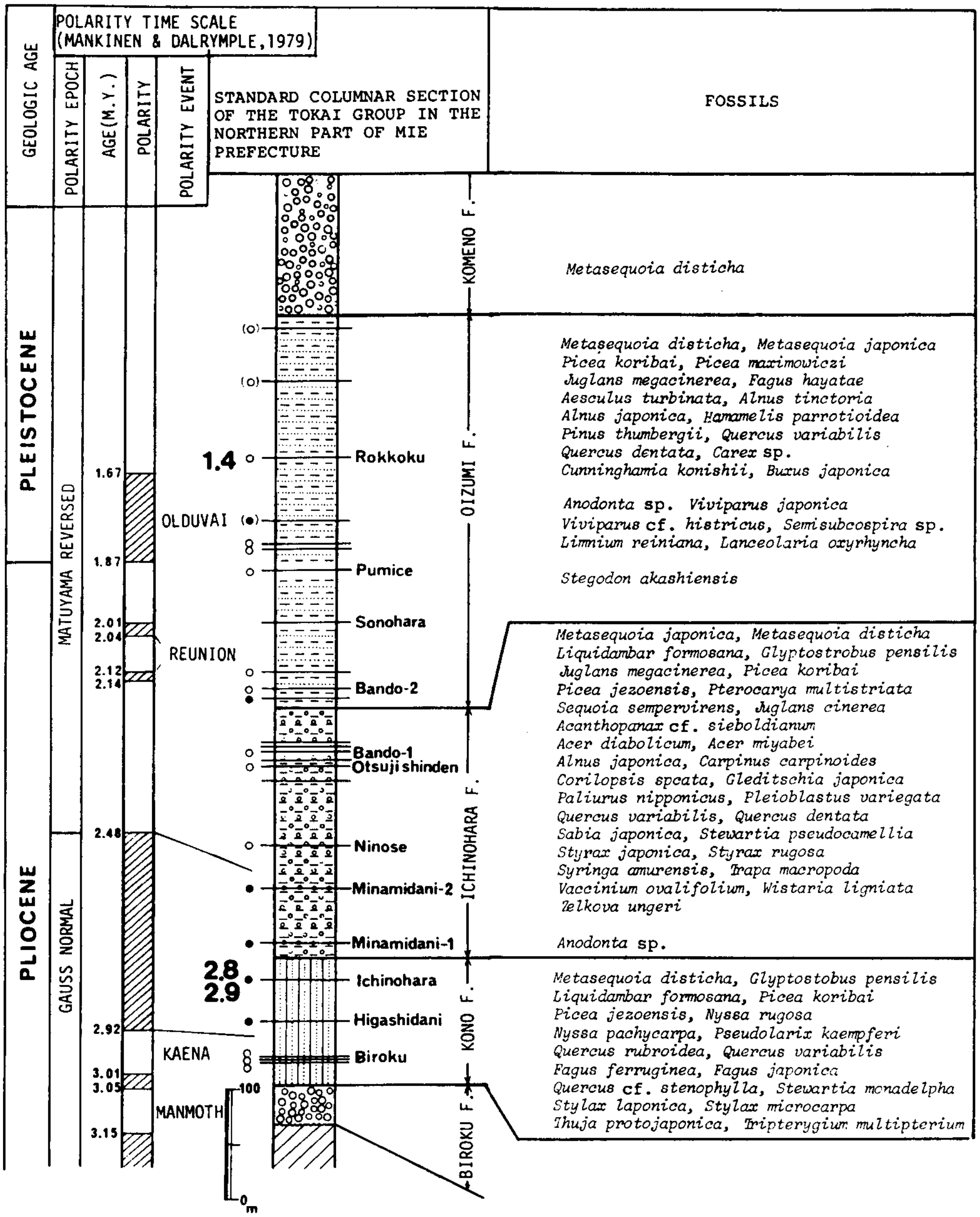

Fig. 27. Chronology of the Tokai Group in Hokuse area. Open circle: reversed polarity, closed circle: normal polarity, 1.4, 2.8 and 2.9: fission-track ages (Ma).

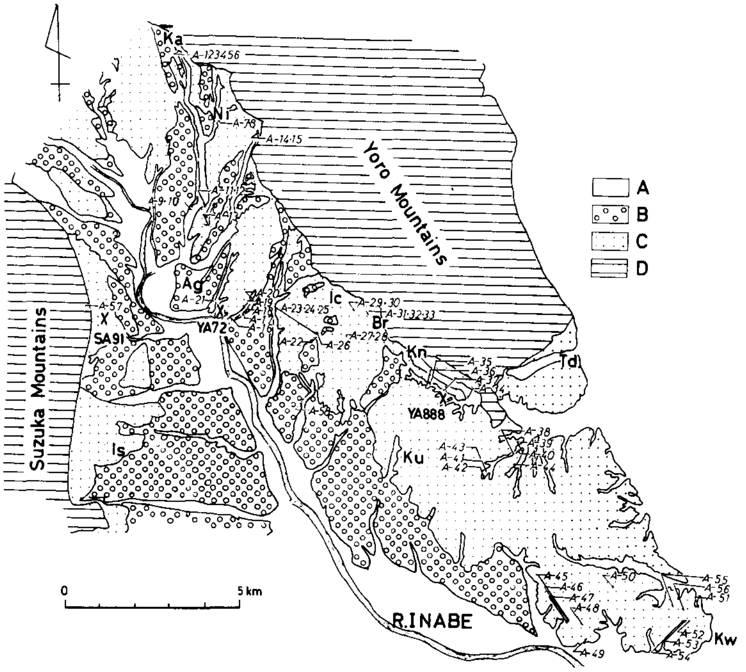

Fig. 28. Locality map of the sampling for fission-track age determination and paleomagnetic research. A: Alluvium, B: Terrace deposits, C: Tokai Group, D: basement rocks

Table 3. Paleomagnetic result of volcanic ash layers (TAKEMURA and TORII, 1978).

Sample No.	Locality No.	Locality	Volcanic ash layer	Magnetic polarity
A-9	YA 1358	Mukohira	unnamed	R
A-11	YA 1359	Mukohira	Pumice v.a.	R
A-12	YA 1359	Mukohira	Pumice v.a.	R
A-13	YA 63	Nishikaino	Pumice v.a.	R
A-1	YA 1412	Kawahara	unnamed	R
A-2	YA 1412	Kawahara	unnamed	R
A-5	YA 1412	Kawahara	Bando-1 v.a.	R
A-6	YA 1412	Kawahara	Bando-1 v.a.	R
A-7	YA 1357	Ninose	Ninose v.a.	R
A-8	YA 1357	Ninose	Ninose v.a.	R
A-14	YA 67	Koharaisshiki	Ichinohara v.a.	—
A-15	YA 67	Koharaisshiki	Ichinohara v.a.	N
A-21	YA 72	Nishikoyamadani	Rokkoku v.a.	R
A-16	YA 96	Higashikoyamadani	unnamed	R
A-17	YA 109	Higashikoyamadani	unnamed	R
A-18	YA 111	Higashikoyamadani	Pumice v.a.	R
A-19	YA 120	Higashikoyamadani	unnamed	R
A-20	YA 121	Higashikoyamadani	Bando-2 v.a.	R
A-22	YA 289	N.Bandoshinden	Bando-2 v.a.	R
A-25	YA 58	N.Bandoshinden	unnamed	—
A-24	YA 58	N.Bandoshinden	unnamed	—
A-23	YA 58	N.Bandoshinden	Bando-1 v.a.	R
A-26	YA 291	N.Bandoshinden	unnamed	R
A-27	YA 419	S.Ichinohara	Ninose v.a.	—
A-28	YA 419	S.Ichinohara	Ninose v.a.	R
A-29	YA 715	N.Ichinohara	Ichinohara v.a.	N
A-30	YA 715	N.Ichinohara	Ichinohara v.a.	—
A-31	YA 643	Biroku	Biroku v.a.	R
A-32	YA 643	Biroku	Biroku v.a.	R
A-33	YA 643	Biroku	Biroku v.a.	R
A-36	YA 846	Konominamidani	Minamidani-2 v.a.	N
A-35	YA 845	Konominamidani	Minamidani-1 v.a.	N
A-37	YA 811	Konominamidani	Ichinohara v.a.	N
A-34	YA 781	Kono	Biroku v.a.	R
A-44	YA 981	Chikarao	Pumice v.a.	R
A-39	YA 977	Chikarao	unnamed	R
A-40	YA 977	Chikarao	Bando-2 v.a.	R
A-42	YA 1026	Chikarao	Minamidani-1 v.a.	N
A-43	YA 1015	Chikarao	Minamidani-1 v.a.	N
A-41	YA 1025	Chikarao	Ichinohara v.a.	N
A-38	YA 979	Chikarao	Ichinohara v.a.	N
A-45	YA 1449	Nukata	unnamed	R
A-46	YA 1449	Nukata	unnamed	R
A-47	YA 1450	Nukata	unnamed	R
A-48	YA 1461	Nukata	Bando-2 v.a.	R
A-49	YA 1076	Nukata	unnamed	N
A-50	YA 1161	Okushinden	Bando-1 v.a.	—
A-51	YA 1133	Nishibessho	Pumice v.a.	R
A-52	YA 1422	Nishibessho	Bando-2 v.a.	R
A-53	YA 1422	Nishibessho	Bando-1 v.a.	R
A-54	YA 1422	Nishibessho	unnamed	R
A-56	YA 1484	Nishibessho	Minamidani-2 v.a.	N
A-55	YA 1137	Nishibessho	Higashidani v.a.	N
A-57	SA 91	River Tashida	Ichinohara v.a.	N

be fragmental. So far, the author tried to measure NRMs of the volcanic ash layers along seven routes in the foothill area of Yoro Mountains where continuous columnar sections were obtained (Table 3 and Fig. 28). As a result, it becomes to be evident that all of ash layers above Minamidani-2 volcanic ash layer horizon reveal reversed polarity except for normal polarity of unnamed ash layer immediately below Bando-2 volcanic ash layer. On the other hand, the ash layers between those of Minamidani-2 and Higashidani reveal normal polarity, but those below that of Higashidani reveal reversed polarity again (TAKEMURA and TORII, 1978).

For the fission-track age, those of three volcanic ash layers of Tokai Group were obtained by YOKOYAMA *et al.* (1980b). The results are as follows:

Ichinohara volcanic ash layer at Kono (loc. YA 888) 2.9±0.3 Ma

Ichinohara volcanic ash layer at the Tashida river (loc. SA91) 2.8±0.3 Ma

Rokkoku volcanic ash layer at Rokkoku (loc. YA 72) 1.4±0.2 Ma

Taking those results into consideration, the deposition of Tokai Group in Hokuse area is able to be correlated with the magnetic time scale of MANKINEN and DALRYMPLE (1979), as the upper half assignable to Matuyama Reversed Epoch, and the lower half corresponding to Gauss Normal Epoch. Therefore, the reversed polarity zone of the lowest part may be represented by Kaena event in Gauss Normal Epoch as shown in Fig. 27. In this way, it is possible to say that the deposition of Tokai Group in Hokuse area was initiated at about 3.0 Ma. On the other hand, based on the fission-track age of Rokkoku volcanic ash layer and magnetostratigraphical evidences, the upper limit of deposition can be estimated to be about 1.2 Ma.

In conclusion, it becomes clear that the deposition of Tokai Group in Hokuse area started at about 3.0 Ma and terminated at about 1.2 Ma.

F. Geologic Structure

It is well known that Southwest Japan is divided tectonically into "Inner zone" and "Outer zone" by the "Median Tectonic Line", and from viewpoint of neotectonism the eastern part of "Inner zone" is further subdivided into such three tectonic provinces as Chubu, Kinki and Chugoku Blocks from east to west. Among them, Kinki Block reveals a triangular plane as named as "Kinki Triangle" by HUZITA (1962). Demarcation of Kinki Block with Chubu one is represented by Yanagase Fault and its southern extension of Yoro-Ise Bay Fault.

The depression around Ise Bay was corresponded to the area of Lake Tokai during Pliocene to Early Pleistocene, and is divided into two parts, western and eastern, by Yoro-Ise Bay Fault (Fig. 29). In this paper, its western half is called "Agé subbasin" and eastern half of it is called "Nagoya subbasin", but it should be noted that the former belongs to Kinki Block, while the latter belongs to Chubu Block. The surveyed area is included in "Agé subbasin" in this sense, and it is

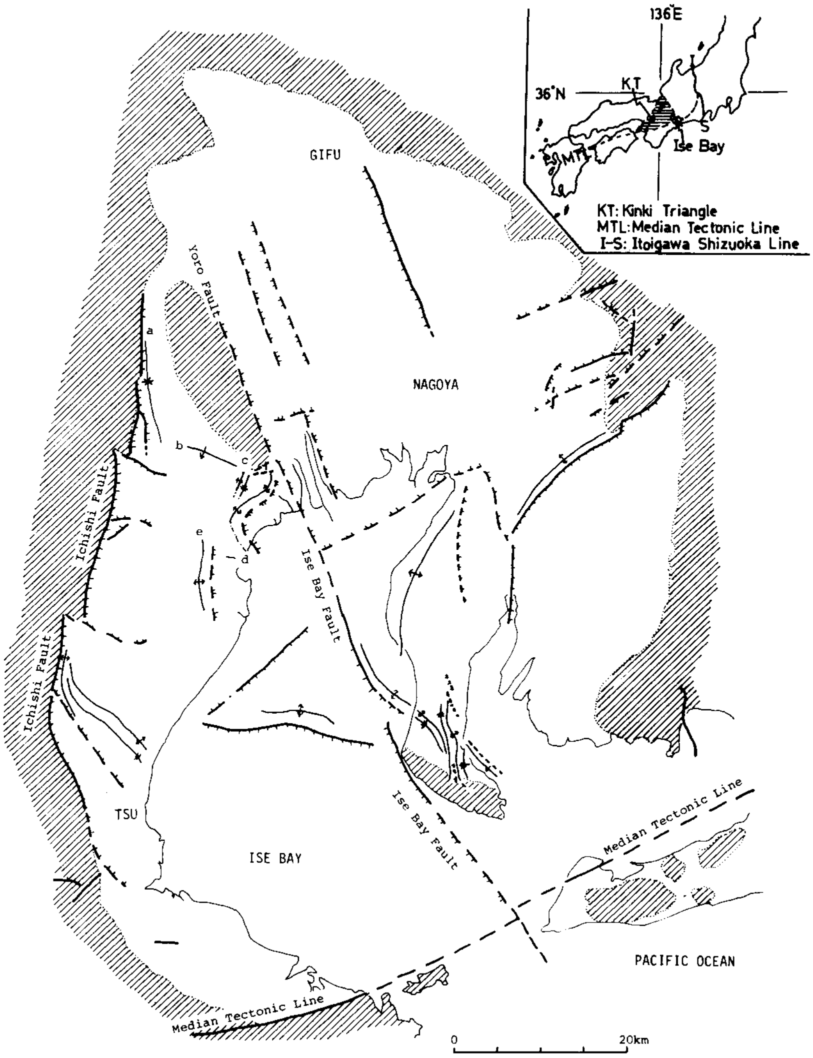

Fig. 29. Geologic structure around Ise Bay (after MAKINOUCHI, 1979, partly modified). a: Shinodate Syncline, b: Ichinohara Flexure, c: Igai Anticline, d: Kuwana Anticline, e: Yokkaichi Flexure

characteristic that Tokai Group forms a basin structure there. In this area, tectonic lines represented by fault, fold and flexure are recognized, which are coupled with three different trends such as Setouchi, Suzuka and Yoro trends.

Generally, in west of the surveyed area Tokai Group is contact by Ichishi Fault with Paleozoic rocks and Cretaceous granite of Suzuka Mountains. In the east, that group rests unconformably on Mesozoic and Paleozoic rocks of Yoro Mountains. In western foothill area of Yoro Mountains, the direction of N 20°W is a general strike trend of Tokai Group in northern part, while it changes to about N 40°W trend in southern part. Dipping gently to west at 20–30 degrees, Tokai Group exposes its upper part to southwest. On the other hand, in eastern foothill area of Suzuka Mountains, the strike trend of Tokai Group is nearly N–S, dipping to east at 60–40 degrees.

Yoro-Ise Bay Fault, Ichishi Fault and Kuwana Anticline are recognized as the first grade tectonic structure. Among them, the first represents southern half of great fault zone which demarcates Kinki Block from Chubu Block. Yoro Fault runs with NNW–SSE trend at eastern foothill area of Yoro Mountains. The western side of this fault (Yoro Mountains) was elevated relatively, and the amount of total vertical displacement might exceed 1,500 m. Ise Bay Fault in Ise Bay (KUWAHARA, 1969; CHUJO and SUDA, 1971) has been recognized by seismic profilling and gravitational survey. Its trend is NNW–SSE direction and relative upheaval of eastern side is recognized.

The west end of Agé subbasin is confined by Ichishi Fault (TAKIMOTO, 1935). This fault runs from Tara to Matsusaka along eastern foothill area of Suzuka Mountains. It extends about 60 km in N–S direction, but in precisely this fault is composed of small faults in echelon. Generally, this fault runs between Tokai Group and basement rocks including Miocene strata, and especially around Tsu and Seki area, Tokai Group is clearly contact with Miocene deposits by this fault. In this case, it is sure that this fault is related to an upheaval of western Suzuka Mountains, but the dip of fault plane is almost in vertical. Tokai Group which is distributed at eastern side of this fault dips steeply at about 50–80°E, and makes a zone of steep dipping strata of about 1 km wide.

