

Stratigraphy and Paleogeography of the Upper Cenozoic Tokai Group around the East Coast of Ise Bay, Central Japan

Katsuhiro NAKAYAMA*

(With 37 Figures and 3 Tables)

Abstract

The Upper Cenozoic Tokai Group, one of the units representative fluvio-lacustrine sediments in Japan, is distributed around Ise Bay. The east coast of the bay is an important area for the study of intra-arc events during the Late Cenozoic in Japan. This paper provides the litho-, tephro-, magneto-, and biostratigraphy of the group. On the basis of these descriptions as well as on sedimentological and structural data, the paleogeography of the group is reconstructed.

The Tokai Group around the east coast of Ise Bay has been geographically divided into "the Seto and Tokoname Groups." "The Seto Group" is further divided into the Seto Porcelain Clay and Yadagawa Formations, and is 250 m in maximum thickness. "The Tokoname Group," with thickness of 770 m, is divided into the Toyooka, Ko(u)wa, and Futto Formations in ascending order. At least 14 and 28 volcanic ash layers occur within "the Seto and Tokoname Groups," respectively. Seven of these volcanic ash layers can be correlated between the groups. Biostratigraphy contains the TB1, TB2, and TB3 biozones in ascending order. The plant fossil assemblage of the TB1 and TB2 biozones suggests a warm climate, but one of the TB1 biozone is dominated by extinct genera and species. The assemblage of the TB3 biozone suggests a cooling climate with a high annual range of temperature. Magnetostratigraphy is the TO-A Reverse, TO-B Normal, TO-C Reverse, TO-D Normal, and TS-E Normal Magnetopolarity Zones in descending order. From these stratigraphical data, it is concluded that the Seto Porcelain Clay Formation was deposited over a period of about 1 m.y. at about 9 Ma. The other parts of the Tokai Group around the east coast of Ise Bay were deposited between 7.0 and 1.9 Ma.

Paleogeography can be explained by block movements, and changes in river systems. The paleogeography of the Tokai Group around the east coast is reconstructed by recognition of 4 stages; stage I (9.0-8.0 Ma ?), stage II (7.0-4.3 Ma), stage III (4.3-3.1 Ma), and stage IV (3.1-1.9 Ma). In stage I, fine clastics were deposited in very small collapse basins of less than 4 km² in area. River systems were poorly developed. From stage II to stage IV, sediments were transported by the Mikawawan, Toyota, and Komaki River Systems. These systems were controlled by small basement blocks about 30-80 km² in area. The Sanage-Chita Uplift Zone, which is the most remarkable structure in the east coast of Ise Bay, consists of 7 small basement blocks. This zone is regarded as two structural units such as the Sanage Uplift Zone and the Chita Uplift Zone. The movement of the Chita Uplift Zone was more rapid than that of the Sanage Uplift Zone.

Generally, each Late Cenozoic intra-arc basin in Southwest Japan comprise several blocks of basement rocks. Movement of the blocks played an important role in sedimentation. Block movement accelerated during the Late Cenozoic.

Key Words: stratigraphy, paleogeography, Late Cenozoic, Tokai Group, block movement, sedimentary basin

Contents

	Page
1. Introduction	78
2. Historical review	80
3. Geological and geographical outline	81

* Department of Geology, Faculty of Science, Shimane University, Nishikawazu-cho 1060, Matsue 690, Japan

4. Stratigraphy -----	82
4.1. Lithostratigraphy -----	82
4.2. Tephrostratigraphy -----	105
4.3. Magnetostratigraphy -----	105
4.4. Biostratigraphy -----	109
4.5. Summary of stratigraphy -----	110
4.6. Stage units -----	114
5. Some sedimentological data -----	114
5.1. Features of gravel -----	114
5.2. Paleocurrent directions -----	121
5.3. Distribution of particular fragments -----	122
6. Geological structure -----	123
6.1. Geological structure of the Seto Group -----	124
6.2. Geological structure of the Tokoname Group -----	124
7. Discussion -----	124
7.1. Stratigraphical position -----	124
7.2. Structural movement -----	129
7.3. Paleogeography -----	134
8. Conclusions -----	139
Acknowledgments -----	140
References -----	140

1. Introduction

Upper Miocene to Lower Pleistocene sediments are widely distributed around Ise Bay in Central Japan. They are named the Tokai Group (ISHIDA & YOKOYAMA, 1969; NAKAYAMA & TODO COLLABORATIVE RESEARCH GROUP, 1989b). In the Kinki district, sediments correlative with the Tokai Group are called the Osaka Group (OSAKA GROUP RESEARCH GROUP, 1951) and the Kobiwako Group (NAKAMURA, 1929), as shown in Fig. 1. The Tokai, Kobiwako, and Osaka Groups constitute the Second Setouchi Supergroup (IKEBE, 1957). The sedimentary basins of the supergroup are typical intra-arc basins. Detailed stratigraphy of the Osaka and Kobiwako Groups and of the Tokai Group around the west coast of Ise Bay has been established (ITIHARA *et al.*, 1984; ITIHARA *et al.*, 1988; KAWABE, 1989; YOSHIDA, 1990). However, less is known about the stratigraphy of the Tokai Group around the east coast of Ise Bay, especially in the northern part of the east coast, due to insufficient sedimentological and structural data. The Tokai Group around the east coast of Ise Bay is faulted and flexured, with the Sanage-Chita Uplift Zone (ADACHI & KUWAHARA, 1981) being the most remarkable geological structure. However, the relationship between it and individual structural elements, such as faults and flexures, has not been documented. In this paper, I establish the detailed stratigraphy of the Tokai Group around the east coast of Ise Bay using litho-, tephro-, magneto-, and biostratigraphy, and then use this stratigraphy, along with sedimentological and tectonic evidence, to reconstruct the paleogeography.

The Tokai Group around the east coast of Ise Bay forms the eastern part of the supergroup, where it is close to the marine Upper Cenozoic fore-arc basins in the Kakegawa and Miura-Boso areas (Fig. 1). Such stratigraphical and tectonic