Kuwana Anticline is an asymmetric folding, which runs from Shimonoshiro, Tado-cho to the west of Yokkaichi City along the coast of Ise Bay. At Kuwana Hills, west of Kuwana City, it has N–S trend, while it turns to NNE–SSW at Kaki and Oyachi Hills of the south. The strata of western wing incline about 10 degrees to west, while those of the eastern wing steeply dip about 60 degrees to east.

The another steep dipping zone of Tokai Group ("Ichinohara Flexure Zone" by the author) is traceable from Ageki to Kono in the foothills of Yoro Mountains, and is with E–W trend. In this zone, the strata incline steeply to southward, 40–60 degrees in the south of Ichinohara and about 25 degrees at the west of Ageki. In the southwest of Chikarao, an asymmetric anticline is observed, which is called as Igai Anticline (MATSUI, 1943). In the west wing of this anticline, the strata of Tokai Group dip toward southeast at 10–20 degrees. In the east wing, the strata dip at 80–90 degrees eastwardly.

In Tara area, Tokai Group of narrow belt between Suzuka and Yoro Mountains, forms a conspicuous synclinal structure. This syncline was called "Shinodate Syncline" by MIYAMURA *et al.* (1976).

III. Paleogeography and Tectonism of Lake Tokai Sedimentary Basin

In the preceding chapter, the stratigraphy, geologic structure and chronology of Tokai Group in the central and northern areas on the west coast of Ise Bay (Sekigahara to Yokkaichi areas) were described. In this chapter, at first, correlation and classification of Tokai Group will be proposed, and in the second, the paleogeography on the basis of stratigraphy, chronology and sedimentology of Lake Tokai will be discussed. Lastly, tectonism since Pliocene around Ise Bay will be considered.

A. Correlation and Subdivision of Tokai Group

As mentioned before, Tokai Group is distributed mainly around Ise Bay.

Tokai Group around Nagoya City is called Seto Group (MAKIYAMA, 1950), and MATSUZAWA *et al.* (1960) subdivided it into two Formations, Seto porcelain clay deposits and Yadagawa Formation. MORI (1971a) studied tephrostratigraphically Yadagawa Formation, and subdivided it into three Members. They are Mizuno (gravels, or sands and gravels dominant), Takahari (irregular alternating beds of lignite, clay, and gravel), and Idaka (alternating beds of gravel, sand and silt) Members in ascending order.

Tokai Group in Chita Peninsula is called Tokoname Group (OSE, 1929), and was studied tephrostratigraphically by ITOIGAWA (1971), and MAKINOUCHI (1975a). MAKINOUCHI (1975a) divided those sediments into three formations: Toyooka (gravels), Kouwa (irregular alternating beds of sand and mud), and Futto (irregular alternating beds of sand and mud) Formations in ascending order.

Recently, Tokai Group in southern part of the west coast of Ise Bay (Nanse) was surveyed by MIYAMURA *et al.* (1981) and WADA (1982). MIYAMURA *et al.* (1981) subdivided those sediments into Saigyodani Gravel, Kusuhara coal bearing, Kameyama and Sakuramura Formations in ascending order.

Previously, a correlation scheme among the sediments of Tokai Group was proposed by ISHIDA and YOKOYAMA (1969). In this study, they correlated Tokai Group with Kobiwako and Osaka Groups, on the basis of the common characteristic volcanic ash layers distributed throughout those groups. They regarded the volcanic ash layers which contain abundant pumice grains like as Shinden volcanic ash layer of Osaka Group, Mushono volcanic ash layer of Kobiwako Group, Pumice, Akogi and Ohtani volcanic ash layers of Tokai Group as an identical volcanic ash layer and then called them collectively "Pumice volcanic ash layer". MORI (1971a), however, proposed another scheme. He correlated Togo volcanic ash layer of Yadagawa Formation in Nagoya (including many pumice grains), refering to the thickness and mineral composition, to Ohta volcanic ash layer in northern area of Chita Peninsula (ITOIGAWA, 1971) and Akogi volcanic ash layer of Nanse area (ITOIGAWA and MORI, 1971). Further, he insisted that Karegawa volcanic ash layer of Hokuse area (MORI, 1971b) (Pumice volcanic ash layer) is situated stratigraphically higher than Akogi volcanic ash layer. MAKINOUCHI (1975a) also correlated Ohtani volcanic ash layer in southern part of Chita Peninsula to each of Togo, Ohta and Akogi volcanic ash layers. By activation analysis of pumice grains, it becomes clear that Pumice volcanic ash layer of Hokuse area is substantialy different from Akogi volcanic ash layer, and that Ohtani volcanic ash layer is possibly correlated with Akogi volcanic ash layer (IKEDA *et al.*, 1977; YOKOYAMA *et al.*, 1978). Consequently, based on those results, the correlation of Tokai Group on both sides of Ise Bay, (Chita and Nanse areas) comes to be established. Moreover, Bando-1 volcanic ash layer in northern Ise area can be correlated with Onbegawa volcanic ash layer in southern Ise area, and thus, stratigraphical relatationship between Hokuse and Nanse areas is also clarified as shown in Fig. 30.

Then, apart from those tephrostratigraphical studies, many data of paleomagnetism and fission-track ages have been gradually accumulated. OTOFUJI *et al.* (1975) carried out NRM measurements for Tokai Group in Chita Peninsula and reported the presence of reversed polarity of the sequences between Koba and Sakai volcanic ash horizons of the upper half, and normal polarity between Kaminoma and Kofu volcanic ash horizons of the lower half. The fission-track ages of volcanic ash layers in Tokai Group in Chita Peninsula were measured by MAKINOUCHI *et al.* (1983). They are as follows: Ohtani volcanic ash layer; 4.3 Ma, Kosugaya volcanic ash layer; 4.2 Ma, Kaminoma volcanic ash layer; 5.3 Ma. In addition, taking the fission-track age of Kamishiraki volcanic ash layer (3.6 ± 0.2 Ma) into consideration, Tokai Group of Chita Peninsula is correlated with the deposits of Gilbert Reversed Epoch to Epoch 5. Because, as stated precedingly, Akogi volcanic ash layer of Nanse area corresponds to Ohtani volcanic ash layer of Chita Peninsula.

Summarized above, the correlation chart of Tokai Group is shown in Fig. 30.

The basal horizon of Tokai Group is different from place to place. At Chita Peninsula, it is about 350 m lower than Ohtani volcanic ash layer (MAKINOUCHI, 1975a), at Tsu area, it is about 400 m lower than Akogi volcanic ash layer (ITOIGAWA and MORI, 1971), at Kameyama area, it is about 350 m lower than Akogi volcanic ash layer (MIYAMURA *et al.*, 1981), and in Nagoya, it is about 100 m lower than Togo volcanic ash layer (MORI, 1971a). It is evident that the basal horizon is relatively higher in northern area than in southern area. It follows that the sedimentary basin of Lake Tokai in Chita Peninsula initiated about 6.0 Ma. In connection with this, in Nagoya and Chita areas, as the upper limit of Tokai Group is defined at the horizon of about 250 m higher than Ohtani (Togo) volcanic ash layer, the deposition terminated at 3–3.5 Ma.

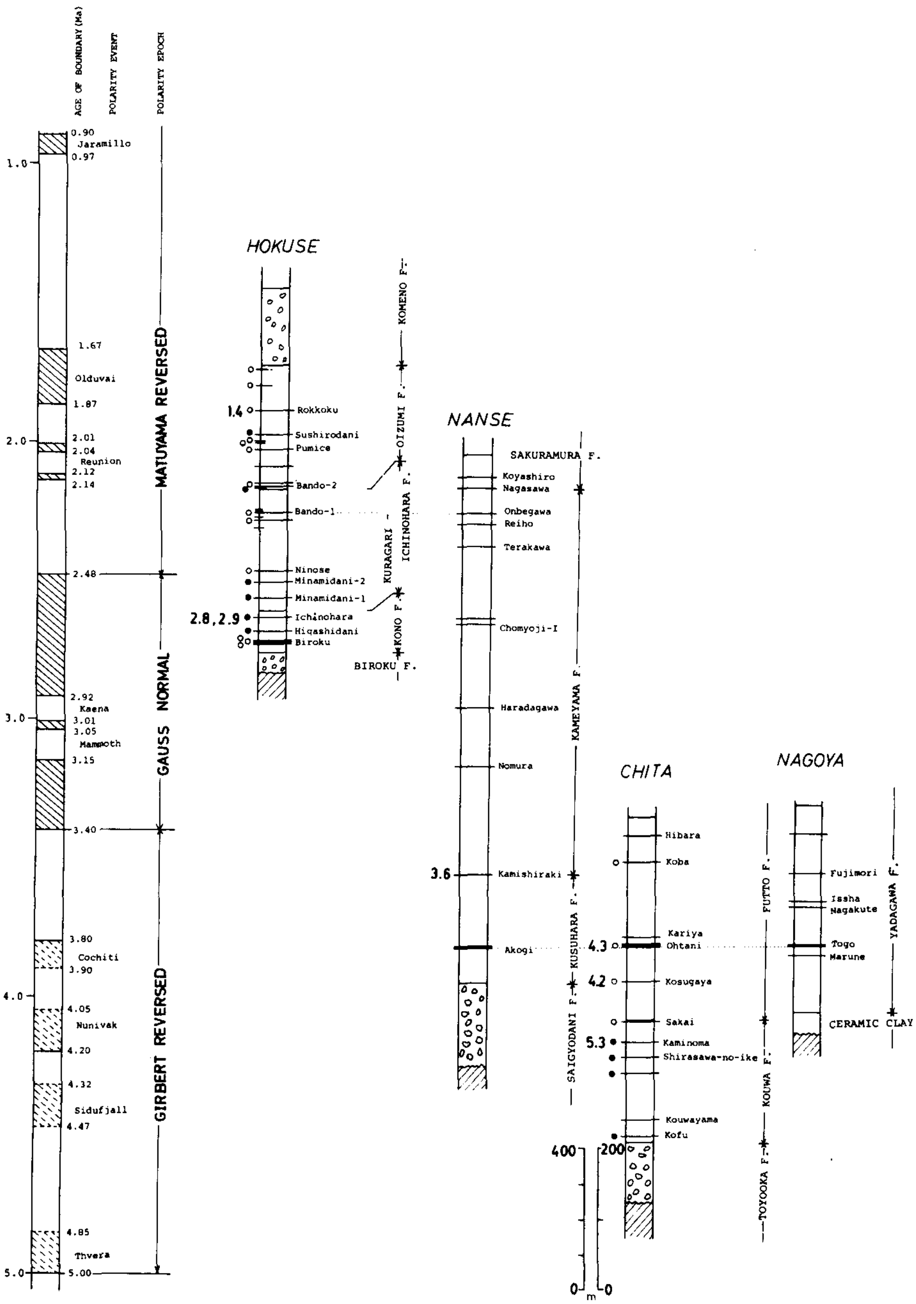

Fig. 30. Correlation chart of the Tokai Group among Hokuse, Nanse, Chita and Nagoya areas. Hokuse: TAKEMURA (1978), Nanse: MIYAMURA *et al.* (1981), Chita: MAKINOUCHI (1975), Nagoya: MORI (1971) Nos in columnar sections show fission-track ages (Ma).

On the other hand, the deposition of Tokai Group in Hokuse area is initiated about 3.0 Ma. This horizon is correlated with the middle Kameyama Formation in Kameyama area. Furthermore, depositional age of the uppermost Tokai Group in Hokuse area is about 1.2 Ma.

To conclude, the sedimentary basin of Lake Tokai was first formed at the area of Chita Peninsula in the southeast and Nanse of the west, and successively expanded to northern area. Consequently, center of the basin migrated to Hokuse area at the time of 3.0 Ma. Accordingly, it is convenient to subdivide the geohistory of the sedimentary basin into two stages; Stage I and Stage II, with the boundary at about 3.0 Ma (Fig. 31).

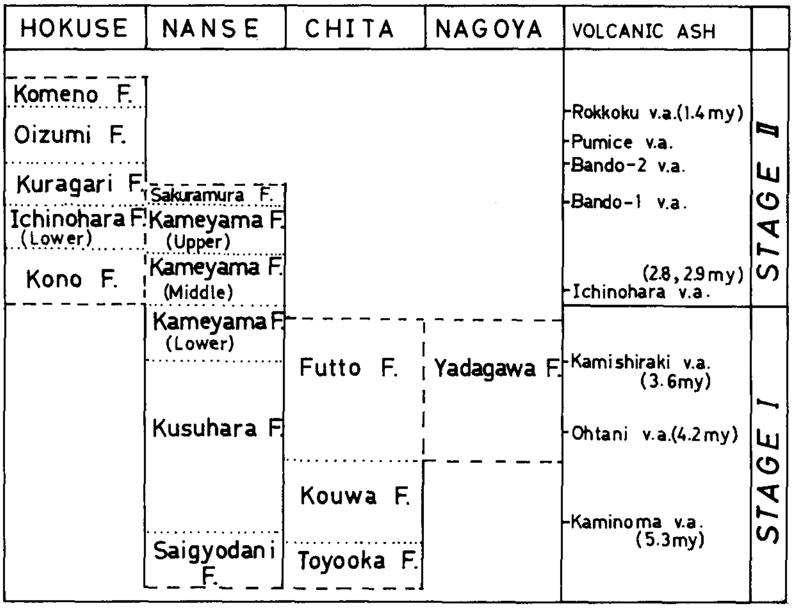

Fig. 31. Subdivision of the sedimentary basin of Lake Tokai.

B. Sedimentary Environments of Tokai Group

As mentioned before, the geohistory of the sedimentary basin of Lake Tokai can be divided into two stages, Stage I and Stage II. In this section, the sedimentological discussion on those deposits (distribution, lithology, composition of gravels and paleocurrent) are concentrated.

a. Stage I.

The sediments of Stage I are widely distributed in the southern Ise area, in Chita Peninsula and in the area around Nagoya City. They are represented by Saigyodani gravel Formation, Kusuhara coal-bearing Formation and the lower

Kameyama Formation (alternating beds of sand and mud) of Nanse area; Toyooka Formation (gravels), Kouwa Formation (alternating beds of sand and mud with lignites) and Futto Formation (alternation of sand and mud) of Chita Peninsula, and Mizuno Member (gravels, or sands and gravels), Takahari Member (irregular alternating beds of lignite, clay, and gravel) and Idaka Member (alternating beds of gravel, sand and silt) of Nagoya area.

As the lowermost horizon of this stage, Saigyodani and Toyooka Formations are able to be enumerated. Saigyodani gravel Formation of southwest coast of Ise Bay is composed mainly of thick gravel bed with pebble to cobble gravels. The gravel bed is composed mainly of chert, shale, sandstone and hornfels gravels along with the gravels of "quartz porphyry" and granite. From the compositional analysis, two types of gravel facies are recognized. One is the gravels containing granite and sandstone derived from neighbouring Miocene Suzuka Group. The other is characterized in containing mainly gravels of "quartz porphyry" transported from distant area. This "quartz porphry" is composed of ryolitic welded tuff. The sedimentary environment of Saigyodani Formation was the mixture of alluvial fan and fluvial environments which includes drainage area of rhyolitic welded tuff.

Toyooka Formation of Chita Peninsula is also composed of thick gravels, the fluvial origin. Gravel bed contains chert, Paleozoic sandstone, sandstone of Miocene Morozaki Group and crystalline schist. The size of gravel decreases westward and, at the west coast of Chita Peninsula, this formation becomes to be composed of sands and gravels, or medium to coarse sands with gravels. Lateral variation of gravel composition is not detected, but, cross laminations which indicate paleocurrent from east to west are developed within the sediments (MAKINOUCHI, 1975a). Conclusively, it is assumed that Toyooka Formation was deposited under fluvial environment in which gravels were supplied from the east including drainage area of crystalline schist.

After the deposition of the gravels, Kouwa Formation and Kusuhara coal-bearing Formation were deposited in the areas of Chita Peninsula and Nanse respectively. Kouwa Formation is composed of irregular alternating beds of sand and mud with lignite beds. At east coast of Peninsula sand layers are overwhelming while at west coast mud layers are dominant. Paleocurrent indicates that the sediments were supplied from the east, and lignite beds are developed in those sediments. These evidences show that Kouwa Formation was deposited under shallow lacustrine conditions. Kusuhara coal-bearing Formation consists also of alternating beds of mud and sand, accompanied with large amount of lignite beds. In the area around Kameyama, it contains gravel beds, thinning down northward (Fig. 32). From those sediments, freshwater molluscs occur, and lignite beds are developed in them. It should be noted that sediments of Kameyama area are coarser than that of Tsu area. Therefore, Kusuhara coal-bearing Formation deposited

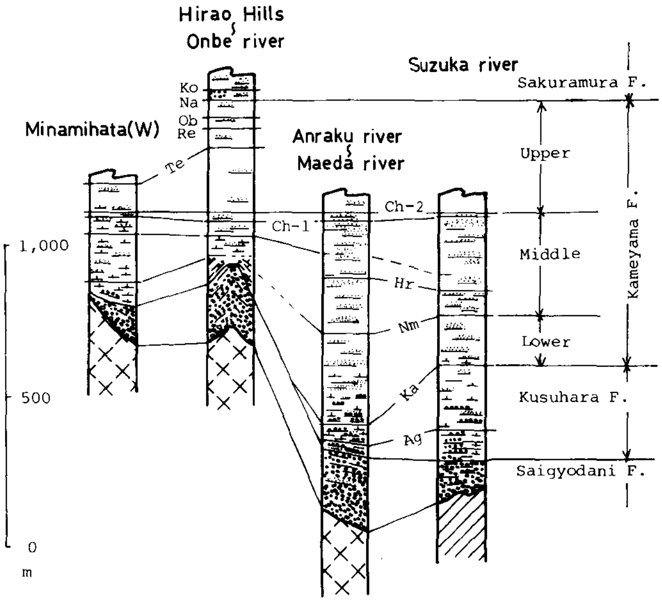

Fig. 32. Columnar sections of the Tokai Group in Kameyama area (after MIYAMURA *et al.*, 1981).

under shallow lacustrine environment, but occasionally the area around Kameyama turned to alluvial plain.

Subsequently, Futto Formation was deposited in Chita Peninsula, and also the upper part of Kusuhara Formation was deposited in Nanse simultaneously. Furthermore, northward expansion of the sedimentary basin brought about the deposition of Yadagawa Formation in Nagoya area. Futto Formation is composed of alternating beds of sand and mud containing lignite beds with coarse materials at its basal part. Futto Formation was deposited under shallow lacustrine environment. Paleocurrent suggested from cross laminations structure is deduced to be from north to south. Yadagawa Formation contains a large amount of gravels, suggesting them to be alluvial fan or plain. In Nanse area, after the deposition of Kusuhara coal-bearing Formation, the lower part of Kameyama Formation, which is composed of alternating beds of sand and mud, was deposited under lacustrine environment.

b. Stage II.

The sedimentary suits assigned to Stage II are distributed exclusively on west coast of Ise Bay, and mainly in Hokuse area. Therefore, at first, lithology and sedimentology of those sediments in Hokuse area will be mentioned, and in the second, those around Kameyama area will be stated.

Biroku Formation is locally distributed in the foothills of Yoro and Suzuka Moun-

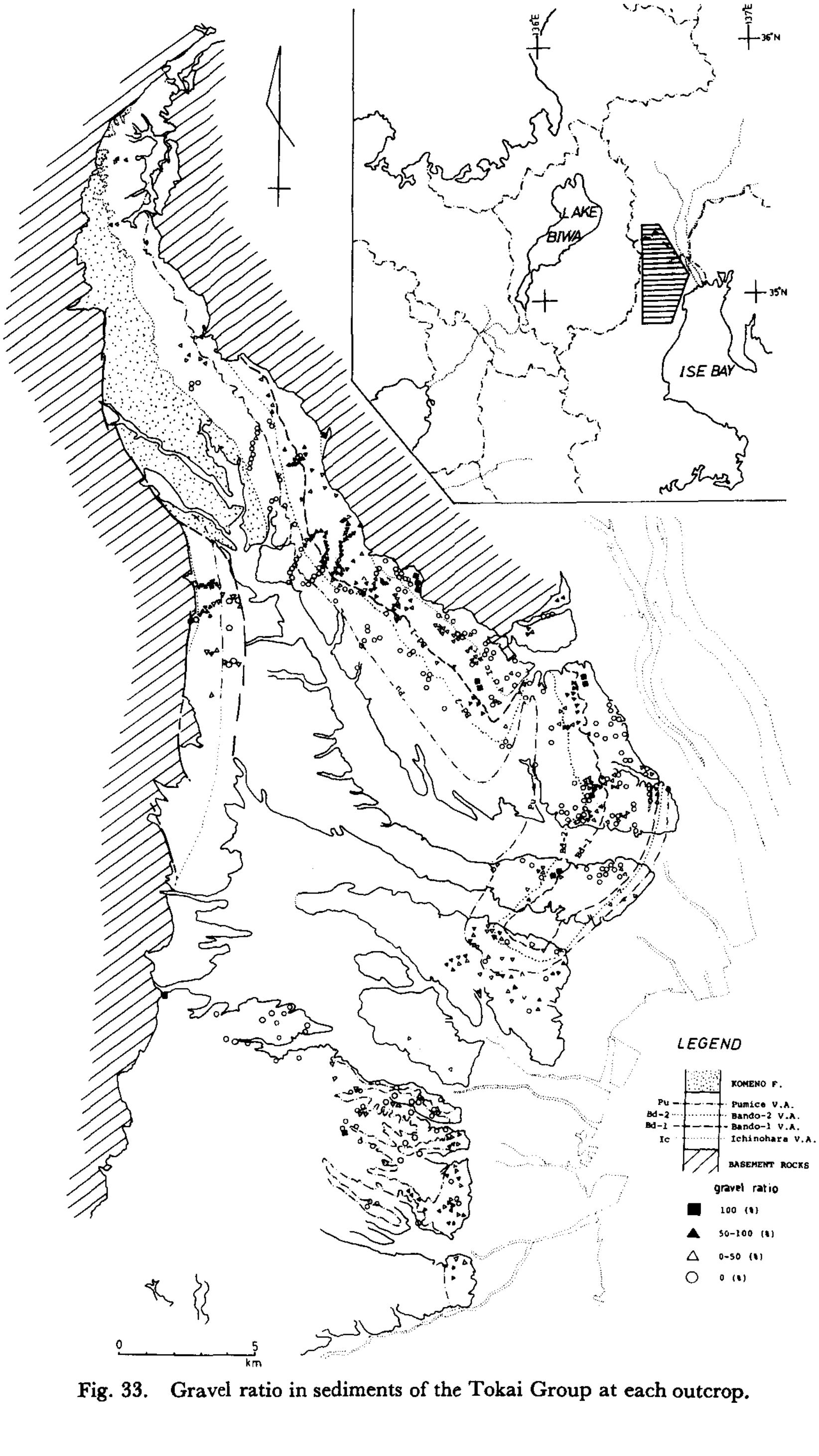

Fig. 33. Gravel ratio in sediments of the Tokai Group at each outcrop.

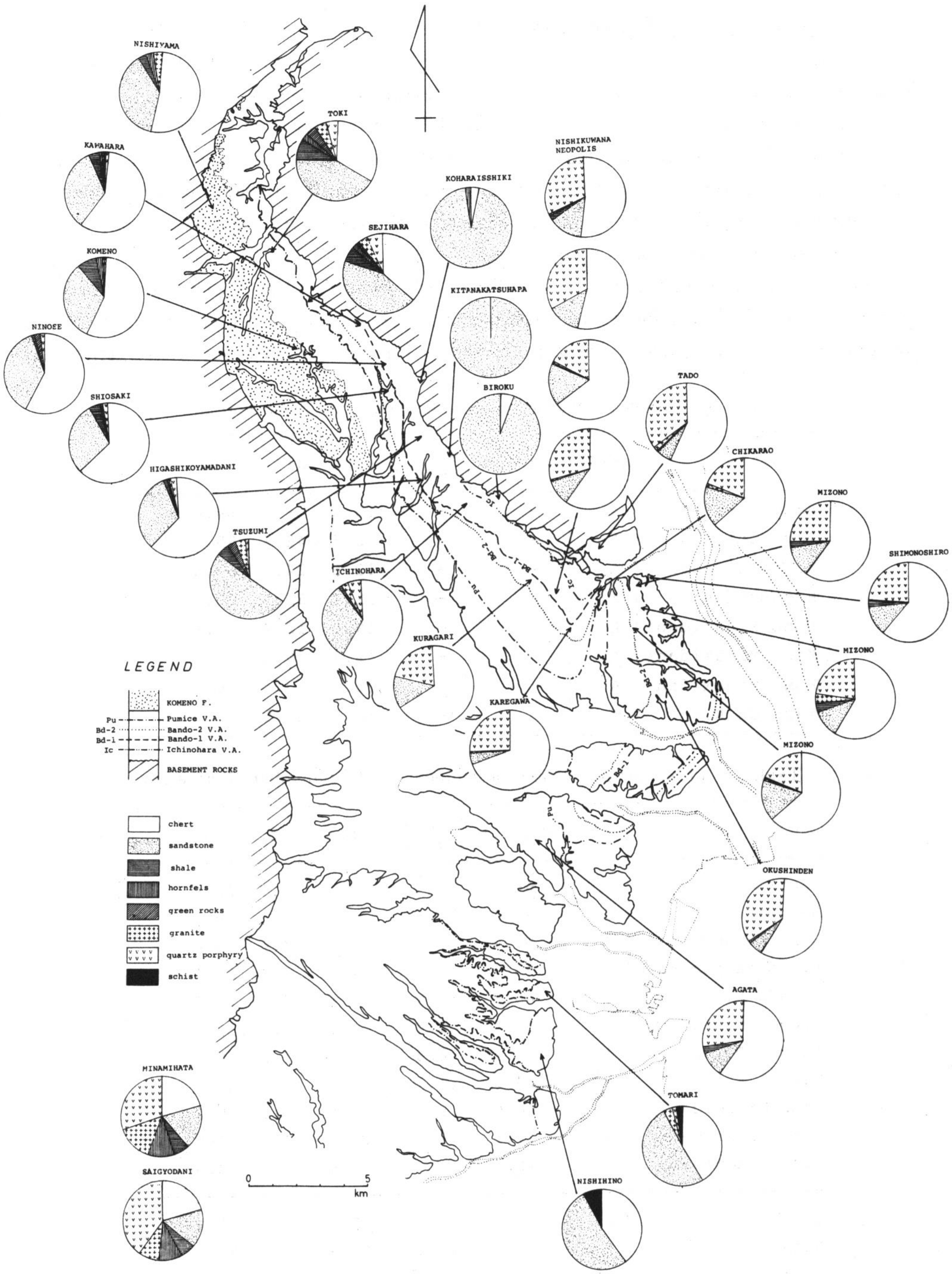

Fig. 34. Gravel composition of the Tokai Group.

tains. It is composed of pebble to cobble gravels with small amount of boulder gravels, and is composed almost entirely of sandstone derived from the basement of Mesozoic and Paleozoic rocks. They are alluvial fan deposits.

Kono Formation is distributed from Inabe to Kuwana area. The lower part of it is composed of alternating beds of sand and mud with a large amount of lignite beds (Table 4), suggesting that this formation was deposited under shallow lacustrine environments. In the sediments, the amount of sand layer increases to the upper, while that of lignite decreases vice versa.

Ichinohara Formation has two sedimentary facies. One is alternating beds of gravels and mud (Inabe facies) and the other (Kuwana facies) is characterized by the presence of alternating beds of sand and mud. The former is the sediments deposited

Table 4. Lithologic proportions of sediments of the Kono Formation.

Locality	area	gravels	sand & gravels	sand	alt.	mud
Akechi R.	A	-	-	15.5	-	84.6
Ichinohara	A	-	-	2.5	42.6	55.0
E. Ichinohara	A	-	-	12.5	24.1	63.4
Higashidani	A	-	-	12.1	30.9	57.0
Kono Minamidani	A	-	-	19.0	12.4	68.6
Kono Minamidani	A	-	-	18.3	29.4	70.6
Kono Minamidani	A	-	-	32.4	3.4	64.2
Tashida R.	C	-	-	15.8	10.5	73.7

Table 5. Lithologic proportions of sediments of the Ichinohara Formation.

Locality	area	gravels	sand & gravels	sand	alt.	mud
Tashida R.	C	66.5	4.3	3.8	4.7	20.6
Sejihara	B	35.1	17.9	15.5	2.5	29.0
Nishikoyamadani	A	57.7	-	5.1	4.6	32.6
Higashikoyamadani	A	53.7	-	8.9	4.4	33.0
Yamada R.	A	45.5	7.9	4.5	14.0	28.1
Rengedani R.	A	30.5	2.4	7.3	6.7	53.1
Akechi R.	A	37.1	8.8	5.9	8.3	40.0
Togami R.	A	24.2	13.1	17.7	17.7	27.4
Kono Minamidani	A	40.0	8.1	11.6	5.6	29.2
Kono Minamidani	A	27.1	17.2	22.9	15.3	17.2
Kono Minamidani	A	16.6	-	22.6	-	60.9
Okushinden	D	-	4.5	27.7	-	67.8
Nukata	D	-	12.0	28.8	21.7	37.5
Kaki	E	-	5.1	33.3	5.2	56.5

under alluvial plain to lacustrine environments. The amount of gravel in the sediments decreases gradually from northwest to southeast (Fig. 33 and Table 5). The thickness of each sedimentary cycle of gravel and mud decreases southeastward laterally, and it decreases upward vertically. The gravels are composed of chert, sandstone and shale gravels originated from Mesozoic and Paleozoic rocks (Fig. 34

Table 6. Composition of gravels of the Tokai Group.

Locality	Area	Horizon	Ch	SS	Sh	Ho	Gre.	Gr	QP	Sch
Saigyodani	(G)	Saigyodani F.	21.0	15.0	6.0	9.5	0.0	8.0	40.5	0.0
Minamihata	(G)	Saigyodani F.	20.5	18.0	6.0	10.5	0.0	14.0	31.5	31.0
Biroku	(A)	Biroku F.	5.0	95.0	-	-	-	-	-	-
Koharaisshiki	(A)		3.0	95.0	-	2.0	-	-	-	-
Kitanakatsuhara	(A)		-	100	-	-	-	-	-	-
Sejihara	(B)	Ichinohara F.	37.0	43.5	6.0	2.0	1.0	3.5	7.0	-
Kawahara	(A)		58.5	33.5	4.0	1.0	1.0	0.5	1.5	-
Shiosaki	(A)		63.5	29.0	4.5	-	1.0	-	2.0	-
Ninose	(A)		57.5	37.0	1.0	-	2.5	-	2.0	
Higashikoyamadani	(A)		62.8	32.0	1.7	-	0.6	0.6	2.3	-
Tsuzumi	(A)		34.9	50.7	4.9	-	3.4	4.8	1.4	-
Ichinohara	(A)		58.8	31.4	1.1	-	-	2.7	6.0	-
Kuragari	(A)	Kuragari F.	66.6	12.9	-	-	-	-	20.5	-
Nishikuwana n.p.	(A)		52.5	13.5	1.5	1.0	-	-	31.5	-
Nishikuwana n.p.	(A)		64.7	16.7	0.5	-	-	0.5	17.6	-
Nishikuwana n.p.	(A)		53.6	12.9	-	-	-	-	33.5	-
Nishikuwana n.p.	(A)		59.2	9.9	-	-	-	0.5	30.4	-
Karegawa	(A)		69.5	4.4	-	-	-	0.5	25.6	-
Chikarao	(A)		63.3	16.1	-	-	-	1.1	19.5	-
Tado	(D)		56.5	6.0	0.5	-	-	1.5	35.5	-
Mizono	(D)		58.7	10.9	3.6	-	-	4.0	22.7	-
Mizono	(D)		60.1	11.7	2.5	-	-	-	25.7	-
Mizono	(D)		63.5	16.3	0.8	-	-	0.4	19.0	-
Shimonoshiro	(D)		61.3	11.7	2.4	-	0.4	-	24.2	-
Okushinden	(D)		58.0	5.5	-	0.5	-	-	36.0	-
Toki	(B)	Oizumi F.	33.0	42.0	8.5	2.5	4.0	4.5	5.5	-
Agata	(E)		59.5	9.8	2.6	-	-	-	28.1	-
Tomari	(F)		41.0	51.0	-	-	-	3.5	1.5	3.0
Nishihino	(F)		40.0	52.0	-	-	-	-	-	8.0
Nishiyama	(B)	Komeno F.	52.0	38.0	3.0	3.0	-	4.0	-	-
Komeno	(B)		56.0	32.0	7.5	2.5	-	1.0	1.0	-

ch: chert, SS: sandstone, Sh: shale, Ho: hornfels, Gre: Green rocks, Gr: Granite, QP: Quartz Porphyry, Sch: Schist and Table 6). The Kuwana facies of Ichinohara Formation, alternating beds of sand and mud is the sediments under lacustrine environments.

Kuragari Formation is distributed in the area from Kuwana to Hirako, and is composed of pebble to cobble size and subround to subangular gravels with sandy matrix. Cross laminations are developed in the sandy part, and small amounts of

Table 7. Lithologic proportions of sediments of the Kuragari Formation.

Locality	area	gravels	sand & gravel	sand	alt.	mud
Kuragari	A	60.2	12.0	12.8	-	14.9
Mizono	D	59.3	5.2	14.5	-	21.0
Okushinden	D	64.0	7.9	11.1	-	16.9
Nukata	D	66.2	10.6	6.6	-	16.6
Kaki (W)	E	50.2	20.8	4.3	9.9	14.9
Kaki (E)	E	36.0	19.4	18.2	-	26.3
Oyachi	E	27.0	18.0	8.7	3.5	42.8

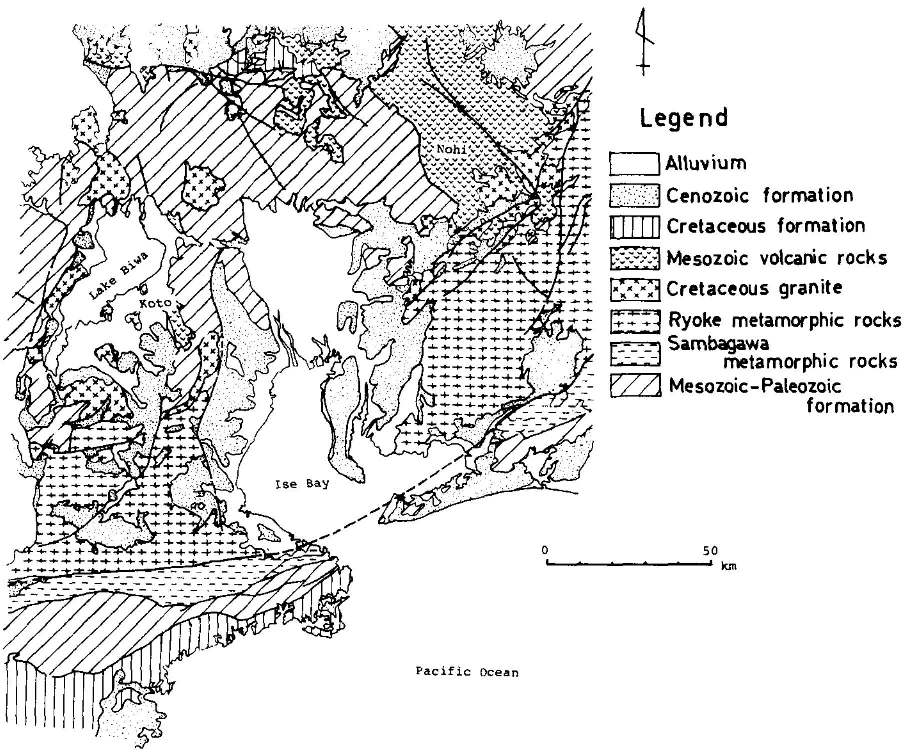

Fig. 35. Geologic system around Ise Bay.

mud layers are intercalated. Therefore, the sediments were deposited under alluvial plain environments. The amount of gravels in the sediments is the highest in Kuwana area, and decreases both southward and westward (Table 7). The gravels consist of chert, sandstone and "quartz porphyry", the last one generally represented by rhyolitic welded tuff of Mesozoic volcanics, which are distributed at eastern area of the sedimentary basin (Nohi area) (Fig. 35). From the cross laminations it is suggested that the paleocurrent direction was from NE to SW (Fig. 36, Table 8 and 9).