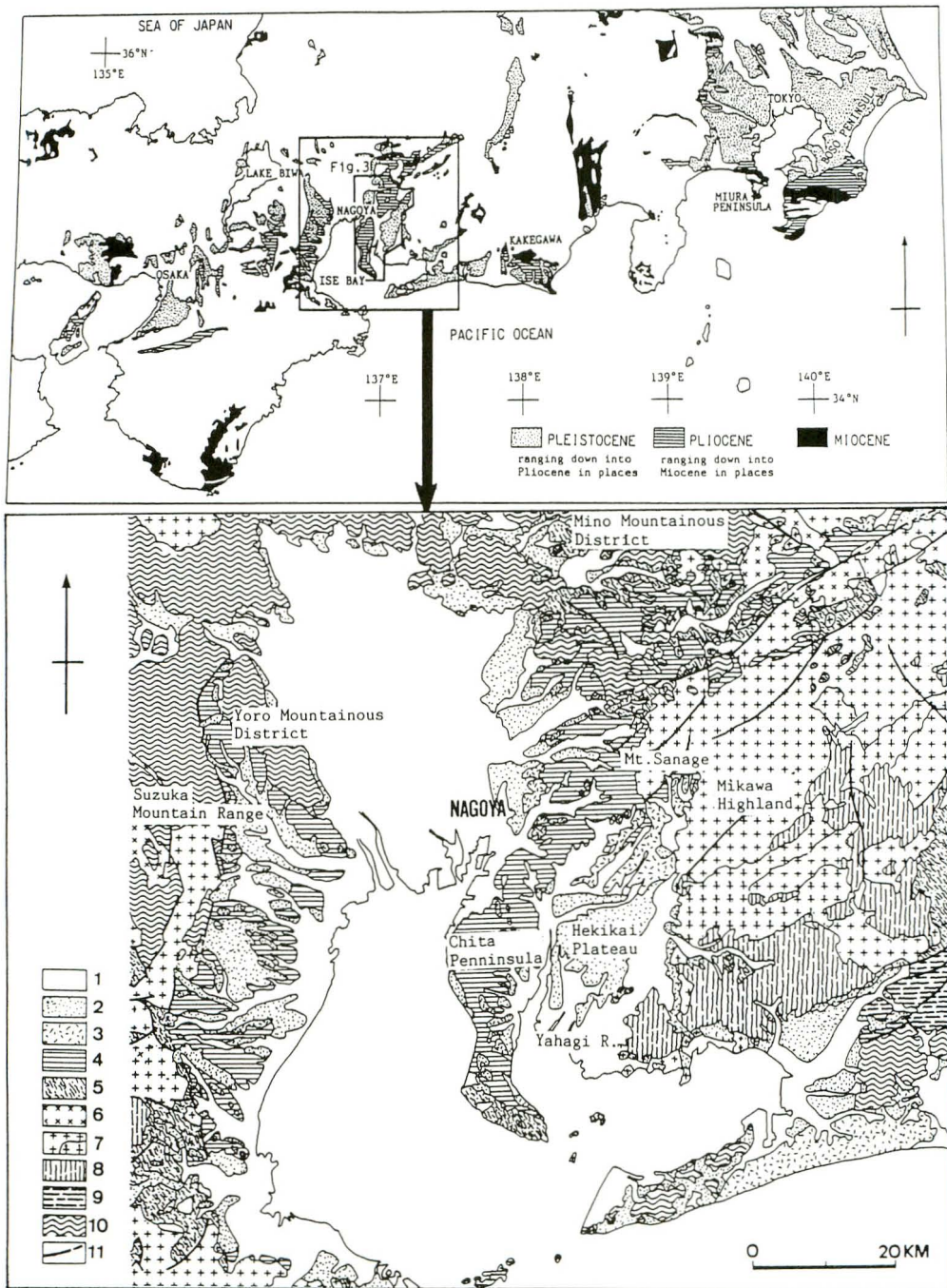


Fig. 1. Distribution of the Plio-Pleistocene in Central Japan (after HIROKAWA *et al.*, 1978), and a geological sketch map around Ise Bay (partly modified from TANAKA *et al.*, 1982).

1: Holocene deposits, 2: Low terrace deposits, 3: Middle-High terrace deposits, 4: Tokai Group, 5–10: Basement rocks of the Tokai Group, 5: Lower-Middle Miocene formations, 6: Rhyolites, 7: Ryoke granitic rocks (dot-added area: Busetsu granite), 8: Ryoke metamorphic rocks, 9: Sanbagawa metamorphic rocks, 10: Mesozoic-Paleozoic formations, 11: Faults.

relationships between marine and nonmarine sequences are important for clarifying geological events during the Late Cenozoic.

2. Historical review

The Tokai Group is distributed in the northern part of the east coast of Ise Bay, in Chita Peninsula, and around the west coast of Ise Bay (Fig. 1). For these three locations, the following local names are customarily used: "the Seto Group" for the first area (MAKIYAMA, 1950), "the Tokoname Group" for the second (OSE, 1929), and "the Age Group" for the third (OGAWA, 1919, 1920), and I use these three names in the local descriptions. Because division into formation has been based on those three groups.

The Seto Group was studied first by MAKIYAMA (1950). MATSUZAWA *et al.* (1960) clarified its distribution and lithofacies in the area from eastern Nagoya to Fujioka-cho, and divided the group into the Seto Porcelain Clay Formation and the overlying Yadagawa Formation. MORI (1971b) studied the stratigraphy of the Yadagawa Formation and subdivided it into the Mizuno, Takabari, and Idaka Members in ascending order. NAKAYAMA (1987) further subdivided the Mizuno Member into the Fujioka and Nisshin Members in ascending order. In addition, the KOMAKI RESEARCH GROUP (1971) and SAKAMOTO *et al.* (1984) confirmed the regional stratigraphy of the group. The Seto Group, however, is still uncertain in some areas.

As for the Tokoname Group, OSE (1929) was first to study it. In the southern Chita Peninsula, MAKINOCHI (1975) divided it into the Toyooka, Ko(u)wa, and Futto Formations in ascending order. In the northern Chita Peninsula, YOSHIDA & OZAKI (1986) divided the group into the Lower Tokoname and Upper Tokoname Formations. MAKINOCHI (1988) confirmed that the group in the northern Chita Peninsula consisted of the Futto Formation, and divided the whole group into the Toyooka, Ko(u)wa, and Futto Formations in ascending order, and subdivided the Futto Formation into lower and upper parts. Both parts of the Futto Formation are the same as the Lower and Upper Tokoname Formations of YOSHIDA & OZAKI (1986).

The Age Group on the west coast of Ise Bay can be separately described as an upper part in the Hokusei area and a lower part in the Chusei area. The Age Group in the Hokusei area has been studied by YOKOYAMA (1971), MIYAMURA *et al.* (1976), YOSHIDA (1988), MORI & KIMURA (1973) and TAKEMURA (1983, 1984). These studies divided the group into the Biroku, Kono, Ichinohara, Ohizumi, and Komeno Formations in ascending order. The Age Group in Chusei area was studied by MIYAMURA *et al.* (1981), WADA (1982), and YOSHIDA (1987). These studies divided the group into the Saigyodani, Kusuhara, Kameyama, and Sakuramura Formations in ascending order.

Volcanic ash layers have been described by MORI (1971a), NAKAYAMA & FURUSAWA (1989), and YOSHIKAWA *et al.* (1991). Paleomagnetic investigations were started by ISHIDA *et al.* (1969). OTOFUJI *et al.* (1975) measured remanent magnetization of

volcanic ash in the lower part of the Tokoname Group, and TAKEMURA & TORII (1978) carried out similar measurements for the Age Group in the Hokusei area. NAKAYAMA & YOSHIKAWA (1990) established the magnetostratigraphy of the Tokai Group, using tephrostratigraphy and correlation. Numerous plant remains from the Tokai Group around the east coast of Ise Bay were identified by MIKI (1948, 1963), and ONOE *et al.* (1986). The pollen record was investigated by YOSHINO (1971). NASU (1972) established the biostratigraphy of the Second Setouchi Supergroup, using previous published data and his own observations. These various stratigraphical studies have not been synthesized.

As for paleogeographical studies, KUWAHARA (1975) and ADACHI & KUWAHARA (1980) presented the Sanage-Chita Uplift Zone and published a significant paleogeographical map. However, in order to rigorously determine the paleogeography, a detailed knowledge of the stratigraphy is needed, along with sedimentological and tectonic data. Previous paleogeographical maps did not clarify the relationship between movements and geological structures such as faults and flexures.

The Late Cenozoic tectonic development of Southwest Japan has been discussed by HUZITA (1983), FUJITA (1990), SUGIYAMA (1992), YOSHIDA (1992), and others. They suggested various models, none of which was based on the detailed geology of the Tokai Group in this study area.

3. Geological and geographical outline

The study area around Ise Bay is bordered to the west by the Suzuka Mountains (800–1200 m in height), the Mikawa Highland (600–1000 m) to the east, and the Mino Massif (greater 300 m) to the north. In the northwestern part of the area, the Yoro Mountains (600–800 m) run through from northwest to southeast. In the northeastern part of the area, Mt. Sanage (629 m) extends from northeast to southwestward. The Nobi Plain is widespread in the northern part of the area, and hilly land (20–300 m), including the Chita Peninsula, lies widely in eastern part (Fig. 1).

The geology around Ise Bay consists of the basement formations, the overlying Tokai Group, and the Quaternary terrace and alluvial deposits. Figure 2 shows the stratigraphical divisions around Ise Bay.

The basement rocks, which form mountains and highlands, are composed of Mesozoic-Paleozoic formations, Ryoke granitic and metamorphic rocks, Nohi rhyolites, and Early to Middle Miocene formations. The Mesozoic-Paleozoic formations have been partly altered to hornfels.

The Tokai Group includes the Seto, Tokoname, and Age Groups which are distributed in different parts of the area. The Seto Group is divided into the Seto Porcelain Clay Formation and the overlying Yadagawa Formation, the latter comprising the Fujioka, Nisshin, Takabari, and Idaka Members (NAKAYAMA 1987). The group reaches 250 m in thickness, and intercalates at least 14 volcanic ash layers. The Tokoname Group, 770 m thick, is divided into the Toyooka, Ko(u)wa

		West Coast of Ise Bay		East Coast of Ise Bay	
		Hokusei	Chusei	Chita Penin.	Owari Hill
Holocene		alluvium	alluvium	alluvium	alluvium
Pleistocene	LP.	Sakabe F. Mitachi F.	Hisai F.	Toya F. Yanashi F.	Toriimatsu Gr. Atsuta F.
	MP.	Rengeji F.	Morotoyama Gr. Kentoyama F.	Noma F.	Shiomizaki Gr. Momoyama F.
	EP.			Kagiya F.	Yagoto F.
		Komeno F.		Taketoyo F.	Karayama F.
		Ohizumi F.			
Pliocene		Kuragari F.	Sakura- mura F.	Tomari F.	
		Ichinohara F.			
		Kono F.		Futto F. (upper)	Idaka M.
		Biroku F.	Kameyama F.	Futto F. (lower)	Takabari M.
					Nisshin M.
Late Miocene		Saigyodani Gravel F.		Kowa F.	
			Kusuhara F.		Fujioka M.
			Koyama Gravel F.	Toyooka F.	
					Seto Porcelain Clay F.
Early- Middle Miocene		Chigusa G.	Ichishi G. Suzuka G.	Morozaki G.	Mizunami G. Shinano F.
Pre- Neogene		Ryoke granitic ricks, Ryoke metamorphic rocks, Mesozoic-Paleozoic formation			

LP.: Late Pleistocene, MP.: Middle Pleistocene, EP.: Early Pleistocene, G.: Group, F.: Formation, M.: Member, Gr.: gravel bed

Fig. 2. Geological system around Ise Bay. Dotted area shows the Tokai Group.

The local names of the Tokai Group are customarily used: "the Seto Group" for the Owari Hill area (the northern part of the east coast of Ise Bay), "the Tokoname Group" for the Chita Peninsula area, and "the Age Group" for the area around the west coast of Ise Bay.

and Futto Formations in ascending order (MAKINOUCHI, 1988). At least 28 volcanic ash layers are present. The Age Group in the Hokusei area reaches over 1000 m in thickness, with at least 30 intercalated volcanic ash layers. The Age Group in the Chusei area is over 1200 m in maximum thickness, and contains at least 22 volcanic ash layers.

4. Stratigraphy

4.1. Lithostratigraphy

The lithostratigraphy of the Tokai Group around the east coast of Ise Bay is

described separately for the Seto and Tokoname Groups. Sketches of the geology and columnar sections are shown in Fig. 3 and Fig. 4, respectively.

4.1.1. Lithostratigraphy of the Seto Group

The Seto Group is found in the Owariasahi-Seto area (where the Seto Porcelain Clay Formation is widely distributed), the Komaki-Kasugai area (where the Seto Porcelain Clay Formation is absent), and the Fujioka-Nisshin area (where the group is the thinnest). Geology, geological cross sections, location map, and columnar sections for each area are shown in Figs. 5–16, and Fig. 17 shows the geology of southeastern Nagoya.

Seto Porcelain Clay Formation (MATSUZAWA *et al.*, 1960)

Type locality: In this paper, I set the type locality at Marufuji mine in Nishiinzo, Seto City (Fa4 in Fig. 10), because the type locality was not defined earlier (MATSUZAWA *et al.*, 1960).

Distribution: The formation occurs in the northern part of Seto City; in Tamomi, Yagusa, Hirohata, Shidare, and Homi of Toyota City; and in Fukami, and Tamomi of Fujioka-cho. It is also present in the sub-surface at Mifune in Toyota City and Sanbongi of Nisshin-cho (C14, C27 in Fig. 14, OTSUKA *et al.*, 1968). Overall, it shows a sporadic distribution restricted to small basins of less than 4 km².

Thickness: 20 m at the type locality, generally 20–30 m; 50 m maximum.

Stratigraphical relations: At the type locality, the formation unconformably overlies the basement granite, and is in turn unconformably overlain by the Yadagawa Formation. Generally, the formation forms the lowermost part of the Seto Group and unconformably overlies basement rocks. The formation abuts against the basement rocks along the periphery of a basin.

Lithofacies: The formation is composed mainly of mud, sand, and lignite beds, along with a few intercalated sandy gravel and gravel beds. The mud beds form porcelain clay beds, called the “Kibushi clay,” in which plant remains are prominent, and the “Gaerome clay” in which numerous quartz grains are visible. The sand beds consist mainly of quartz grains termed “Keisa.” Clasts in sandy gravel beds are generally subrounded to rounded pebbles, and consist mainly of chert derived from the Mesozoic-Paleozoic formations. At the type locality, the formation comprises 4 cycles of quartz grain rich sand and quartz grain dominant mud (Fa4 in Fig. 10). Around Seto City, quartz rich sand beds occur in the southeastern to eastern part of the city, and Kibushi clay and lignite beds are dominant in the northern part, including the type locality. The Nishiinzo volcanic ash layer, found in the middle of the formation in the Seto area, is strongly weathered.

In the Fujioka-Nisshin area, the formation is well exposed at Shidare mine (C06

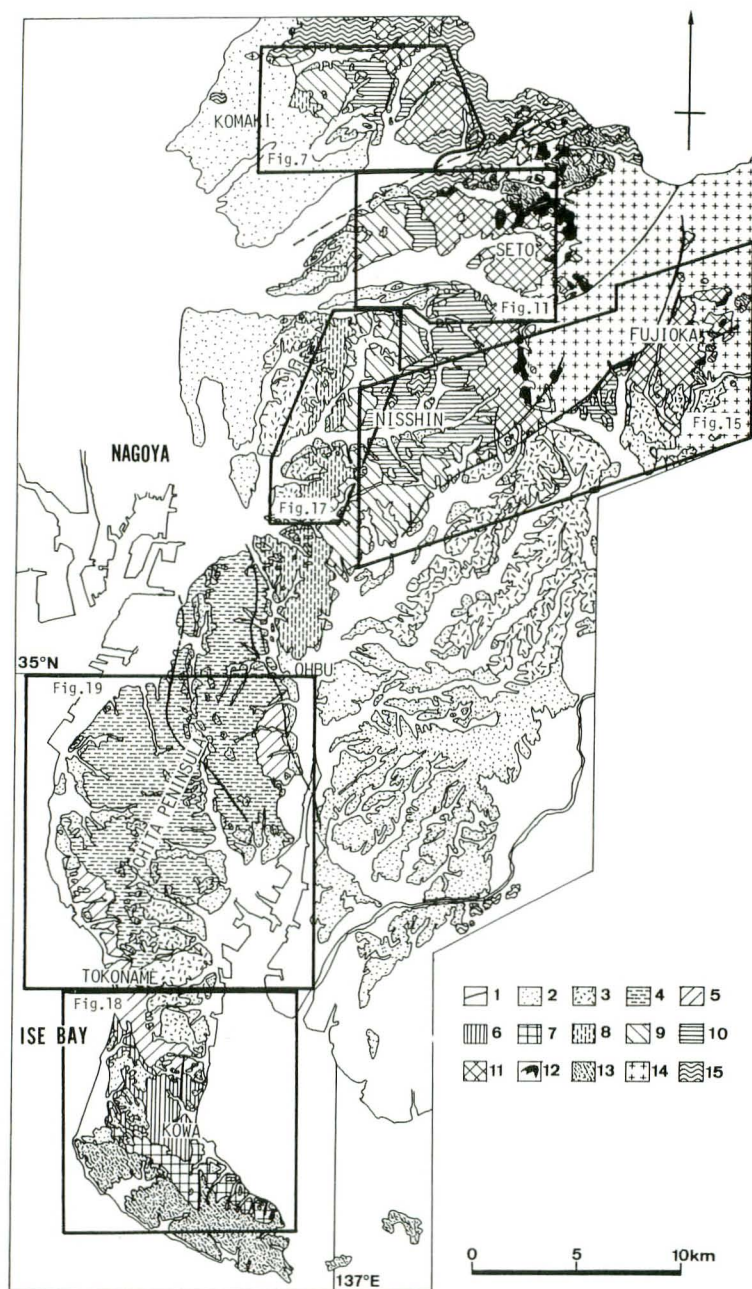
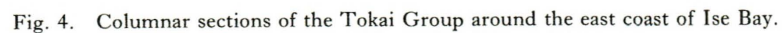


Fig. 3. Geological sketch map of the Tokai Group around the east coast of Ise Bay (after MAKINOCHI & NAKAYAMA, 1990).

1: Fault & flexure, 2: Low terrace deposits, 3: Middle-High terrace deposits, 4-7: Tokoname Group, 4: Futto Formation (upper), 5: Futto Formation (lower), 6: Kowa Formation, 7: Toyooka Formation, 8-12: Seto Group, 8-11: Yadagawa Formation, 8: Idaka Member, 9: Takabari Member, 10: Nisshin Member, 11: Fujioka Member, 12: Seto Porcelain Clay Formation, 13: Lower-Middle Miocene formations, 14: Granitic rocks, 15: Mesozoic-Paleozoic formations.