Table 8. Paleocurrent direction deduced from cross laminations in Inabe and Kuwana areas.

Locality	Horizon	Mean direction of paleocurrent	Consistency ratio	Number	Average dip
Kuragari (N)	Kuragari F.	98	99.9	3	23.3
Kuragari (N)		186	99.8	5	24.6
Kuragari (N)		205	99.7	4	37.3
Kuragari (N)		210	99.7	10	25.1
Kuragari (E)		213	99.5	10	31.5
Kuragari (E)		241	99.1	6	32.0
Kuragari (E)		200	99.7	3	23.7
Kuragari (E)		253	99.5	8	33.9
Karegawa (W)		271	99.8	5	28.2
Karegawa (W)		228	99.9	2	16.5
Karegawa (W)		255		1	18.0
Mizono (S)		258	99.6	5	19.6
Mizono (S)		213	99.6	5	28.1
Mizono (S)		220	99.6	11	35.8
Mizono (S)		199	99.5	8	31.3
Mizono (S)		180	99.7	11	36.5
Mizono (S)		243	99.6	10	37.0
Okushinden (S)		206	98.9	5	31.2
Okushinden (S)		168	99.9	3	32.4
Okushinden (S)		208	99.9	5	30.8
Okushinden (S)		180	99.7	6	36.9
Okushinden (S)		185	99.8	10	36.5
Okushinden (S)		206	99.8	10	35.7
Okushinden (S)		212	99.8	10	39.0
Ichinohara (S)	Oizumi F.	212	98.9	9	34.7
Kuragari (N)		183	98.5	7	29.4
Kuragari (N)		248	99.3	6	31.5
Kuragari (N)		218	99.6	5	27.6
Chikarao (E)		212	98.4	9	28.2
Mizono (S)		280	99.8	5	33.3

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

Table 9. Paleocurrent direction deduced from cross laminations in Kaki area.

Locality	Horizon	Mean direction of paleocurrent	Consitency ratio	Number	Average dip
Akao (S)	Kuragari F.	246	99.1	8	24.0
Akao (S)		204	99.0	9	25.3
Isaka (N)		323	99.7	3	26.8
Isaka (N)		185	99.3	10	25.9
Isaka (N)		152	99.9	5	26.8
Isaka (N)		181	99.2	7	23.9
Isaka (N)		272	99.7	3	21.4
Yamamura		229	99.6	8	38.7
Yamamura		250	99.6	5	37.6
Shimada	Oizumi F.	216	99.8	5	39.0
Shimada		174	99.8	10	28.9
Shinden (S)		256	99.5	5	27.8
Shinden (S)		186	99.6	5	39.0
Shinden (S)		255	99.2	6	22.3
Shinden (S)		232	99.9	2	20.5
Isaka dam (N)		258	99.8	5	26.7
Isaka dam (N)		251	99.6	7	21.8

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

As for Oizumi Formation, four lithofacies are recognized. They are alternating beds of gravel and mud facies (Tara facies), alternating beds of sand and mud facies, sandy alternating beds of sand and mud facies, and sands and gravels. The first one is distributed around Tara area, the amount of gravels in the sediments decreases southward (Table 10). Gravels are mainly composed of chert, sandstone, and shale from the basements of Mesozoic and Paleozoic rocks (Fig. 34 and Table 6). Therefore, the sediments of this facies were deposited under alluvial plain environments with some lacustrine episodes. The second facies of alternating beds of sand and mud is distributed from Inabe to Kuwana area. The occurrence of fossil diatoms and molluscs suggest that this facies was deposited under stable lacustrine environment. The third facies of sandy alternating beds of sand and mud is distributed around Kaki and Oyachi areas. Cross laminations suggest that paleocurrent direction is from NE to SW (Tables 11 and 12). This facies represents the deposits along coastal area of the lake. The gravels are composed of chert, sandstone, and "quartz porphyry" (Table 6). The last facies of sands and gravels is developed only at eastern end of hills to the west of Yokkaichi. The composition of gravels is characterized by the presence of crystalline schist (Table 6).

Komeno Formation is distributed in the area to the north of Inabe, and is composed almost entirely of gravels. This sedimentary facies represents alluvial fan.

Table 10. Lithologic proportions of sediments of the Oizumi and the Komeno Formations.

Locality	area	gravels	sand & gravel	sand	alt.	mud
Kariyagawa	B	68.6	-	4.3	1.3	25.8
Sushirodani	B	29.9	14.6	11.9	-	43.6
Uchiage	B	15.2	19.5	12.1	4.9	48.4
Higashidani	B	5.8	29.1	11.3	11.2	42.5
Kanae	B	-	5.6	39.7	7.9	46.9
Komeno	A	-	6.8	43.3	13.1	36.8
Tashida R.	C	6.9	2.9	17.6	14.1	58.5
Nishikoyamadani	A	1.5	-	25.1	37.0	36.5
Higashikoyamadani	A	-	2.3	13.4	21.8	62.6
Akechi R.	A	-	-	3.8	34.0	62.3
Kuragari	A	-	2.4	32.9	16.2	48.6
Karegawa	A	2.2	1.4	37.8	7.8	50.7
Nukata	D	-	-	10.7	10.7	78.7
Kaki (W)	E	-	42.9	-	6.2	50.9
Kaki (E)	E	5.3	24.6	26.0	-	44.1
Heizu	E	12.8	15.1	7.5	7.7	56.9
Osawadai	E	-	30.9	4.3	9.0	55.8
Agata	E	-	51.9	13.4	10.5	24.1
Kawashima	F	-	7.2	30.5	27.4	35.0
Tomari	F	19.4	41.8	3.2	-	35.5

Locality	area	gravel	sand & gravel	sand	alt.	mud
Nishiyama	B	100	-	-	-	-
Komeno	B	75.2	-	-	6.1	18.7

The amount of gravels in the sediments decreases northward (Table 10), and according to YOKOYAMA (1969), the paleocurrent direction is from south to north (Fig. 37). The composition of gravels is dominated by chert and sandstone.

The sediments assigned to Stage II around Kameyama is represented by upper and middle Kameyama Formations and also by Sakuramura Formation. In middle Kameyama Formation, the basal part contains sand and gravel layers, but is composed mostly of alternating beds of mud and sand. It is lacustrine deposits. Cross laminations suggest that paleocurrent direction is from SW to NE (YOKOYAMA, 1969). Upper Kameyama Formation is composed of alternating beds of sand and mud, and is similar depositional environment to that of underlying middle Kameyama

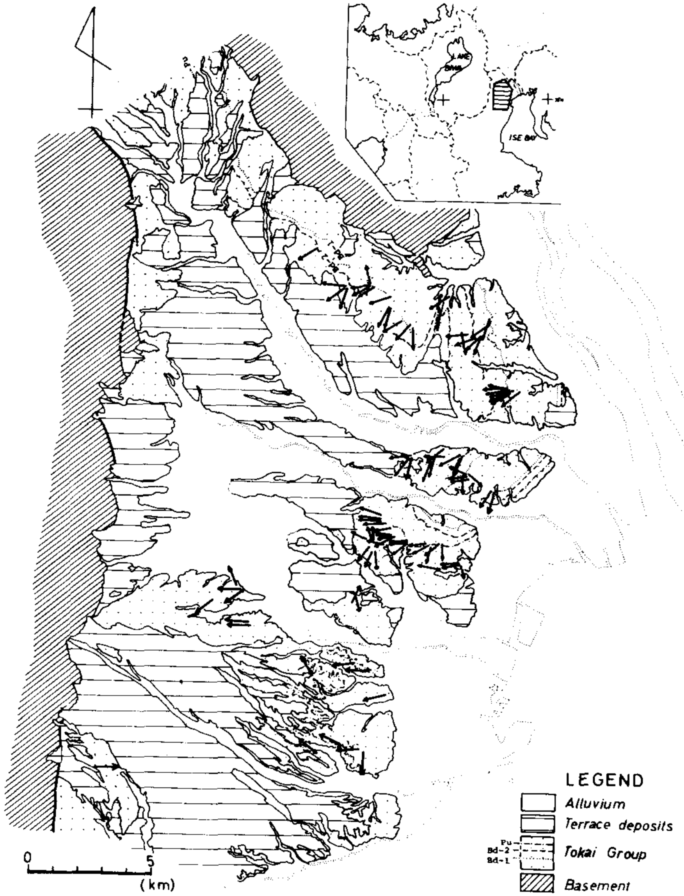

Fig. 36. Paleocurrent directions of the Tokai Group on the west coast of Ise Bay.

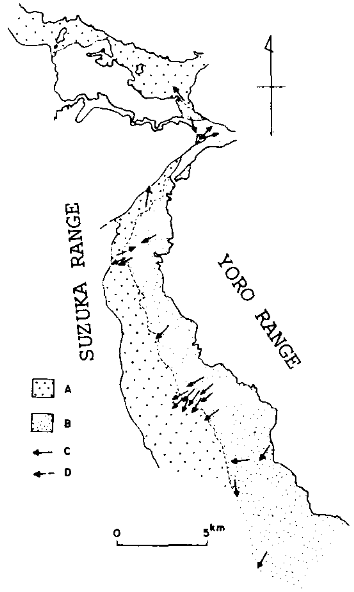

Fig. 37. Paleocurrent directions of the Tokai Group in Tara area (after YOKOYAMA, 1969).

A: Komeno Formation, B: Oizumi and Ichinohara Formations, C: mean directions of cross beddings, D: mean directions of inclination of gravels.

Table 11. Paleocurrent direction deduced from cross-laminations in Oyachi area

Locality	Horizon	Mean direction of paleocurrent	Consistency ratio	Number	Average dip
Agata	Oizumi F.	153	99.0	5	34.2
Agata		99	99.8	5	30.3
Agata		236	99.8	6	33.8
Agata		80	99.5	5	23.6
Agata		248	99.6	5	24.3
Agata		274	99.8	5	30.8
Agata		166	99.8	7	31.7
Agata		178	99.6	6	21.4
Agata		165	99.8	5	25.3
Agata		162	98.3	6	27.8
Agata		206	99.9	5	24.5
Yamanoisshiki		228	99.7	8	34.7
Yamanoisshiki		184	99.8	7	38.0
Yamanoisshiki		185	99.9	6	37.3
Akatsukidai		187	99.8	5	22.2
Akatsukidai		168	99.9	3	31.7
Akatsukidai		181	99.4	4	23.0
Akatsukidai		154	99.9	4	31.0
Akatsukidai		171	99.6	8	34.8
Oyachi (S)		274	99.3	10	30.1
Oyachi (S)		218	99.7	10	34.3
Ikaruga		187	99.8	5	15.1
Ikaruga		175	99.8	5	25.8
Ikaruga		280	99.4	5	34.7
Tarusaka		165	99.2	5	22.9
Tarusaka (N)		250	99.4	10	26.7
Tarusaka (N)		186	99.3	5	26.0
Tarusaka (N)		204	99.8	6	27.5
Mitachi		33	99.5	4	28.8
Mitachi		286	99.8	5	27.4

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

Table 12. Paleocurrent direction deduced from cross-laminations in Yokkaichi and Kameyama area.

Locality	Horizon	Mean direction of paleocurrent	Consistency ratio	Number	Average dip
Komono (E)	Oizumi F.	224	99.8	5	33.2
Komono (E)		177	99.8	5	28.8
Komono (E)		98	99.9	2	46.5
Sakura (W)		43	97.6	5	28.4
Sakura (W)		221	99.8	5	22.6
Sakuradai		169	99.8	8	27.6
Sakuradai		176	99.5	4	24.5
Kawashima (S)		120	99.4	6	26.1
Aobacho		193	99.6	5	31.5
Aobacho		173	98.8	5	30.4
Nishihino		195	99.4	4	31.0
Hagicho (W)		137	99.9	3	26.4
Sasagawacho (S)		154	99.8	5	30.1
Sasagawacho (S)		227	99.1	2	20.6
Sasagawacho (S)		265	99.7	3	28.1
Nishishonai	Kameyama F.	353	99.6	5	24.8
Iwahara		72	99.6	51	18.1

Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

Formation. Sakuramura Formation is distributed in the area to north of Kameyama City. As it is composed of alternating beds of gravel, mud and sand with a large amount of lignite beds, then, it is shallow lacustrine deposits.

C. Paleogeography of Lake Tokai Sedimentary Basin

In this section, paleogeography of Lake Tokai at two stages; Stage I and Stage II will be discussed.

a. Stage I (ca 6.0 Ma to 3.0 Ma)

In the early Stage I, an alluvial plain environments was dominated in the area around Chita Peninsula and Nanse area, in which gravelly sediments were deposited there. In Nanse area, these gravels were supplied from west, while from east in Chita Peninsula. The gravels deposited in Nanse area contains rhyolitic welded tuff originated from Koto Rhyolite area (WADA, 1982), and it is inferred that the water course of those days, the Koto-Kameyama water course of KUWAHARA (1971), ran from Koto area to Kameyama area (Fig. 38–a). On the other hand, the presence of gravels originated from granite and Miocene sandstone of Suzuka Mountains suggest that this area was not in depositional condition. The gravels deposited in Chita Peninsula contains crystalline schist derived without doubt from Sambagawa belt nearby, suggesting the water course from southeast to northwest.

Succeedingly, a large water body of Lake Tokai appeared in the area extending from Nanse area to present Chita Peninsula. This lake was the ellipsoidal in shape with E–W elongation, and in Chita Peninsula, coarse materials were supplied from east. After then, northward development of the sedimentary basin took place in and an alluvial plain with gravelly sediments appeared in the area around Nagoya. Moreover, the lake continued in the southern area, where alternating beds of mud and sand were deposited (Fig. 38–b). In Chita Peninsula area, coarse materials were supplied from north.

b. Stage II (ca 3.0 Ma to 1.2 Ma)

Northwestery migration of the sedimentary basin of Lake Tokai underwent ca 3.0 Ma. Since that time, new sedimentary basin of Lake Tokai existed mainly in Hokuse area and Ise Bay area (Fig. 39). In this section, transition of Lake Tokai during the Stage II will be described with each time interval (substage) defined by four volcanic ash layers (Ichinohara, Bando-1, Bando-2 and Pumice volcanic ash layers). Relationship between the lithology and those datum planes is shown in Fig. 40.

i) substage below the Ichinohara volcanic ash layer

The distribution of the sediments in this substage is known from foothills of Yoro Mountains to north of Kameyama, which are represented by gravels of Biroku