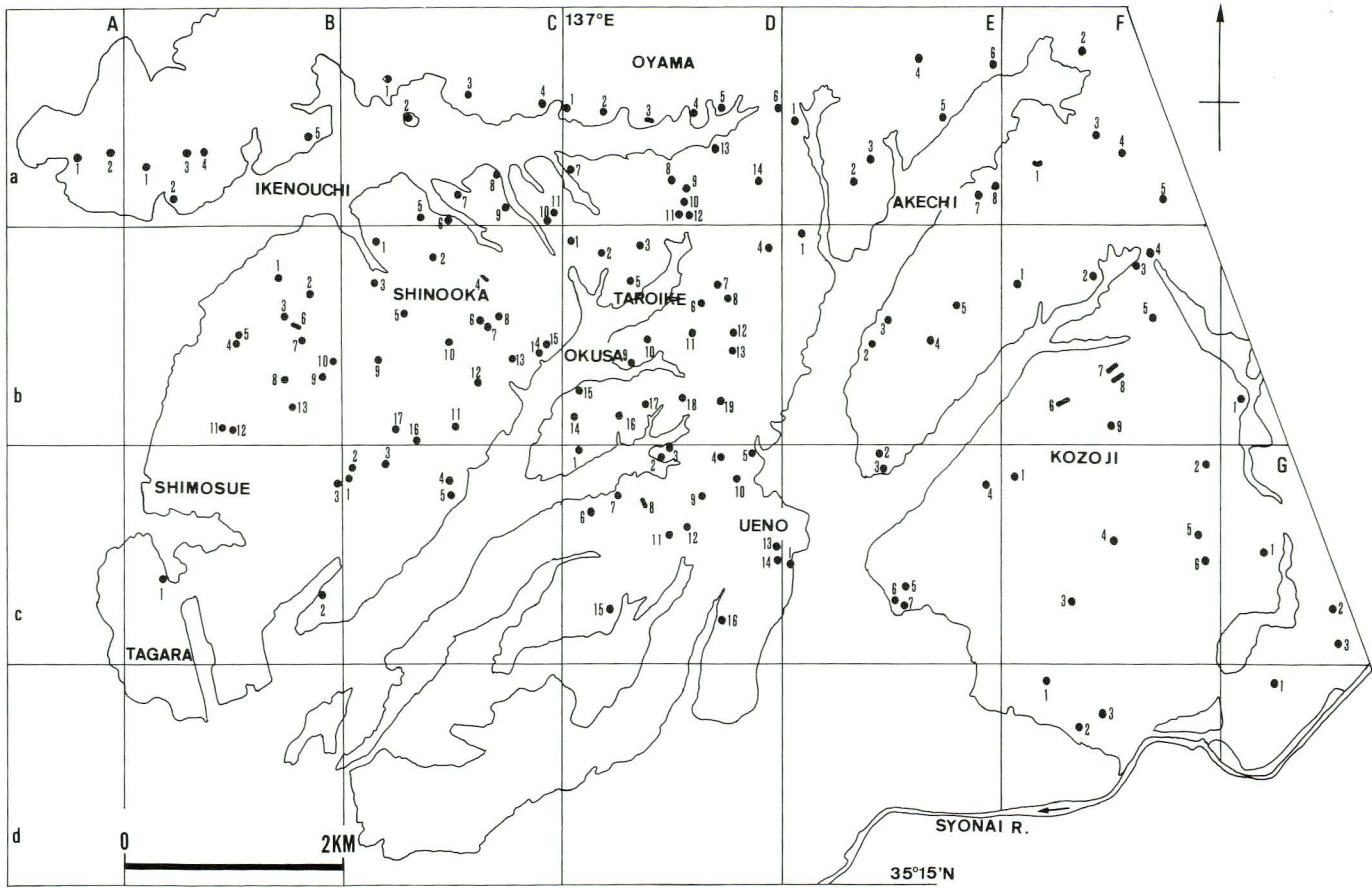


Fig. 5. Locations of columnar sections in the Komaki-Kasugai area (see Fig. 6).

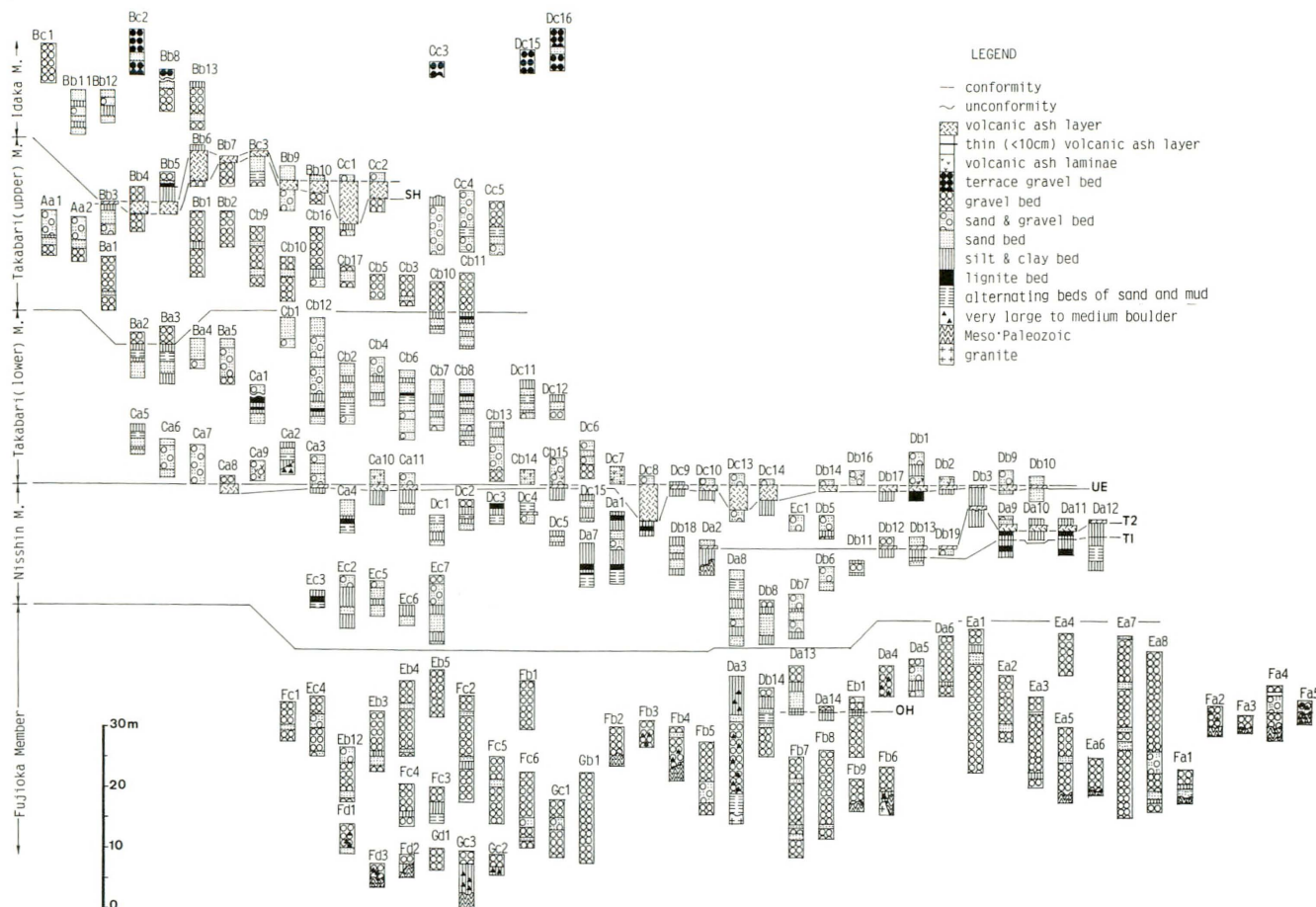


Fig. 6. Columnar sections of the Komaki-Kasugai area.

SH: Shinooka volcanic ash layer, UE: Ueno volcanic ash layer, T2: Taroike 2 volcanic ash layer, T1: Taroike 1 volcanic ash layer, OH: Ohshima volcanic ash layer. See Fig.5 for column locations.

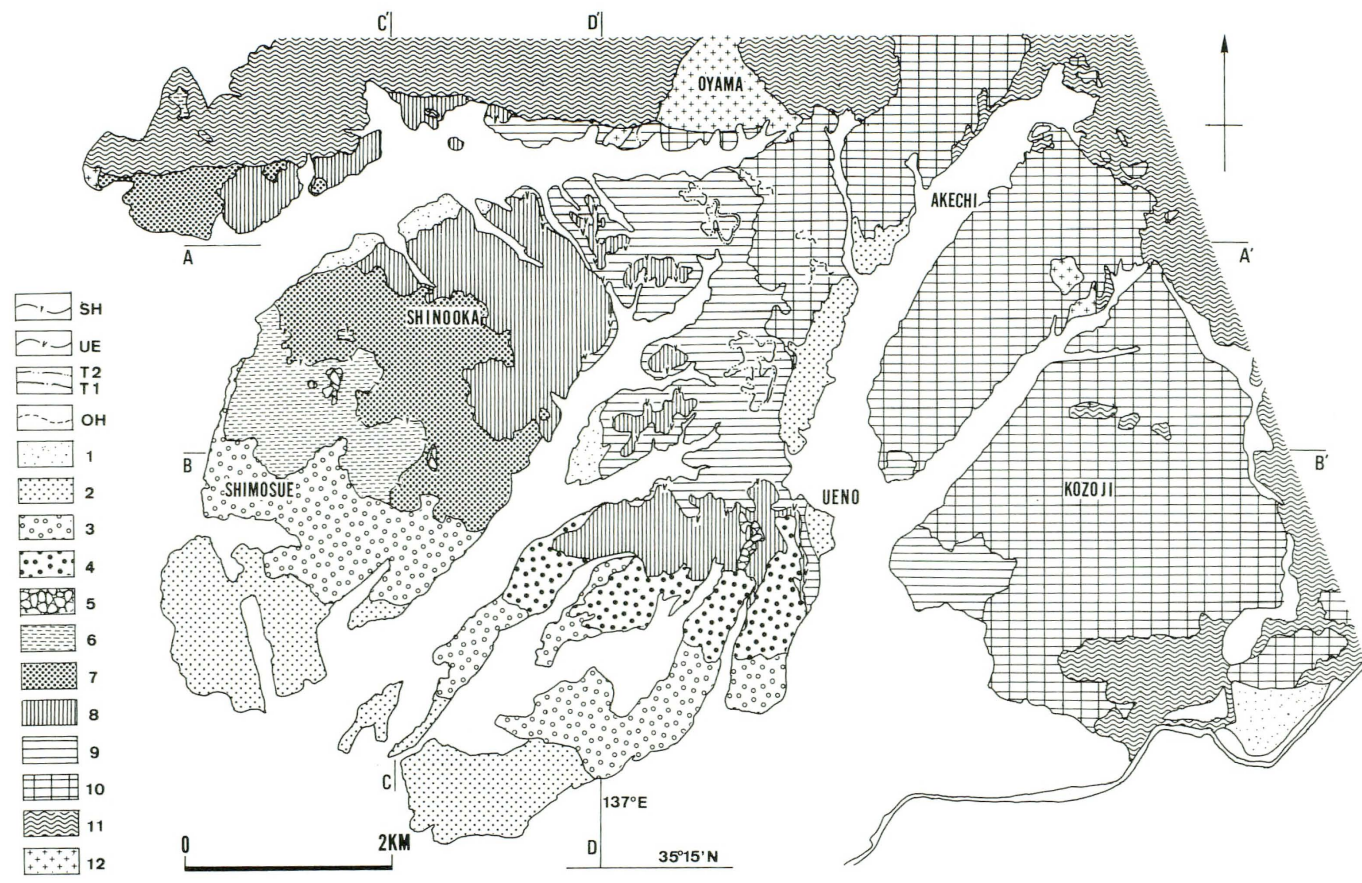


Fig. 7. Geological map of the Komaki-Kasugai area.

1-5: Terrace deposits, 1: Low terrace deposits, 2: Middle terrace deposits (Atsuta Formation), 3-4: High terrace deposits, 3: Momoyama gravel bed, 4: Toukaen gravel bed and Shiomizaka gravel bed, 5: Kamisue Formation, 6-10: Seto Group, 6: Idaka Member, 7: Takabari Member (upper), 8: Takabari Member (lower), 9: Nisshin Member, 10: Fujioka Member, 11: Mesozoic-Paleozoic formations, 12: Granite, SH: Shinooka volcanic ash layer, UE: Ueno volcanic ash layer, T2: Taroike 2 volcanic ash layer, T1: Taroike 1 volcanic ash layer, OH: Ohyama volcanic ash layer.

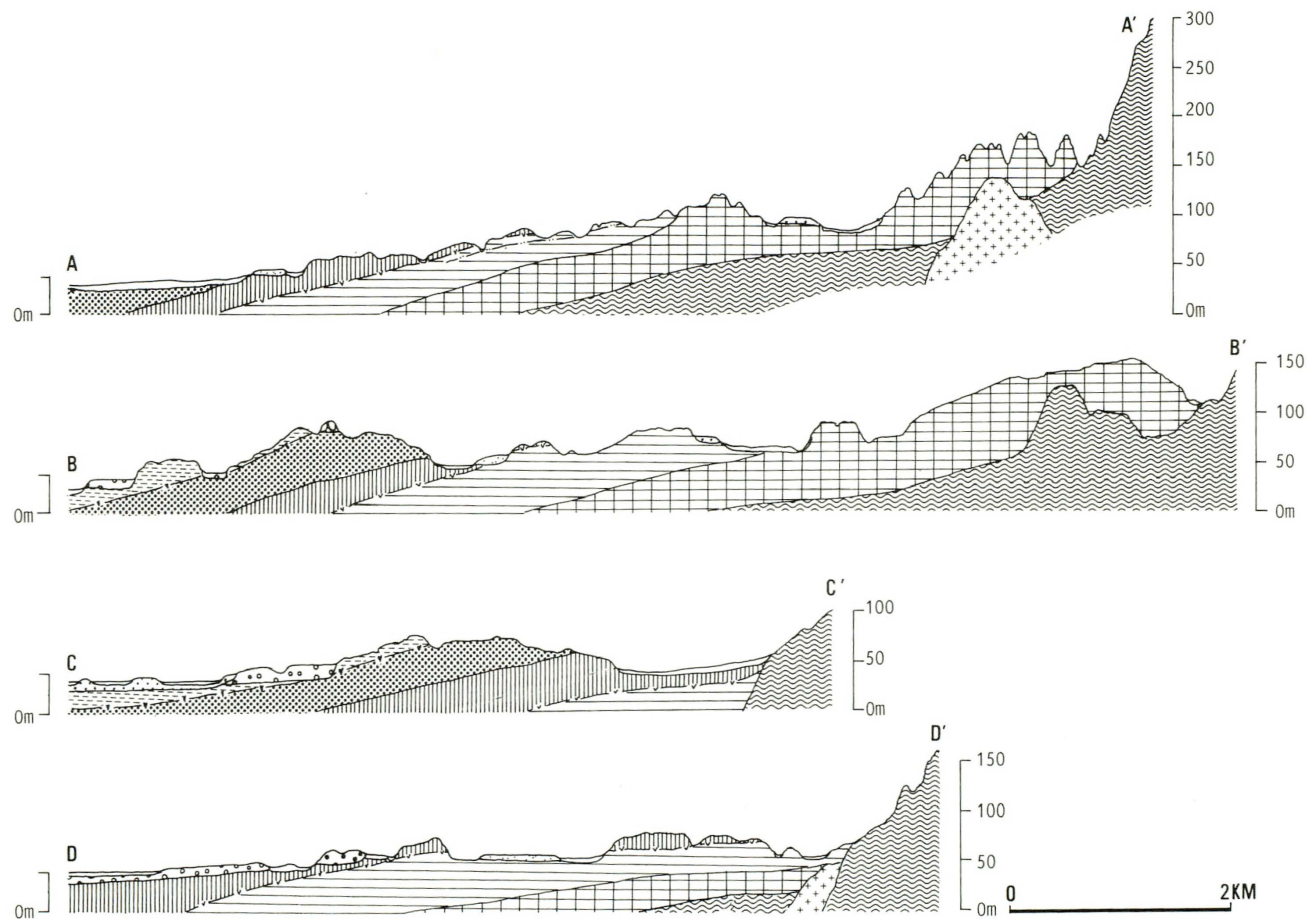


Fig. 8. Geological cross sections of the Komaki-Kasugai area.
Legend and profile lines are shown in Fig. 7.