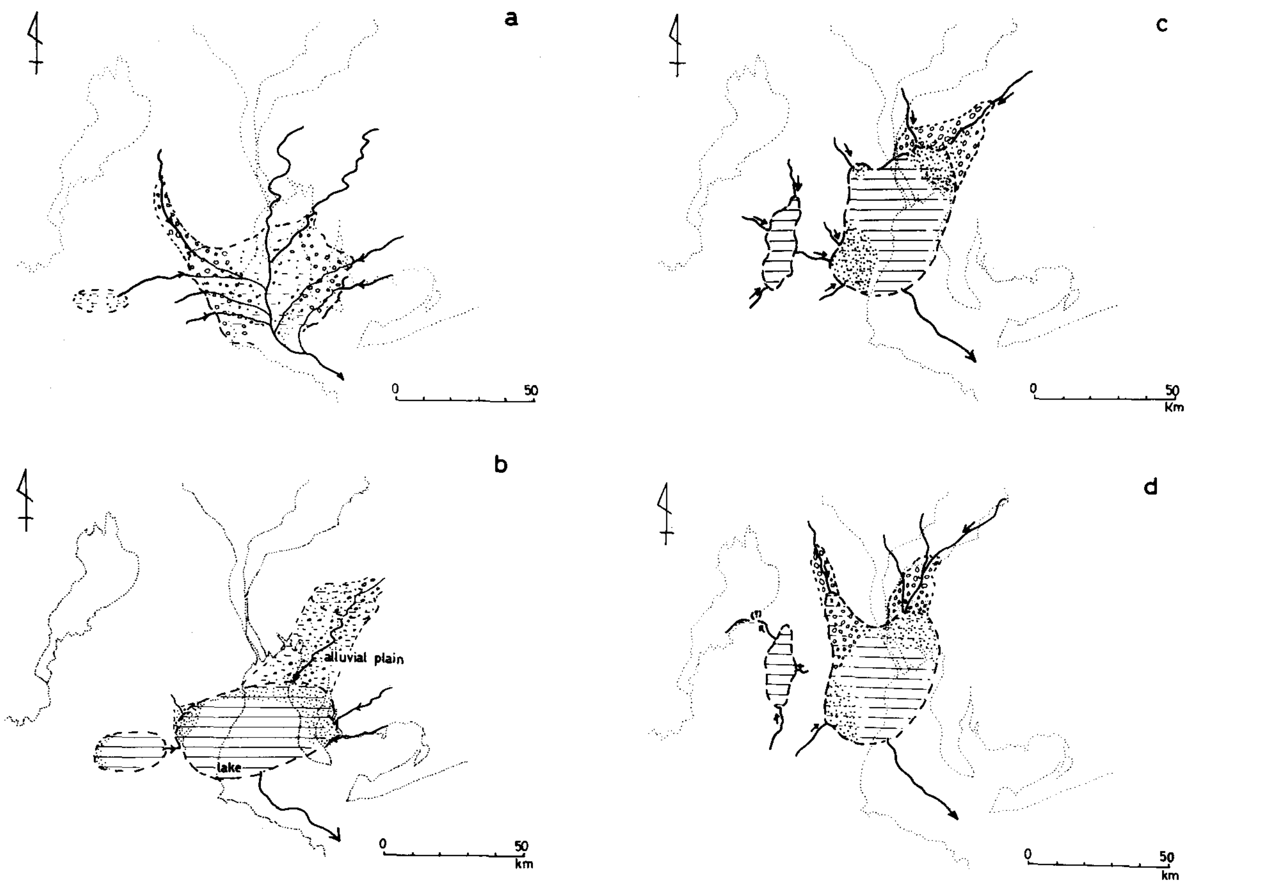

Fig. 38. Paleogeographic map of the sedimentary basin of Lake Tokai since Pliocene.

a; Depositional age of the Saigyodani Formation b; Depositional age of the Kusuhara and Lower Kameyama Formations
c; Depositional age of the Kono Formation d; Depositional age of the Lower Ichinohara Formation

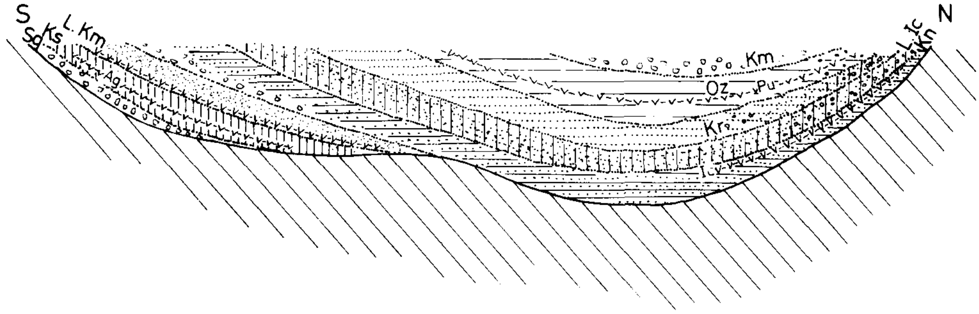

Fig. 39. Generalized geologic profile of the Tokai Group on the west coast of Ise Bay. (Sg: Saigyodani Formation, Ks: Kusuhara Formation, L. Km: Lower Kameyama Formation, Kn: Kono Formation, L. Ic: Lower Ichinohara Formation, Kr: Kuragari Formation, Oz: Oizumi Formation, Km: Komeno Formation, Ag: Akogi volcanic ash layer, Ic: Ichinohara volcanic ash layer, Pu: Pumice volcanic ash layer)

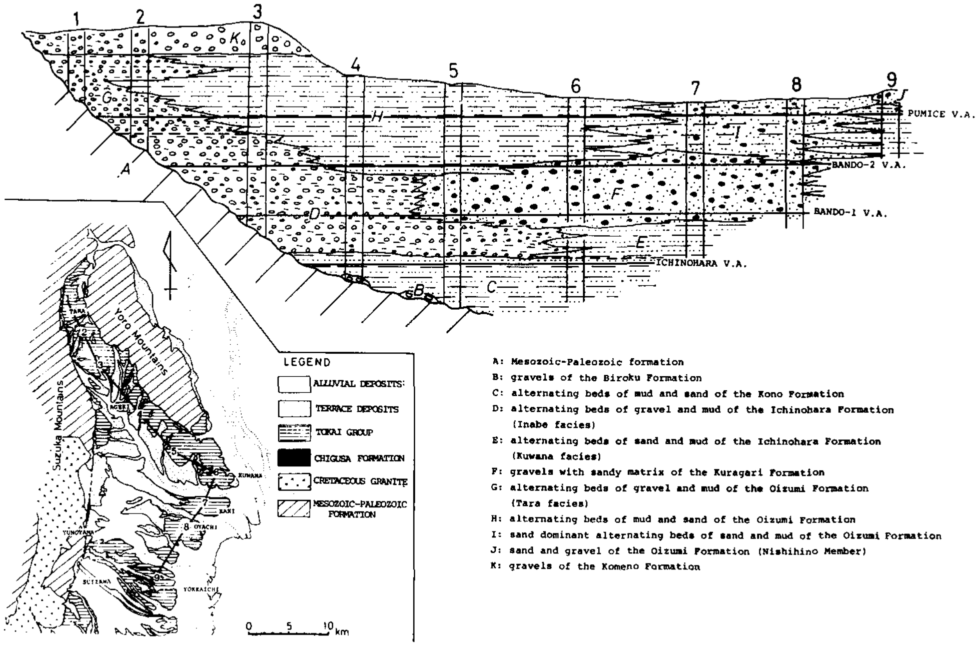

Fig. 40. Relationship between lithology and volcanic ash layers in Hokuse area.

Formation, alternating beds of Kono Formation, and alternating beds of sand and mud of middle Kameyama Formation. In the northern part of the sedimentary basin, alluvial fans were developed locally at foothill areas of present Yoro and Suzuka Mountains which were yet in low-relief topography, but the supply of coarse materials was very rare except for the gravels of alluvial fans. In Inabe and its southern area, shallow lacustrine sediments were widely developed (Fig. 38–c). In the southernmost part of the sedimentary basin, coarse materials were supplied from Suzuka Mountain area as a result of upheaving of southern area. The areas of Nanse, Nagoya and Chita Peninsula where the sedimentary basin of the Stage I almost was dried up.

ii) substage between Ichinohara and Bando-1 volcanic ash layers

This substage can be further subdivided into three phases. In the early phase, shallow lacustrine environment continued from the former substage, in which alternating beds of mud and sand were deposited.

The middle phase is represented by the deposition of alternating beds of gravel and mud (Inabe facies of the Ichinohara Formation), and alternating beds of sand and mud (Kuwana facies of the Ichinohara Formation). In the Inabe and Hokusei area, an alluvial plain was widely developed, where gravels were supplied from north, while lacustrine environment developed in Kuwana area (Fig. 38–d).

The last phase is represented by the deposition of alternating beds of gravel and mud (Inabe facies of Ichinohara Formation), and sand and gravels (Kuragari Formation). In the Inabe and Hokusei area, an alluvial plain was developed, where alternating beds of gravel and mud were deposited. It means that same environment as the middle phase was continued to this phase. In Kuwana area, the water body existed precedingly was filled up by the materials supplied from northeastern area, and consequently, an alluvial plain with sand and gravels was widely developed (Fig. 41–e). Those coarse materials were the first sediments which were supplied beyond present Nohbi Plain area.

iii) substage between Bando-1 and Bando-2 volcanic ash layers

This substage is represented by Inabe facies of Ichinohara Formation and Kuragari Formation. In Inabe and Hokusei area, an alluvial plain was developed with supply of coarse materials from northern area. Alongside with this, in Kuwana, Kaki and Oyachi areas, an alluvial plain was developed by the supply of coarse materials from eastern area. It indicates that same environment as the last phase of the former substage still existed.

iv) substage between Bando-2 and Pumice volcanic ash layers

This substage is represented by alternating beds of gravel and mud (Tara facies of Oizumi Formation), alternating beds of mud and sand (Oizumi Formation), and sandy alternating beds of sand and mud. Gravel supply from north was limited only to Tara area. In this way, an alluvial plain was developed in Tara area. In Inabe and Hokusei area, an alluvial plain condition was changed to lacustrine environment, and then alternating beds of mud and sand were deposited there. In Oyachi and Kaki area, coarse material supply from east was further continued. In this substage, it is clear that the depositional field of coarse materials polarized gradually from north to south, and it may depend upon gradual uplift of Kuwana Anticline area of the north.

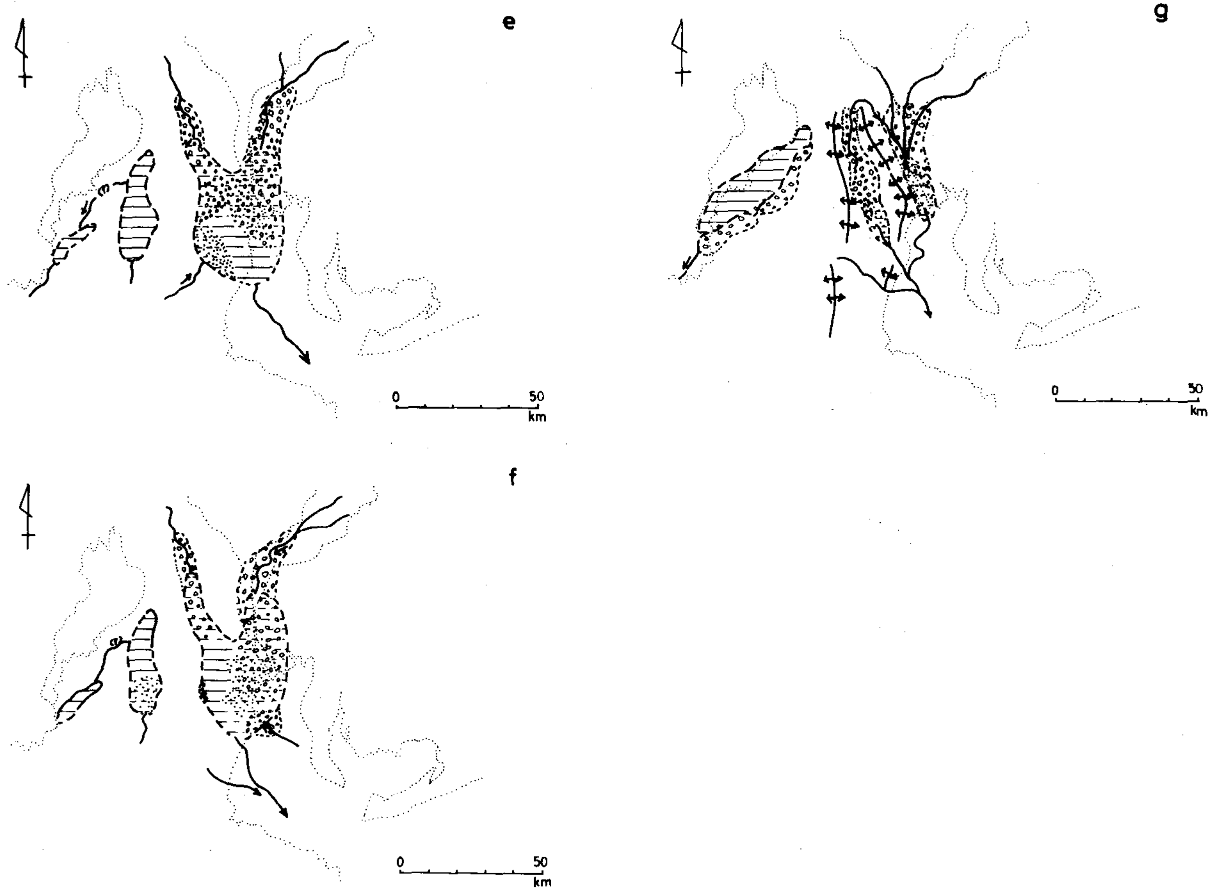

Fig. 41. Paleogeographic map of the Lake Tokai Sedimentary Basin since Pliocene.
e: Depositional age of the Kuragari Formation, f : Depositional age of the Oizumi Formation,
g: Depositional age of Komeno Formation

v) substage between Pumice volcanic ash layer and the base of Komeno Formation

It seems that same environment as the former substage continued throughout Tara, Inabe, Kuwana, Kaki, Oyachi areas in this substage. Although an alluvial plain was developed in narrow belt in Tara area, and lacustrine water body continued from Inabe to Kuwana area. In Kaki and Oyachi area, an alluvial plain was developed by supply of coarse materials from northeast. Also, in Yokkaichi area, an alluvial plain was developed by the gravels supply from east (Fig. 41–f).

vi) substage of Komeno Formation deposition (Fig. 41–g)

This substage represents the last stage of sedimentary basin transition of Lake Tokai. In this substage, vast area of alluvial fan developed by filling up the sedimentary basin with gravels supplied from south. It may be influenced by rapid upheaval of present Suzuka Mountain area. At the same time, topographic contrast became distinct by rapid upheaval of present Yoro Mountain area and movement of Kuwana Anticline.

D. Tectonism Around Ise Bay Since Pliocene to Early Pleistocene

In this section, tectonic development around Ise Bay since Pliocene will be discussed taking the opinions of KUWAHARA (1968) and MAKINOUCHI (1976, 1979) into consideration.

KUWAHARA (1968) discussed tectonism of eastern area of Ise Bay (the area from Nohbi Plain to Tono district including Kiso Mountains). He stated that this area had received tilting movement since Pliocene and this movement formed the topographic contrast between the sedimentary basin of Lake Tokai and eastern upheaving area. He called this tilting block as "Chubu Tilting Block". After the extinction of Lake Tokai, the sedimentary basin were differentiated and a tilting block ("Nohbi Tilting Block") was appeared in the area of Nohbi Plain. This movement was called the "Sanage Movements". In addition, he recognized two types of tectonic movements (Type-1 and Type-2), originated in crustal undulation of the Second Setouchi Depression. Type-1 is of long wave undulation which formed main depressional zone with parallel axis to the Setouchi trend. Type-2 is of short wave undulation crossing with the axis of the Setouchi trend, which made the alternating arrangement of basin and ridge in the depressional zone (KUWAHARA, 1968).

MAKINOUCHI (1976, 1979) paid much attention to the unconformable relation between Tokoname Group (Tokai Group) and Taketoyo Formation distributed at Chita Peninsula. He distinguished two tectonic movements, one formed Lake Tokai and the other the Taketoyo Fomation, respectively. He called the former the "Chita Movements" and correlated the latter to the "Sanage Movements".

As mentioned in the section of geologic structure, the sedimentary basin of Lake Tokai is divided into two subbasins by Yoro-Ise Bay Faults. In other words, this tectonic line is the boundary between Kinki and Chubu Blocks (HUZITA, 1962).

Therefore, the transition of the sedimentary basin of Lake Tokai has to examine in relation to the interaction between both tectonic blocks. The studies of KUWAHARA (1968) and MAKINOUCHI (1976, 1979) were based on the researches carried out in the Nagoya and the Chita Peninsula areas, both belonging to Chubu Block. Moreover, as mentioned in the section of the correlation among Tokai Group, the sediments in the later half of the geohistory of Lake Tokai (Stage II) is only distributed on west coast of Ise Bay which belongs to Kinki Block. Accordingly, the status of tectonic movement in central and northern area of west coast of Ise Bay has upmost importance in understanding of the tectonic development during the age of Lake Tokai. Tectonic developments in those areas during the age of Lake Tokai is summarized as follows (Fig. 42).

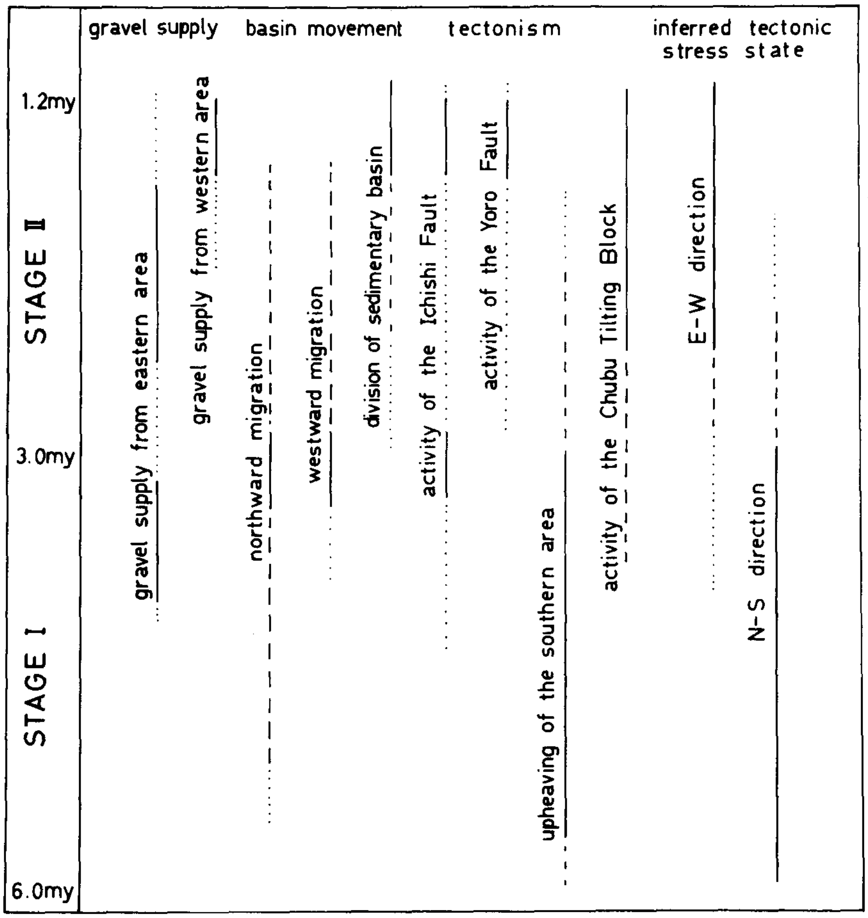

Fig. 42. Tectonic development around the sedimentary basin of Lake Tokai.