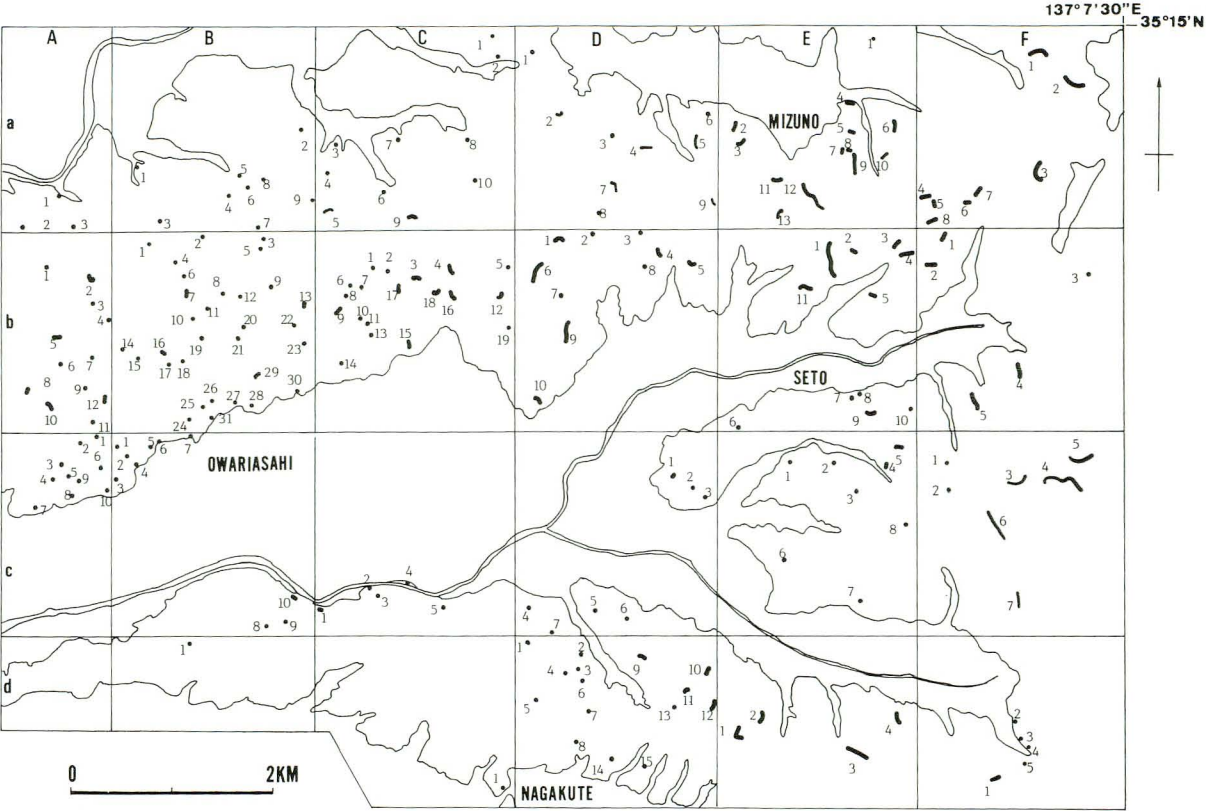


Fig. 9. Locations of columnar sections of the Owariasahi-Seto area (see Fig. 10).

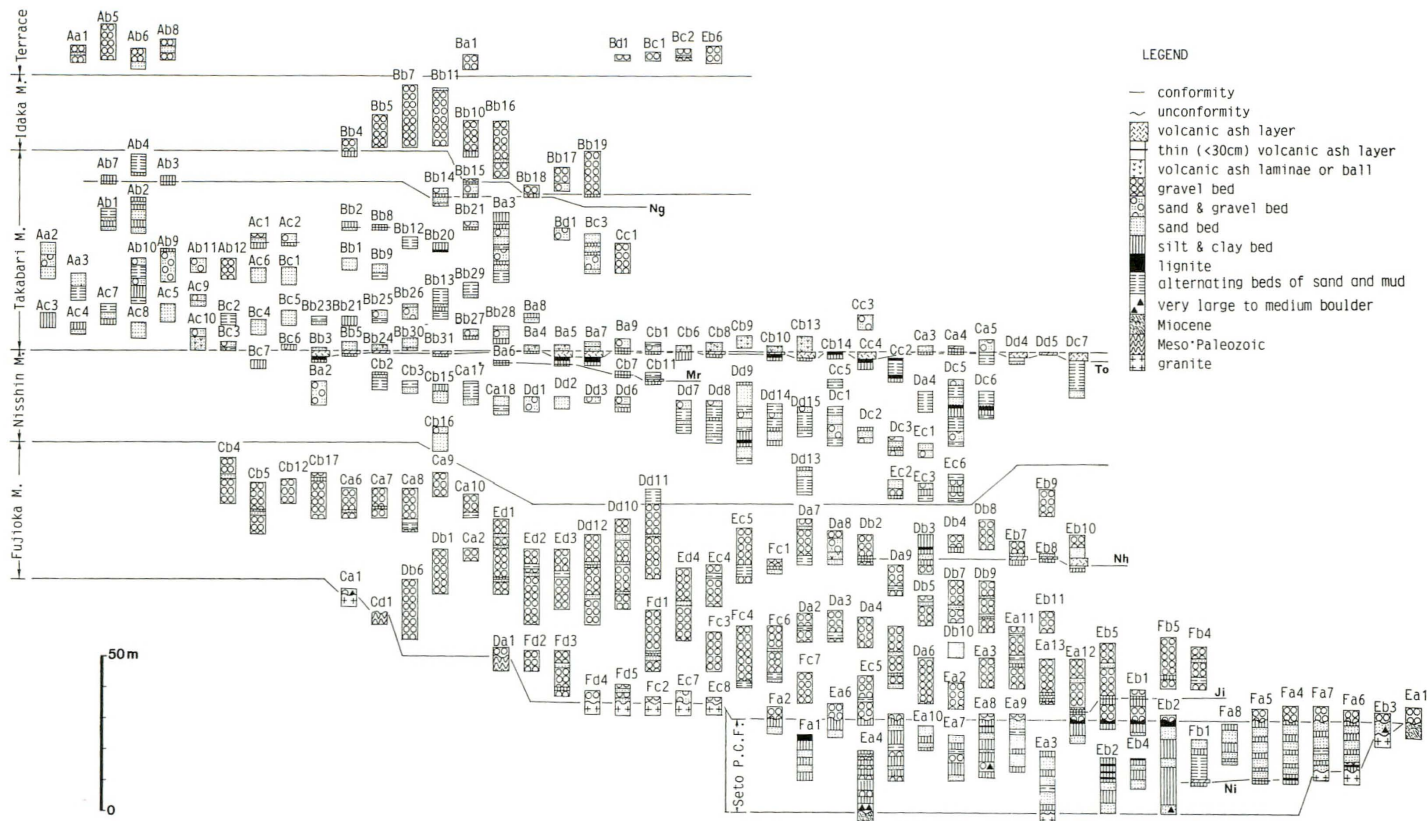


Fig. 10. Columnar sections of the Owariasahi-Seto area.

Ni: Nishiinzo volcanic ash layer, Ji: Jinya volcanic ash layer, Nh: Nishiiba volcanic ash layer, Mr: Marune volcanic ash layer, To: Togo volcanic ash layer, Ng: Nagahazama volcanic ash layer. See Fig. 9 for column locations.