Before the appearence of the sedimentary basin of Lake Tokai, it is inferred that the area around Ise Bay was a low-relief topographic lowland which was resulted by the peneplanation in late Miocene (KUWAHARA, 1968; MAKINOUCHI, 1976, 1979). The geohistory of Lake Tokai in Stage I began with the deposition of a large amount of gravels in the southern area. It suggests that the topographic contrast between subsiding and upheaving areas appeared around this area. From the distribution of gravel facies, it is inferred that the elongated depressional zone developed at that time with axis parallel to the Setouchi trend, and successively, a large lake appeared in this depressional zone. This water body extended from Tsu to Chita Peninsula area, and was ellipsoidal with E–W elongation. The subsiding movement in this stage belonged to the tectonic movement of the Setouchi trend (HUZITA, 1968), the tectonic stress being in N–S direction. In late Stage I, that depressional zone slightly shifted from south to north. It reflected upheaving of southern sedimentary basin, and thus, tectonic stress continued to be in N–S direction. In this stage, however, a large amount of gravels were supplied from east in the area around Nagoya, suggesting the tectonic movement of Chubu Tilting Block.

To recapitulate, the tectonic movements of Stage I was assignable to the tectonism of the Setouchi trend with tectonic stress state in N–S direction, and that Chubu Tilting Block joined to this tectonic movements in the later part of Stage I.

It was about 3.0 Ma that center of the sedimentary basin migrated further to the north. This migration was associated with rapid upheaving of southern area of the sedimentary basin. Moreover, the area around Nagoya and of Chita Peninsula were mostly dried up. It follows that the upheaving occurred also in eastern area, Chubu Tilting Block. The large-scale migration of the sedimentary basin took place under the influence of rapid upheaving of south and Chubu Tilting Block of the east. Differentiation of the sedimentary basin started through the migration process from Stage I to Stage II. The embryonic fault of Yoro separated Kinki Block from Chubu Block, and both became to be influenced by different crustal movements.

In the early part of Stage II, muddy sediments abutted against the basement rocks of Yoro Mountains. It is evident that Yoro Mountains had already stood as a barrier in the sedimentary basin of Lake Tokai, but the area around the sedimentary basin were under low-relief topographic condition. Topographic contrast between depressional area and upheaving area became to be distinct step by step. Such contrast is represented by a large amount of gravel supply of that time. After then, the topographic contrast decreased as being represented as the upward fining cycle from Ichinohara Formation to Oizumi Formation. Through Stage II, the sedimentary basin migrated gradually northward with continuous upheaving of the southern area. Moreover, the tilting movement of Chubu Tilting Block supplied a large amount of gravels of Kuragari Formation from the east. Yoro Mountains and Kuwana Anticline upheaved gradually. Consequently, the western sedimentary basin resulted to migrate to west under the influence of those tectonic activities. In the latest Stage II, it is clear that Suzuka Mountains upheaved rapidly in N–S trend, and thus, the N–S structural trend became to be more conspicuous in the western half of the sedimentary basin.

Summarizing above, the tectonic movements during Stage I was under the stress state in N–S direction and it formed the depressional zone with E–W trend, that is, the Setouchi trend. Chubu Tilting Block joined with this movements. In Stage II, the tectonic stress state in E–W direction was represented mainly by the movement of Chubu Tilting Block, but influence of that in N–S direction was conspicuous in the western half of Lake Tokai. Furthermore, such structure with N–S trend as being represented by Suzuka Mountains became to be conspicuous (Fig. 42). Therefore, it has been recognized by those resolutions of tectonic history that the tectonism of the surrounding area of Lake Tokai should be analyzed from the viewpoint of the interaction between upheaving of the southern area under the tectonic stress state in N–S direction and tilting movement of Chubu Tilting Block influenced by the tectonic stress state in E–W direction.

IV. Subdivision of the Second Setouchi Supergroup and Tectonic Development

In Chapter III, the relation between transition of sedimentary basin of Lake Tokai and tectonism has been considered. Based on those results, the tectonism of Southwest Japan since Pliocene will be discussed here.

A. Tectonism of Southwest Japan since Pliocene

Rokko Movements was defined as all of the crustal movements occurred since Pliocene in the Setouchi Depression by IKEBE (1956, 1957). ITIHARA (1960) proposed the concept of the "Climax of Rokko Movements" in middle Pleistocene age before the formation of terrace deposits based on distinct difference of the structural features between Osaka Group and the terrace deposits. Furthermore, HUZITA (1962) distinguished two structural trends in this tectonic province, and IKEBE and HUZITA (1966) redefined Rokko Movements only to the crustal movement with meridional structural trend.

As for the tectonic movement around Ise Bay, KUWAHARA (1968) proposed a concept of "Sanage Movements", and he pointed out that this movements is the same as Rokko Movements. Therefore, these all belong to tectonic movements in Quaternary Period. On the other hand, MAKINOUCHI (1979) recognized two types of tectonic movement since Pliocene from the studies on the sediments of Chita Peninsula. According to him, among them, the younger movement was correlated to Rokko Movements, while the older movement was newly defined as "Chita Movements".

The latter implies 'the tectonic movement which caused Tokoname Group to deposit, deform and dislocate during the sedimentary process, mainly of Pliocene age' (MAKINOUCHI, 1979).

The Quaternary tectonic stress state in this province has been discussed enthusiastically from the viewpoint of active faults distribution, geodesic survey and earthquake mechanism (HUZITA, 1968, 1969; HUZITA and KISHIMOTO, 1972; HUZITA *et al.*, 1973; HUZITA and OHTA, 1977). Comprehensively, it has been deduced that stable tectonic compressional stress state with E–W trend governed all the area during that time. Recently, HUZITA (1980) recognized two types of tectonic zone, one parallel to the Japan Trench and the other to Nankai Trough since the middle Pleistocene, and stated that they were compressed under the movements of the Pacific and Philippine Sea Plates. Directions of stress state since Miocene were established by dyke swarms method (KOBAYASHI, 1977, 1979; TAKEUCHI, 1980 and so on). As to that of Inner zone of Southwest Japan, the N–S compressional stress field was predominant during late Miocene and Pliocene Time (KOBAYASHI, 1977, 1979; KOBAYASHI and NAKAMURA, 1978). Therefore, HUZITA's idea (1969) which suggested change of tectonic stress field from N–S compressional state to E–W compressional state is verified now. But, it remains to establish the detailed age and areal differences.

B. Correlation among Tokai, Kobiwako and Osaka Groups

As main Plio-Pleistocene sequences in the Second Setouchi Depression, Tokai, Kobiwako and Osaka Groups can be enumerated (Fig. 1). ISHIDA and YOKOYAMA (1969) attempted a correlation among those three groups tephrochronologically. Succeedingly, ISHIDA *et al.* (1969) reported magnetostratigraphy of Plio-Pleistocene sequences in Kinki and Tokai districts, and they correlated it with the time scale of Cox and DALRYMPLE (1967). Thereafter, a great deal of informations from paleomagnetism, fission-track ages and tephrochronology were accumulated. After reexamination of the results of ISHIDA *et al.* (1969), MAENAKA *et al.* (1977) proposed the magnetostratigraphy of Plio-Pleistocene sequences in Kinki district.

Kobiwako Group is developed mainly in Koto area (southeastern side of Lake Biwa) and Kosei area (western side of Lake Biwa). The stratigraphy of those deposits were summarized by YOKOYAMA *et al.* (1979) and YOKOYAMA (1984). Generally speaking, the upper part of this group (Katata Formation) is distributed in Kosei area, while the lower part of the group (Iga-Aburahi, Sayama, Gamo and Yokaichi Formations in ascending order) is distributed in Koto area.

In Kosei area, a characteristic volcanic ash layer called the Azuki volcanic ash layer is intercalated in the lower part. The fission-track age of this layer is 0.87 Ma (NISHIMURA and SASAJIMA, 1970), and that of Biotite volcanic ash layer which is about 20 m above the former is 0.70 Ma (NISHIMURA and YOKOYAMA, 1975). Together with the detailed magnetostratigraphy done by HAYASHIDA *et al.* (1976), it is possible to say that those sediments range from late Matuyama Reversed Epoch to early Brunhes Normal Epoch. The uppermost part of the group is composed of gravels (Ryuge sands and gravels).

Correlation among two core samples in and around Lake Biwa and Kobiwako Group in Kosei area was carried out tephrostratigraphically by YOKOYAMA (1975) and TAKEMURA *et al.* (1976).

In Koto area, magnetostratigraphy and fission-track ages clarified that Kobiwako Group in this area ranges from Gilbert Reversed Epoch to Matuyama Reversed Epoch (MAENAKA *et al.*, 1977; TAMURA *et al.*, 1977; KOBIWAKO RESEARCH GROUP, 1977; HAYASHIDA and YOKOYAMA, 1979; NISHIMURA and SASAJIMA, 1970; YOKOYAMA *et al.*, 1977a, 1980a). The uppermost part in the Koto area is composed of gravels (Yokaichi Formation).

In Osaka Group around Osaka Bay, the upper part is characterized by alternating beds of marine and non-marine facies (ITIHARA and KAMEI, 1970; ISHIDA, 1970). The initiation of such an alternation was about 1.2 Ma (YOKOYAMA, 1979).

To the contrary, the lower part of Osaka Group is characterized mainly by lacustrine and fluvial sediments, and the upper and lower parts are unconformable (YOKOYAMA *et al.*, 1977b; YOKOYAMA *et al.*, 1980c; IIDA, 1980). Its lower part ranges from Gauss Normal to early Matuyama Reversed Epoch (NISHIMURA and SASAJIMA, 1970; YOKOYAMA, 1979; IIDA, 1980; MAENAKA *et al.*, 1977; TORII *et al.*, 1975; YOKOYAMA and HAYASHIDA, 1980). The correlation among Tokai, Kobiwako and Osaka Groups may be shown as proposed in Fig. 43.

As stated precedingly, the sedimentary basin of Lake Tokai appeared at about 6.0 Ma and shifted the place to northwest on a large-scale in about 3.0 Ma and ceased its existence at about 1.2 Ma. From the viewpoint of distribution pattern of the sediments and the age of their deposition, the geohistory of Lake Tokai can be divided into two stages, Stage I from 6.0 Ma to 3.0 Ma and Stage II from 3.0 Ma to 1.2 Ma.

The sedimentary basin of Paleo-lake Biwa appeared at about 5–6 Ma and shifted its place on a large-scale to north from Iga Basin to Ohmi Basin at about 3.0 Ma. After disappearance of water body in Koto area, center of the lake basin migrated to northwest at about 1.2 Ma.

Further west, the sedimentary basin around Osaka Bay appeared at about 3.0 Ma, but alternating beds of marine and non-marine sediments began to cover the lower part of Osaka Group unconformably at about 1.2 Ma.

It follows that important episodes of the geohistory are in common among those three sedimentary basins; of about 3.0 Ma and of about 1.2 Ma, respectively (Fig. 44).

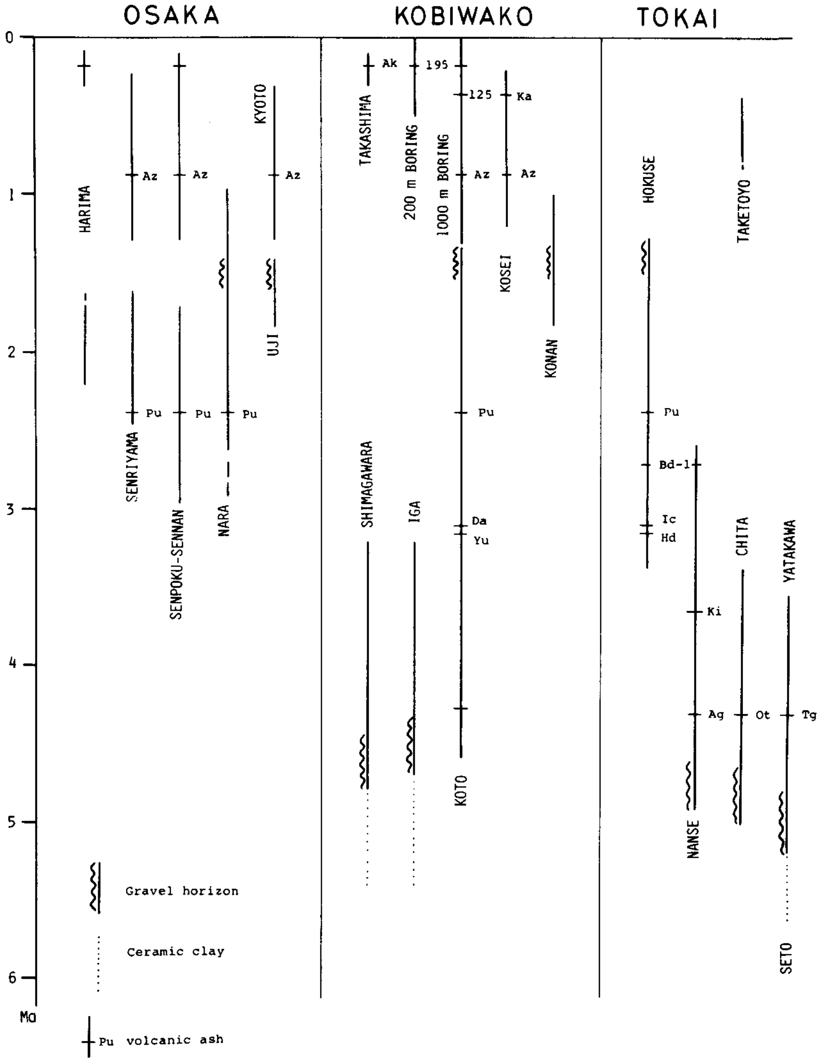

Fig. 43. Correlation chart among the Tokai, Kobiwako and Osaka Groups.

C. Comparison of Sedimentary Basin Transition between Paleo-lake Biwa and Lake Tokai

It has been known that the geohistory of the Second Setouchi Supergroup can be subdivided by tectonosedimentary facies of about 3.0 Ma and 1.2 Ma. This suggests that the change of tectonic stress state of this province took place simultaneously throughout three sedimentary basins. In this section, to compare the

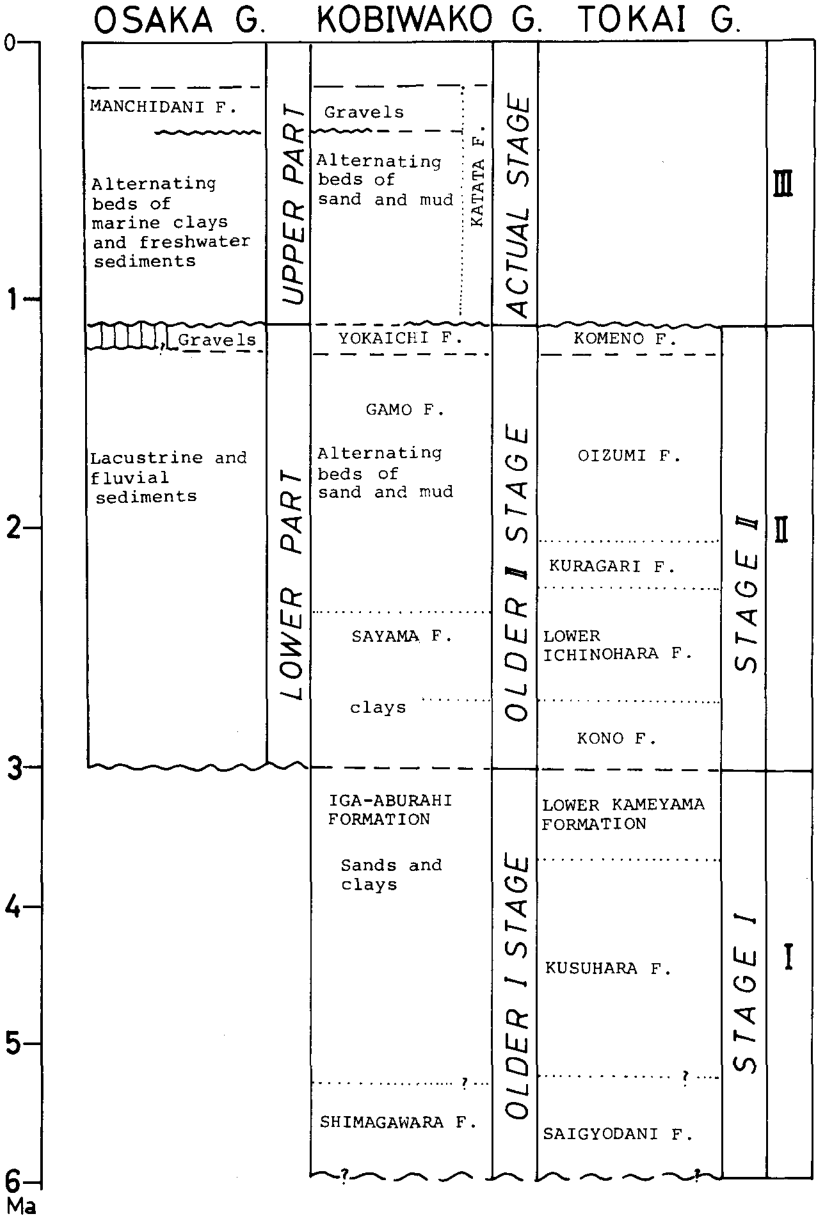

Fig. 44. Subdivision of the Second Setouchi Supergroup.

geohistory of Lake Tokai with that of Paleo-lake Biwa, patterns of sedimentary basin transition will be discussed.