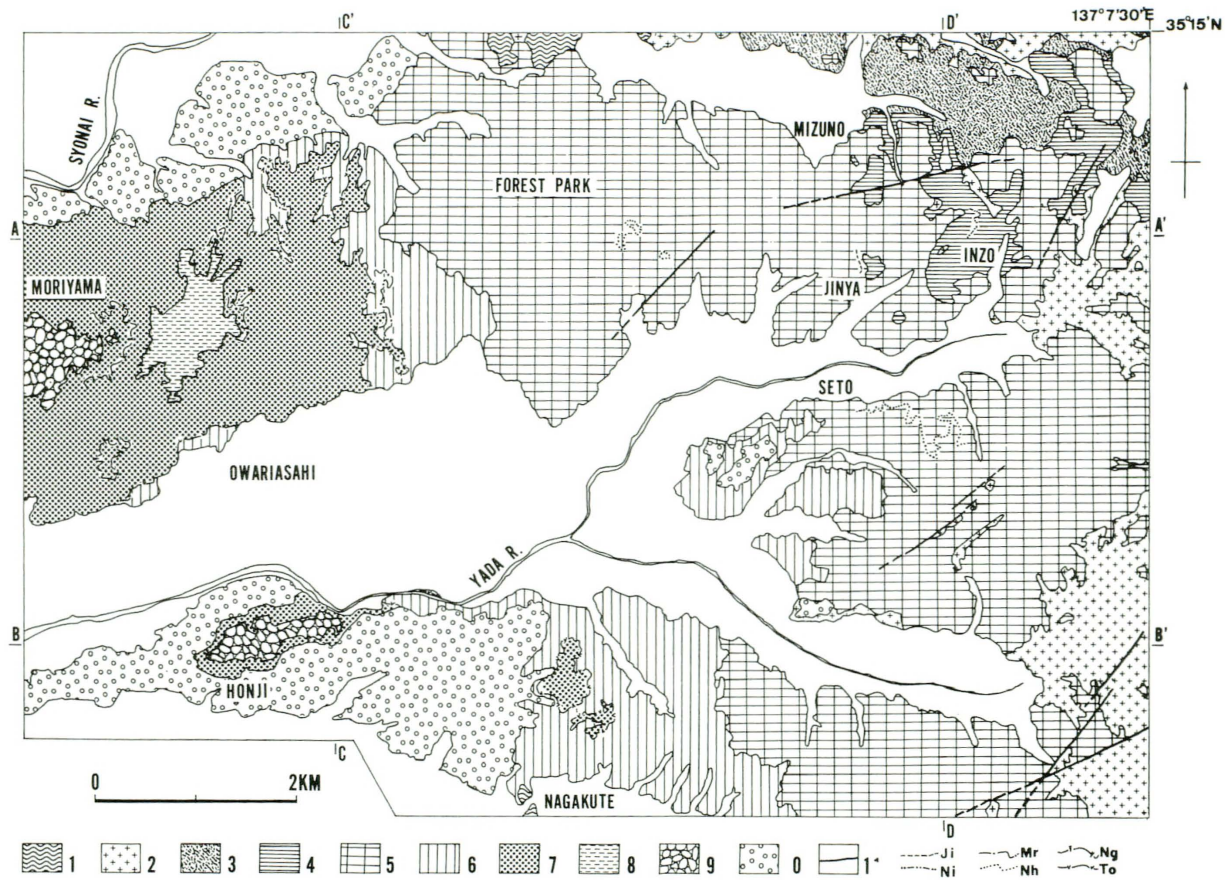


Fig. 11. Geological map of the Owariasahi-Seto area.

1: Mesozoic-Paleozoic formations, 2: Granite, 3: Miocene Shinano Formation, 4-8: Seto Group, 4: Seto Porcelain Clay Formation, 5-8: Yadagawa Formation, 5: Fujioka Member, 6: Nisshin Member, 7: Takabari Member, 8: Idaka Member, 9: Yagoto and Karayama Formations, 10: Middle-Low terrace deposits, 11: Fault, Ni: Nishiinzo volcanic ash layer, Ji: Jinya volcanic ash layer, Nh: Nishiiba volcanic ash layer, Mr: Marune volcanic ash layer, To: Togo volcanic ash layer, Ng: Nagahazama volcanic ash layer.

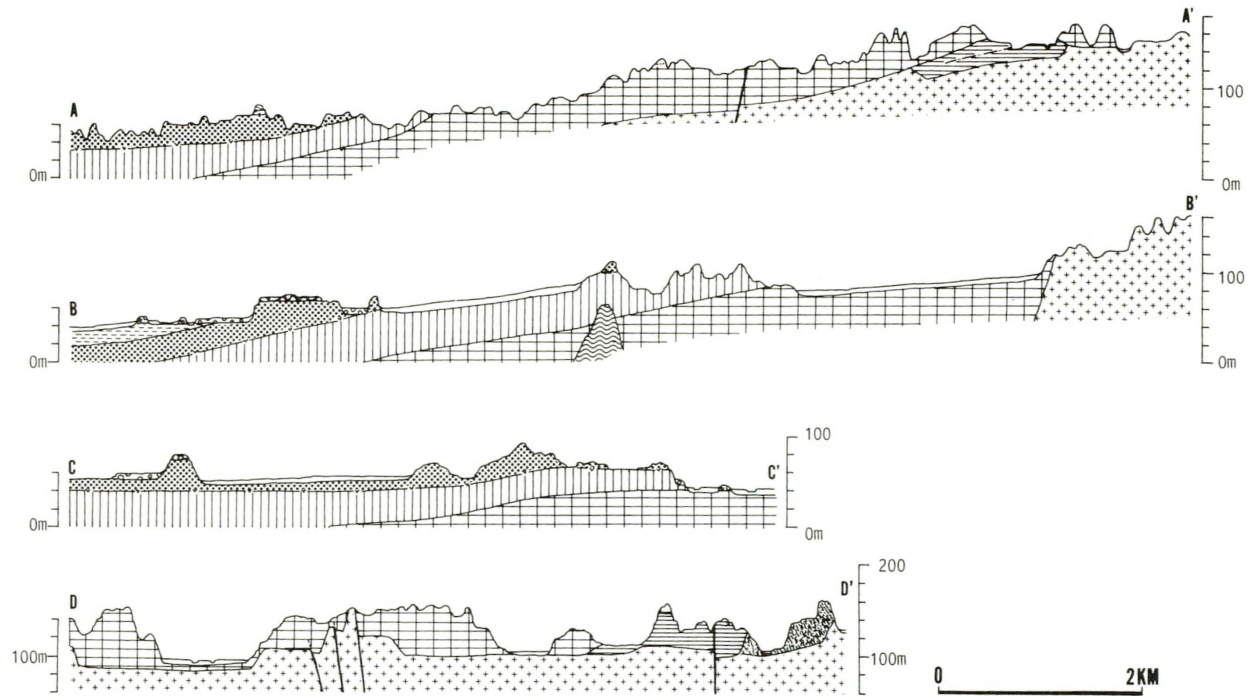


Fig. 12. Geological cross sections of the Owariasahi-Seto area.
Legend and profile lines are shown in Fig. 11.

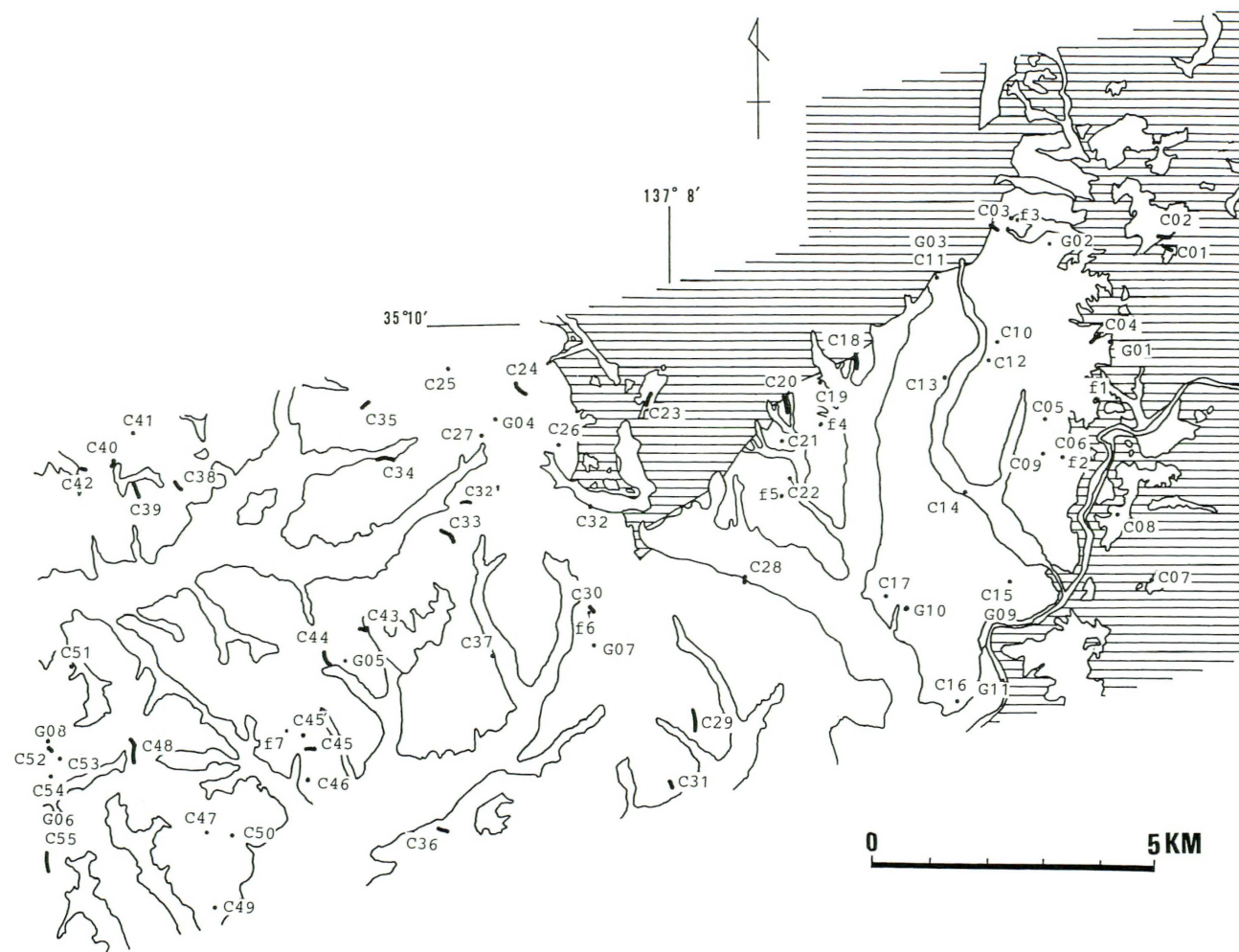


Fig. 13. Point map of the Fujioka-Nisshin area (after NAKAYAMA, 1987).