According to YOKOYAMA (1969, 1984), the geohistory of Paleo-lake Biwa is divided into four stages: Older I, Older II, Actual I and Actual II stages. At first, Paleo-lake Biwa appeared in Iga Basin and clay dominant sediments were deposited in this water body ("Iga-ko") (YOKOYAMA *et al.*, 1980a) (Older I stage). In the second, center of the sedimentary basin shifted its place to north from Iga Basin to Ohmi Basin, forming stable water body ("Sayama-ko") with massive clay deposition. Northward shifting of the sedimentary basin was inherited (Older II stage). During the time from Older II stage to Actual I stage, center of the sedimentary basin migrated to northwest on a large-scale, and the gravels of Yokaichi Formation represents the last sediments of Older II stage. The sedimentary basin of Actual I stage shifted its place gradually to west, accompanied by the upheaval of the eastern mountain area. This explanation was supported by the results of lithology, paleocurrent, sedimentological studies on the deposits of Kosei area and those of the 1,000 m drilling cores at the rivermouth of the Yasu river (YOKOYAMA, 1979; TAKEMURA *et al.*, 1979). The gravels of the uppermost part of Kobiwako Group in Kosei area is sediments of the last Actual I stage. These gravels was the first sediments supplied from present western Hira Mountains. Followingly, the crustal movements along Katata Fault became more active, and, after then, in Actual II stage, the area of actual Hokko (northern lake) basin of present Lake Biwa began to subside rapidly.

Therefore, the similarities deduced from the process of those two sedimentary basin transition are summarized as follows:

i) In early stage, the sedimentary basin appeared in southern area of the basin, and migrated gradually to north.

ii) Succeedingly, the sedimentary basin migrated to northwest on a large-scale.

iii) The sedimentary basin migrated gradually to west, and at last, it is divided by the structural movements in N–S trend accompanied rapid subsidence of the eastern area.

In this way, similar pattern of transition can be recognized in both sedimentary basins of Paleo-lake Biwa and Lake Tokai. But, large-scale northwestward migration was heterochronous, that is, about 3.0 Ma in Lake Tokai, and about 1.2 Ma in Paleo-lake Biwa.

D. Tectonism and Basin Migration

As mentioned before, the geohistory of the Second Setouchi Province had two conspicuous episodes of ca 3.0 Ma and of ca 1.2 Ma and a similar pattern of basin transition was revealed as recognized in both sedimentary basins of Lake Tokai and Paelo-lake Biwa. This suggests that the changes of the tectonic stress state were common throughout that province.

The sedimentary basins before ca 3.0 Ma (Stage I of Lake Tokai and Older I stage of Paleo-lake Biwa) are mainly characterized by E–W arrangement of depressional zone and their northward migration. It may owe to the upheaval of the southern area under the tectonic stress state in N–S direction. But, in the middle of Stage I, Lake Tokai received a large amount of gravel supply from east which related to the movements of Chubu Tilting Block. It suggested the beginning of new structural control which superposed the older one.

At the time of ca 3.0 Ma, the sedimentary basin of Lake Tokai migrated northwest.

After that time, the sedimentary basin of Lake Tokai migrated to west as a whole, though slightly northward, by active movement of Chubu Tilting Block under the stress state of E–W trend. But, in the same time interval, the sedimentary basin of Paleo-lake Biwa was migrating gradualy northward by the upheaval of southern area.

At the time of ca 1.2 Ma, the sedimentary basin of Lake Tokai became to extinct being accompanied with the upheaving of Suzuka and Yoro Mountains with N–S structural trend. It was peculiar that the sedimentary basin of Paleo-lake Biwa transfered its position to northwest. After then, it migrated gradually westward by tilting of eastern area. This fact means the origination of conspicuous movement under E–W tectonic stress in the Ohmi Basin.

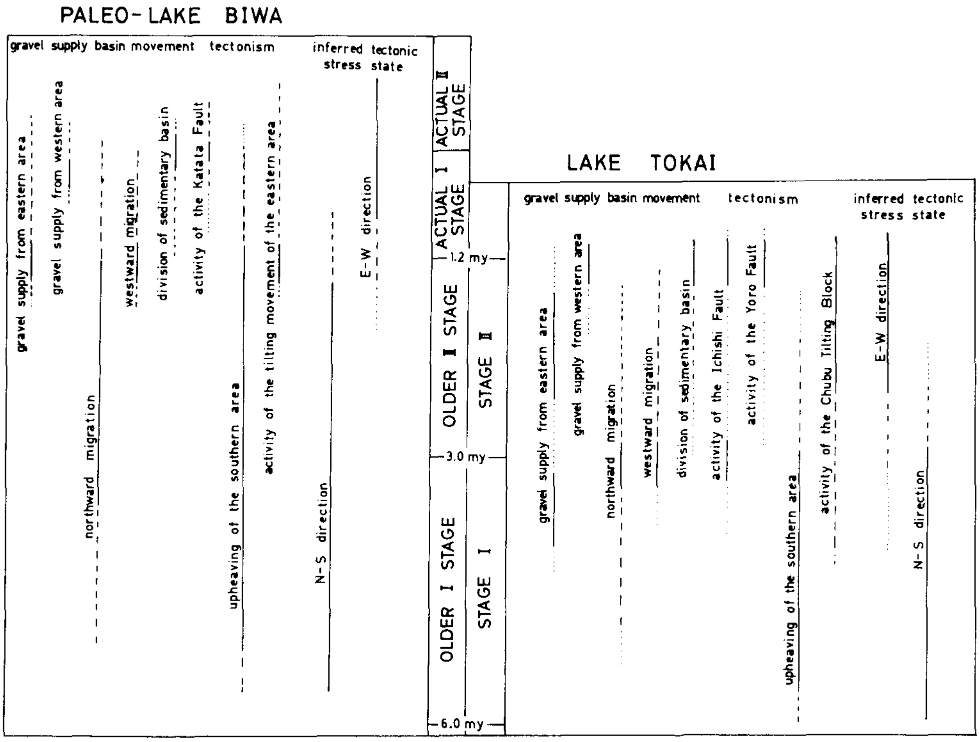

Fig. 45. Comparison of the tectonic development between the sedimentary basins of Lake Tokai and the Paleo-lake Biwa.

In this way, the sedimentary basin migration in Lake Tokai and Paleo-lake Biwa is commonly explained by the hypothesis of interaction between upheaving of the southern area and tilting of the eastern area (Fig. 45).

Conclusively, the author proposed an idea that the deposition of the Second Setouchi Supergroup since Pliocene was under the influence of superposed two tectonic stress states which are represented by upheaving of southern area and tilting of eastern area. Hitherto, HUZITA (1969) and others have stated that the tectonic stress state change since Miocene took place in the Inner zone of southwest Japan during the time of Pliocene and Pleistocene. This change from N–S compressional stress state to E–W one was conspicuous. Therefore, the result of the present work is not contradictory to that idea and confirms chronological setting and detailed process of tectonosedimentary turnover since Pliocene.

V. Summary

1. Plio-Pleistocene Tokai Group of west coast of Ise Bay consists mainly of sands, muds and gravels in fluvial and lacustrine origin, and contains numerous volcanic ash layers and lignite beds. The stratigraphy of Tokai Group in Hokuse area (northern part of the west coast of Ise Bay) is summarized as shown in Table 2. On the basis of tephrostratigraphy, lateral facies changes of those deposits were described precisely (Fig. 24).

2. On the basis of tephrostratigraphy, biostratigraphy, paleomagnetism and fission-track ages, Tokai Group in Hokuse area was clarified to have a range from Kaena event of Gauss Normal Polarity Epoch to early Matuyama Reversed Polarity Epoch (about 3.0 Ma to 1.2 Ma) (Fig. 27).

3. In geologic structure on west coast of Ise Bay, three conspicuous tectonic trends (Setouchi, Suzuka and Yoro trends) are discriminated (Fig. 29). Tokai Group in Hokuse area forms a basin structure.

4. The correlation among the sediments of Tokai Group in various areas (west coast of Ise Bay, Chita Peninsula and area around Nagoya) was carried out precisely (Fig. 30). Consequently, it becomes to be clear that the geohistory of the sedimentary basin of Lake Tokai can be subdivided into two stages, Stage I (about 6.0 Ma to 3.0 Ma) and Stage II (about 3.0 Ma to 1.2 Ma).

5. In order to make sure the paleogeography of Lake Tokai, sedimentological data (lithology, lithologic proportion, gravel composition, paleocurrent directions and sedimentary facies) were described. On the basis of chronostratigraphy and those sedimentological data, the paleogeography of Lake Tokai was reconstructed (Figs. 38 & 41). Furthermore, the process of sedimentary basin transition was examined from those paleogeographical researches. They are summarized as follows: After wide distribution of alluvial plains in early Stage I, a large water body appeared in southern

area of the basin, which extends from Tsu area to actual Chita Peninsula. Succeedingly, though, in the area around Nagoya of the north, the gravels were supplied from eastern area and alluvial plain was developed widely, water body preexisted still remained in southern area.

At about 3.0 Ma, in accordance with northward shifting of the sedimentary basin which covered the area from Nanse to Chita Peninsula, and stable water body became to appear in Hokuse area. After that, sedimentary basin was more developed northwardly, but, as the gravels supplied from northern area were accumulated there, an alluvial plain was formed accompanied with a water body around Kuwana area. Subsequently, the gravels supplied from eastern area reached to present west coast of Ise Bay beyond present Nohbi Plain, and filled water body of the former age. Thus, water body reduced its extent and was remained only in southwestern area. Followingly, as coarse materials from northern area decrease in supply, water body was developed to north. In the last, a large amount of gravels from southwestern area (Suzuka Mountains) filled up that sedimentary basin and Lake Tokai attained to its terminal stage.

6. In connection with the mode of sedimentary basin transition, tectonic development around Ise Bay was discussed. Tectonic development of surrounding areas should be considered from the interaction between upheaving of southern area under tectonic stress state of N–S direction and movement of Chubu Tilting Block influenced by the tectonic stress state of E–W direction.

7. By tephrostratigraphy, magnetostratigraphy and fission-track ages, the correlation among Tokai, Kobiwako and Osaka Groups was made (Fig. 43). Consequently, it becomes clear that the boundary of Stage I and Stage II of Lake Tokai (about 3.0 Ma) is fairly coincidental with the boundary of Older I and Older II stages of Paleo-lake Biwa, and also with the initial stage of the sedimentary basin around Osaka Bay. This boundary should be regarded to have important role in geohistory of the Second Setouchi Inland Depression. Moreover, it is very curious that the extinction of Lake Tokai (about 1.2 Ma) was correlated with the boundary between Older stage and Actual stage of Paleo-lake Biwa, and also with the first appearance of alternating beds of marine and non-marine deposition around Osaka Bay.

8. To compare Lake Tokai with Paleo-lake Biwa, similar migration pattern of the sedimentary basin was recognized. But a large-scale migration of Paleo-lake Biwa to northwest occurred later than that of Lake Tokai.

9. Similar migration pattern of two sedimentary basins (Paleo-lake Biwa and Lake Tokai) were examined as the results of mutual interaction between southern area upheaving and tilting movement of eastern area. Before a large-scale northwestward migration of the basin, tectonic stress state was under N–S compression, but it changes to E–W compression after the migration. These results obtained from tectonosedimentary analysis are concordant with the results deduced from analytical studies of

dyke swarms, active faults, earthquake mechanism and so on. This change of stress field seems to be delayed in western area. These two tectonic stresses discussed here may correspond to two types of Quaternary tectonic zone proposed by HUZITA (1980).

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References

AKAMINE, H., HOSONO, M. and KUBO, K. (1951): Coal-bearing Tertiary in the Kameyama district, Mie Prefecture. *Misc. Rep. Inst., Natr. Resources*, **19–21**, 149–158.*

ARAKI, Y. (1953): On the Cenozoic Erathem along the Ano River, Mie Prefecture. *Bull. Liberal Arts Dep. Mie Univ.*, **10**, 63–68.*

CHUJO, J. and SUDA, Y. (1971): Gravitational study of northern Ise Bay. *Bull. Geol. Surv. Japan*, **22**, 415–435.*

CHUJO, J. and SUDA, Y. (1972): Gravitational study of southern Ise Bay and Mikawa Bay. *Bull. Geol. Surv. Japan*, **23**, 573–594.*

COX, A. and DALRYMPLE, G. B. (1967): Geomagnetic polarity epochs, Nunivak Island, Alaska. *Earth Planet. Sci. Lett.*, **3**, 173–177.

HATA, Y. (1967): Cenozoic strata in the Komono district, Mie Prefecture. *Rep. Resources Exploit. Inst.*, **4**, 77–107.*

HAYASHIDA, A., YOKOYAMA, T., TAKEMURA, K., DANHARA, T. and SASAJIMA, S. (1976): Preliminary report on magnetostratigraphy of the Kobiwako Group on the west coast of Lake Biwa, central Japan. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **4**, ed. S. Horie, 96–108.

HAYASHIDA, A. and YOKOYAMA, T. (1979): Paleomagnetic chronology of the Plio-Pleistocene Kobiwako Group on the east coast of Lake Biwa, central Japan. *Rock Mag. Paleogeophys.*, **6**, 48–51.

HUZITA, K., IKEBE, N., ITIHARA, M., KOBATAKE, N., MORISHIMA, M., MORISHITA, A., NAKAGAWA, C. and NAKASEKO, K. (1951): Osaka Group and the related Cenozoic Formations. *Chikyu Kagaku (Earth Science)*, (6), 13–24.*

HUZITA, K. (1954): Stratigraphic significance of the plant remains contained in the late Cenozoic formations in central Kinki, Japan. *Jour. Inst. Polytech. Osaka City Univ.*, **2**, 74–88.

HUZITA, K. (1962): Tectonic development of the Median zone (Setouchi) of southwest Japan, since

the Miocene. *Jour. Geosci. Osaka City Univ.*, **6**, 103–144.
HUZITA, K. (1968): Rokko Movements and its appearence —Intersecting structural patterns of southwest Japan and Quaternary crustal movements—. *Quat. Res.* (*Daiyonki Kenkyu*), **7**, 248–260.*
HUZITA, K. (1969): Tectonic development of southwest Japan in the Quaternary Period. *Jour. Geosci. Osaka City Univ.* **12**, 53–70.
HUZITA, K. and KISHIMOTO, Y. (1972): Neotectonics and seismicity in the Kinki area. *Kagaku* (*Science*), **42**, 422–430.**
HUZITA, K., KISHIMOTO, Y. and SHIONO, K. (1973): Neotectonics and seismicity in the Kinki area, southwest Japan. *Jour. Geosci. Osaka City Univ.*, **16**, 93–124.
HUZITA, K. and OTA, Y. (1977): Quaternary tectonics. In *The Quaternary Period: Recent studies in Japan.* 127–152.*
HUZITA, K. (1980): Role of the Median Tectonic Line in the Quaternary tectonics of the Japanese Islands. *Mem. Geol. Soc. Japan*, (18), 129–153.
IIDA, Y. (1980): Unconformity of the early Pleistocene in the Osaka Group of Sen-nan area, south of Osaka, Japan. *Master thesis of Kyoto Univ.*, 79 pp.
IKEBE, N. (1933): Kobiwako series, a Pleistocene deposits in the west side of Lake Biwa. *Chikyu*, **20**, 241–260.*
IKEBE, N. (1934): Cenozoic strata in Koka-gun, Omi Province, along the west side of Suzuka Range. *Jour. Geol. Soc. Japan*, **41**, 399–401.**
IKEBE, N. (1956): Cenozoic geohistory of Japan. *Proc. 8th Pacific Sci. Congr.*, **2**, 446–456.
IKEBE, N. (1957): Cenozoic sedimentary basin in Japan, with special reference to the Miocene sedimentary basin. *Shinseidai no Kenkyu* (*Cenozoic Res.*), (24–25), 1–10.**
IKEBE, N., CHIJI, M. and ISHIDA, S. (1966): Catalogue of the late Cenozoic proboscidea in the Kinki district, Japan. *Jour. Geosci. Osaka City Univ.*, **9**, 47–56.
IKEBE, N., and HUZITA, K. (1966): The Rokko Movements, the Plio-Pleistocene crustal movements in Japan. *Quaternaria*, **8**, 277–287.
IKEDA, T., TAKEMURA, K. and YOKOYAMA, T. (1977): Contents of trace elements in volcanic pumice grains by neutron activation analysis. *Tsukumo Chigaku*, (12), 43–57.**
ISHIDA, S., MAENAKA, K. and YOKOYAMA, T. (1969): Paleomagnetic chronology of volcanic ash of the Plio-Pleistocene series in Kinki district, Japan —The research of younger Cenozoic strata in Kinki district, part 12—. *Jour. Geol. Soc. Japan*, **75**, 183–197.
ISHIDA, S. and YOKOYAMA, T. (1969): Tephrochronology, paleogeography and tectonic development of Plio-Pleistocene in Kinki and Tokai districts, Japan —The research of younger Cenozoic strata in Kinki province, part 10—. *Quat. Res.* (*Daiyonki Kenkyu*), **8**, 31–43.*
ISHIDA, S. (1970): The Osaka Group —The cyclic sediments of lacustrine and bay in Plio-Pleistocene, Japan—. *Quat. Res.* (*Daiyonki Kenkyu*), **9**, 101–112.*
ITIHARA, M. (1960): Some problems of the Quaternary sedimentaries, Osaka and Akashi area. *Chikyu Kagaku* (*Earth Science*), (49), 15–25.*
ITIHARA, M. (1966): The Osaka Group and the Rokko Movements. *Chikyu Kagaku* (*Earth Science*), (85–86), 12–18.*
ITIHARA, M. and KAMEI, T. (1970): The Osaka Group. *Kagaku* (*Science*), **40**, 282–291.**
ITOIGAWA, J. (1971): Research on the Seto Group, Part 2 —The stratigraphy of the Tokoname formation in the environs of the Chita Peninsula, Japan—. *Prof. Heiichi Takehara Mem. Vol.*, 83–98.*
ITOIGAWA, J. and MORI, S. (1971): The Tokai Supergroup. *Daishiki* (*The Quaternary*), (16), 117–120.**
KAKUTA, T. and AKAMINE, H. (1958): *Parastegodon akashiensis* TAKAI found from Kaminoyamada, Fujiwara-mura, Inabe-gun, Mie Prefecture. In *Paleontology and Geology in North Ise*, Sangi Railway Co., 32–49.**
KAMEI, T. and SETOGUCHI, T. (1970): Some remarks on mammalian faunas in early Pleistocene. *Quat. Res.* (*Daiyonki Kenkyu*), **9**, 158–163.*
KATO, Y. (1957): Geologic structure of the area surrounding the southern end of the Yoro Range

and the building of the Suzuka Range. *Jour. Geol. Soc. Japan*, **63**, 475–484.*

KAWAI, N., YASKAWA, K., NAKAJIMA, T., TORII, M. and HORIE, S. (1972): Oscilating geomagnetic field with a recurring reversal discovered from Lake Biwa. *Proc. Japan Acad.*, **48**, 186–190.

KOBAYASHI, Y. (1977): Comments. *Monograph*, (20), *Assoc. Geol. Collab. Japan*, 239.**

KOBAYASHI, Y. and NAKAMURA, K. (1978): Restoration of tectonic stress field of Tertiary southwest Japan by means of Dikes. Abst. G.D.P. (Tokyo), 86.

KOBAYASHI, Y. (1979): Late Neogene dike swarms and regional stress field in the Inner belt of southwest Japan. *Bull. Volc. Soc. Japan*, **24**, 153–168.*

KOBIWAKO RESEARCH GROUP (1977): The Kobiwako Group in the western part of Minakuchi Hills, Shiga Prefecture, Japan. *Chikyu Kagaku (Earth Science)*, **31**, 115–129.*

KUWAHARA, T. (1968): The Noobi Plain and its fault block movements. *Quat. Res. (Daiyonki Kenkyu)*, **7**, 235–247.*

KUWAHARA, T. (1969): The Ise Bay- Sedimentary basin in the Environs of Ise Bay and Neotectonics in Southwest Japan. *Symposium Kaigan Heiya (Symposium on Coastal Plain)*, 21–30, Geol. Soc. Japan.**

KUWAHARA, T. (1971): Note on the neotectonics of the southwest Japan. *Jour. Res. Group Quat. Japan "Daishiki" (The Quaternary)*, (16), 93–105.**

MAENAKA, K., YOKOYAMA, T. and ISHIDA, S. (1977): Paleomagnetic stratigraphy and biostratigraphy of the Plio-Pleistocene in the Kinki district, Japan. *Quat. Res.*, **7**, 341–362.

MAKINOUCHI, T. (1975a): The Tokoname Group in the southern part of the Chita Peninsula, central Japan. *Jour. Geol. Soc. Japan*, **81**, 67–80.*

MAKINOUCHI, T. (1975b): The Taketoyo Formation in the southern part of the Chita Peninsula, central Japan. *Jour. Geol. Soc. Japan*, **81**, 185–196.*

MAKINOUCHI, T. (1976): Geologic structures of the southern part of the Chita Peninsula and tectonic movements around the Ise Bay, central Japan. *Jour, Geol. Soc. Japan*, **82**, 311–325.*

MAKINOUCHI, T. (1979): Chita Movements, the tectonic movements preceding the Quaternary Rokko and Sanage Movements. *Mem. Fac. Sci. Kyoto Univ., Geol. Mineral.*, **46**, 61–106.

MAKINOUCHI, T., DANHARA, T. and ISODA, K. (1983): Fission track ages of the Tokai Group and associate formations in the east coast of Ise Bay and their significance in geohistory. *Jour. Geol. Soc. Japan*, **89**, 257–270.*

MAKIYAMA, J. (1938): Japonic proboscidea. *Mem. Coll. Sci. Kyoto Imperial Univ.*, **14**, 1–59.

MAKIYAMA, J. (1950): *Chubu-chiho (central Japan), Regional Geology of Japan.* 233 pp, Asakura-Shoten, Tokyo.**

MAKIYAMA, J. (1956): Cyclic nepton group of Kinki area, Japan. *Mem. Coll. Sci. Univ. Kyoto*, **23**, 169–177.

MANKINEN, E. A. and DALRYMPLE, G. B. (1979): Revised geomagnetic polarity time scale for the interval 0–5 my. BP. *Jour. Geophys. Res.*, **84**, 615–626.

MATSUDA, T., NAKAMURA, K. and SUGIMURA, A. (1978): Active fault and neotectonics —acculation of crustal deformation. In *Tectonic movement of the earth— Present and Quaternary*, ed. K. Kasahara and A. Sugimura, *Earth Science*, **10**, Iwanami Shoten Tokyo, 89–157.**

MATSUI, H. (1943): On the geology in the environs of Yokkaichi and Kuwana, Mie Prefecture. *Sci. Rep. Kyoto Univ.*, (B), **2**, 1–11.**

MATSUI, H. (1966): Transporting directions of sediments of the Kuragari Formation. *Prof. Susumu Matsushita Mem. Vol.*, 89–95.*

MATSUZAWA, I., KATO, Y., KUWAHARA, T., KIMURA, T., UEMURA, T. and TSUZUKI, Y. (1960): *Geology of southwestern areas of Sanageyama*, 35 pp, Aichi Prefecture.**

MIKI, S. (1948): Floral remains in Kinki and adjacent district since the Pliocene with descriptions 8 new species. *Kobutsu to Chishitsu (Mineralogy and Geology)*, **9**, 105–144.*

MIYAMURA, M., MIMURA, K. and YOKOYAMA, T. (1976): *Geology of the Hikonotobu district.* Quadrangle Ser., Kyoto (11), No. 18, Geol. Surv. Japan.*

MIYAMURA, M., YOSHIDA, F., YAMADA, N., SATO, T. and SANGAWA, A. (1981): *Geology of the Kameyama*

District. Quadrangle Ser., Kyoto (11), No. 42, Geol. Surv. Japan.*

MORI, I. (1974): Plio-Pleistocene sediments in the area of the Yoro Mountains. *Nagoya Chigaku*, **30**, 16–26.**

MORI, I., KIMURA, I., YAMADA, J. and TAKEHARA, H. (1977): The tectonic and geomorphic development of the west coast of Ise Bay. *Mem. Geol. Soc. Japan*, (14), 185–194.*

MORI, S. (1971a): The Yadagawa Formation of the Seto Group in the east of Nagoya City, Aichi Prefecture. *Jour. Geol. Soc. Japan*, **77**, 635–644.*

MORI, S. (1971b): Some volcanic ash layers in the Seto and Age Groups. Researches on the Seto Group, part 3. *Prof. Heiichi Takehara Mem. Vol.*, 99–111.*

MORI, Y. and KIMURA, I. (1973): Tephrochronology of the Plio-Pleistocene in Inabe district, Mie Prefecture. *Nagoya Chigaku*, **28–29**, 26–33.**

NAKAMURA, K. (1977): Volcanoes as possible indicators of tectonic stress orientation — principle and proposal. *Jour. Volcanol. Geotherm. Res.*, **2**, 1–16.

NISHIDA, J. and ISHIDA, S. (1975): Paleomagnetic study of the Osaka Group using marine and nonmarine clays near Komyoike, Osaka Prefecture. *Rock Mag. Paleogeophus.*, **3**, 32–35.

NISHIKAWA, K., NISHIBORI, T., KOBAYAKAWA, T., TAJIMA, T. and YOKOYAMA, T. (1979): On the gravel beds, Pre-Kobiwako Group found at high land of Suzuka Mountains and in basins of Kobiwako Group. *Land and Life in Shiga*, 301–308.*

NISHIMURA, S. and SASAJIMA, S. (1970): Fission-track age of volcanic ash layers of the Plio-Pleistocene series in Kinki district, Japan. *Chikyu Kagaku (Earth Science)*, **24**, 222–224.

NISHIMURA, S. and YOKOYAMA, T. (1973): Fission-track ages of volcanic ashes in 200 m core sample of Lake Biwa. *Proc. Japan Acad.*, **49**, 615–618.

NISHIMURA, S. and YOKOYAMA, T. (1975): Fission-track ages of volcanic ashes of core samples of Lake Biwa and the Kobiwako Group (2). In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **3**, 138–142.

OGAWA, T. (1919): Tertiary strata of Ise. *Shimazu-jiho*, **6**.**

OTOFUJI, Y., MAKINOUCHI, T. and NISHIDA, J. (1975): Preliminary report on magnetostratigraphy of Tokoname Group in Chita Peninsula. *Rock Mag. Paleogeophys.*, **3**, 36–40.

OSE, T. (1929): Topography and geology of the Chita Peninsula. *Jour. Geogr.*, **41**, 338–345.*

SUZUKI, K., HOSONO, M., KUBO, K. and NAKASEKO, K. (1947): Coal-bearing Tertiary in the area of the Seki-cho, Mie Prefecture. *Jour. Geol. Soc. Japan*, **53**, 89–90.**

SUZUKI, K., HOSONO, M. and KUBO, K. (1948): Coal-bearing Tertiary in the area of the Seki-cho, Suzuka-gun, Mie Prefecture. *Jour. Geol. Soc. Japan*, **54**, 50–55.*

TAKAYA, Y. (1963): Stratigraphy of the Paleo-Biwa Group and the paleogeography of Lake Biwa with special reference to the origin of the endemic species in Lake Biwa. *Mem. Coll. Sci. Univ. Kyoto*, **30**, 81–118.

TAKEHARA, H. (1961): Stratigraphy of the Agé Group, northern Mie Prefecture, Japan. *Prof. Jiro Makiyama Mem. Vol.*, 45–50.*

TAKEHARA, H. (1966): Geology of the west hilly land near Yokkaichi City on the west coast of Ise Bay, central Japan. *Prof. Susumu Matsushita Mem. Vol.*, 83–87.*

TAKEMURA, K., NISHIMURA, S., DANHARA, T. and YOKOYAMA, T. (1976): Properties and fission-track age of volcanic ashes in the 1,000 m core sample of Lake Biwa with special reference to correlation by tephra among the 1,000 m, 200 m boring core samples of Lake Biwa and the Kobiwako Group. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **4**, ed. S. Horie, 70–95.

TAKEMURA, K. (1978): Stratigraphy of the Plio-Pleistocene Agé Group in the northern part of Mie Prefecture. *Master thesis of Kyoto University*, 152 pp.

TAKEMURA, K. and TORII, M. (1978): Magnetostratigraphy of the Plio-Pleistocene Agé Group in the northern part of Mie Prefecture, Japan. *Rock Mag. Paleogeophys.*, **5**, 69–72.

TAKEMURA, K., IIDA, Y. and YOKOYAMA, T. (1979): Mineral composition and origin of sand grains in the 1,000 m core sample and at the coast and river around Lake Biwa, Japan. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **7**, ed. S. Horie, 78–99.

TAKEMURA, K. (1984): The Pliocene-Pleistocene Tokai Group in Inabe area, Mie Prefecture, central

Japan, with special reference to the relationship between lithostratigraphy and tephrostratigraphy. *Jour. Geol. Soc. Japan*, **90**, 799–813.*

TAKEUCHI, A. (1980): Tertiary stress field and tectonic development of the southern part of the Northeast Honshu Arc, Japan. *Jour. Geosci. Osaka City Univ.*, **23**, 1–64.

TAKIMOTO, K. (1935): The Cenozoic strata in the Isshi district, Ise Province. *Chikyu*, **23**, 326–338.*

TAMURA, M., MATSUOKA, C. and YOKOYAMA, T. (1977): Stratigraphy of the Gamo Formation of Plio-Pleistocene Kobiwako Group in the northern hills of Minakuchi-cho, south of Lake Biwa, central Japan. *Jour. Geol. Soc. Japan*, **83**, 749–762.*

TORII, M., YOSHIKAWA, S. and ITIHARA, M. (1974): Paleomagnetism on the water-laid volcanic ash layers in the Osaka Group, Sennan and Senpoku hills, southwestern Japan. *Rockmag. Paleogeophys.* **2**, 34–37.

WADA, Y. (1982): The Agé Group in the vicinity of Kameyama City, Mie Prefecture, central Japan. *Jour. Geol. Soc. Japan*, **88**, 121–139.*

YASUDA, T. (1957): The fossil plants of the Neogene strata in the North Ise area, Mie Prefecture. *Nagoya Chigaku*, **11**.**

YOKOYAMA, T. (1968): Transition of Paleo-Lake Biwa during the Pliocene deduced from paleocurrent directions and other sedimentological features of sandy facies in the Kobiwako Group, central Japan. —The research of younger Cenozoic strata in Kinki province, part 11—. *Jour. Geol. Soc. Japan*, **74**, 623–632.*

YOKOYAMA, T. (1969): Tephrochronology and paleogeography of the Plio-Pleistocene in the eastern Setouchi geologic province, southwest Japan. *Mem. Fac. Sci. Kyoto Univ., Geol. Mineral.*, **36**, 19–85.

YOKOYAMA, T. (1971): Upheaval of the Suzuka Range (1), with special reference to the stratigraphy of the Plio-Pleistocene series in northern Mie Prefecture, central Japan —The research of younger Cenozoic strata in Kinki district, part 19—. *Prof. Heiichi Takehara Mem. Vol.*, 55–67.*

YOKOYAMA, T. (1973): An outline of Quaternary system around Lake Biwa-ko and geologic observations of 200 m core sample obtained from that lake, with special reference to mineralogic analysis of volcanic ash layers found in the core sample. *Japan Jour. Limnol.*, **34**, 111–118.*

YOKOYAMA, T. (1975): Plio-Pliestocene Kobiwako Group on the west coast of Lake Biwa with special reference to correlation to the 200 m core sample of Lake Biwa by tephra. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **3**, ed. S. Horie, 114–137.

YOKOYAMA, T., NAKAGAWA, Y., MAKINOUCHI, T. and ISHIDA, S. (1977b): Subdivision of Plio-Pleistocene in Kinki and Tokai district, Japan. *Proc. First CPNS.* 408–412.

YOKOYAMA, T., DANHARA, T., KOBATA, Y. and NISHIMURA, S. (1977a): Fission-track ages of volcanic ashes of core samples of Lake Biwa and the Kobiwako Group (3). In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **5**, ed. S. Horie, 44–53.

YOKOYAMA, T., TAKEMURA, K., IKEDA, T. and MAKINOUCHI, T. (1978): Contents of trace elements in volcanic pumice grains and volcanic ashes by neutron activation analysis. *Tsukumo Chigaku*, (13), 16–28.**

YOKOYAMA, T. (1979): Tectonic development of the Nanko Basin, southern part of Lake Biwa. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **7**, ed. S. Horie, 115–134.

YOKOYAMA, T., MATSUOKA, C., TAMURA, M. and AMEMORI, K. (1979): On the Kobiwako Group. *Land and Life in Shiga*, 309–389.*

YOKOYAMA, T. and HAYASHIDA, A. (1979): Recent problems on magnetostratigraphy of the Osaka Group, typical Plio-Pleistocene in Japan. *Tsukumo Chigaku*, (15), 68–76.**

YOKOYAMA, T., MAKINOUCHI, T., TAKEMURA, K., HAYASHIDA, A., SANNOMIYA, T. and YAMAMURA, H. (1980a): Stratigraphy of the Pliocene Iga-Aburahi Formation of the Kobiwako Group in the east of Iga-Ueno City, Mie Prefecture. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, **8**, ed. S. Horie, 45–64.

YOKOYAMA, T., MATSUDA, T. and TAKEMURA, K. (1980b): Fission-track ages of volcanic ashes in the Tokai Group, central Japan (I). *Quaternary Res. (Daiyonki Kenkyu)*, **19**, 301–309.*

YOKOYAMA, T., NAKAGAWA, Y., DANHARA, T., and TAKEMURA, K. (1980c): On the Shiba Uncon-

formity (I). Discovery and significance of clino-unconformity between Pliocene and Pleistocene sediments in the Osaka Group, central Japan. *Sci. Eng. Rev. Doshisha Univ.*, **21**, 61–80.*
YOKOYAMA, T. (1984): Stratigraphy of the Quaternary System around Lake Biwa and geohistory of the ancient Lake Biwa. In *Lake Biwa*, ed. S. Horie, The Hague, Dr.W. Junk, 43–128.
* in Japanese with English abstract
** in Japanese