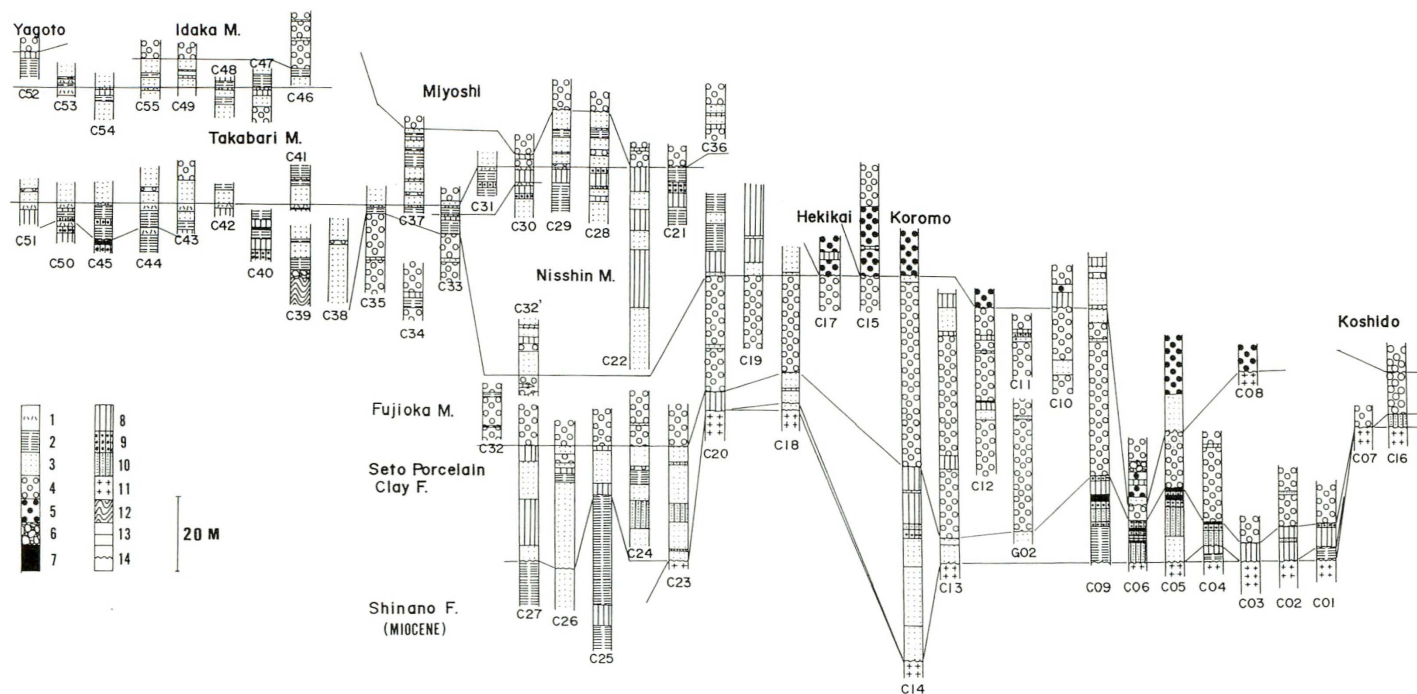


Fig. 14. Columnar sections of the Fujioka-Nisshin area (after NAKAYAMA, 1987).
 1: Volcanic ash layer, 2: Silt, 3: Sand, 4: Gravel, 5: Decayed gravel, 6: Poorly sorted gravel, 7: Lignite, 8: Clay, 9: Clay with plant remains, 10: Clay with quartz grains, 11: Granite, 12: Mesozoic-Paleozoic formations, 13: Conformity, 14: Unconformity, Koshido, Koromo, Hekikai, Miyoshi, and Yagoto: Terrace deposits.

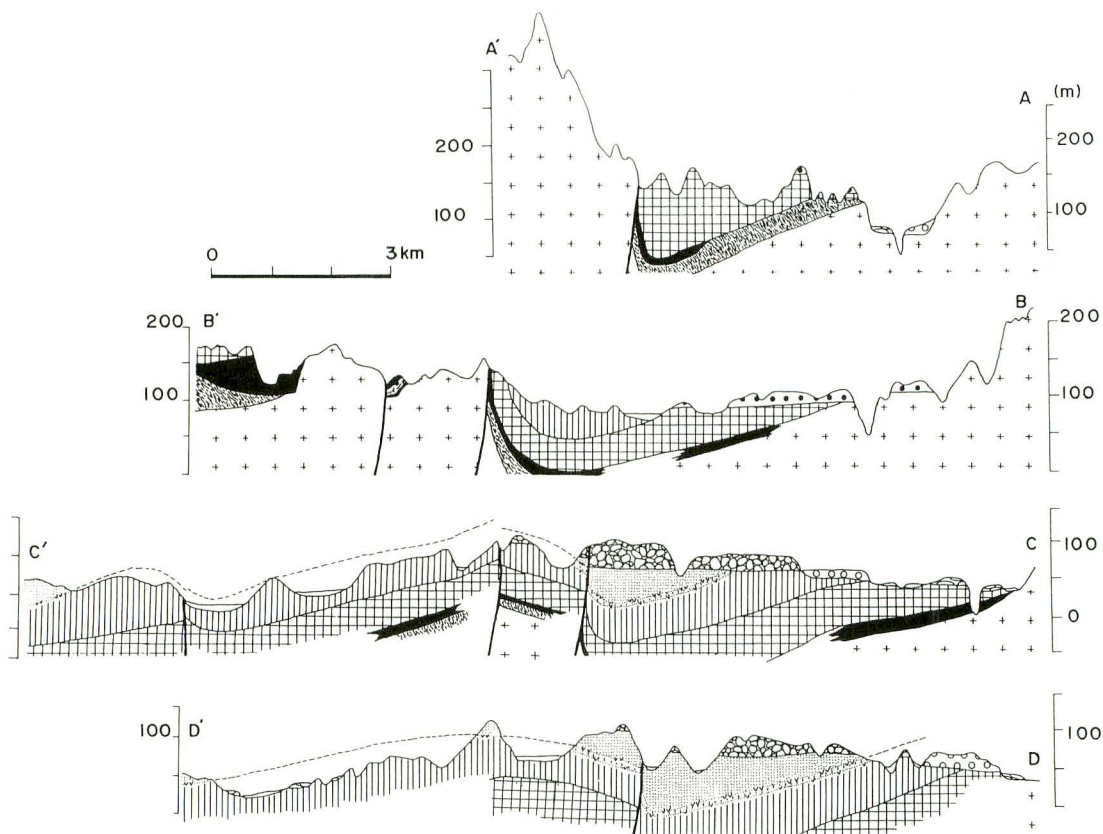


Fig. 16. Geological cross sections of the Fujioka-Nisshin area (NAKAYAMA, 1987).
Legend and profile lines are shown in Fig. 15.

in Fig. 14). The formation in this area can be divided into two assemblages; one dominated by quartz sand and “Gaerome clay,” found at Yagusa, Hirohata, and Kano, and the other dominated by lignite and “Kibushi Clay,” found near Tamomi and Shidare (see Fig. 28). The Hirohata volcanic ash layer occurs in the upper horizon of the formation at Hirohata.

Yadagawa Formation (MATSUZAWA *et al.*, 1960)

No “type locality” was described because the facies changes rapidly (MATSUZAWA *et al.*, 1960). In this paper, I describe a type locality for each member. Through these type localities are not along a particular route, I define them as the composite-stratotype of the formation.

Fujioka Member (NAKAYAMA, 1987)

Type locality: Mine site at Fukami of Fujioka-cho (G02 in Fig. 14).

Distribution: The member is widely distributed from Kozoji of Kasugai City to Nagakute-cho through Seto City, Fujioka-cho, and Miyoshi-cho.

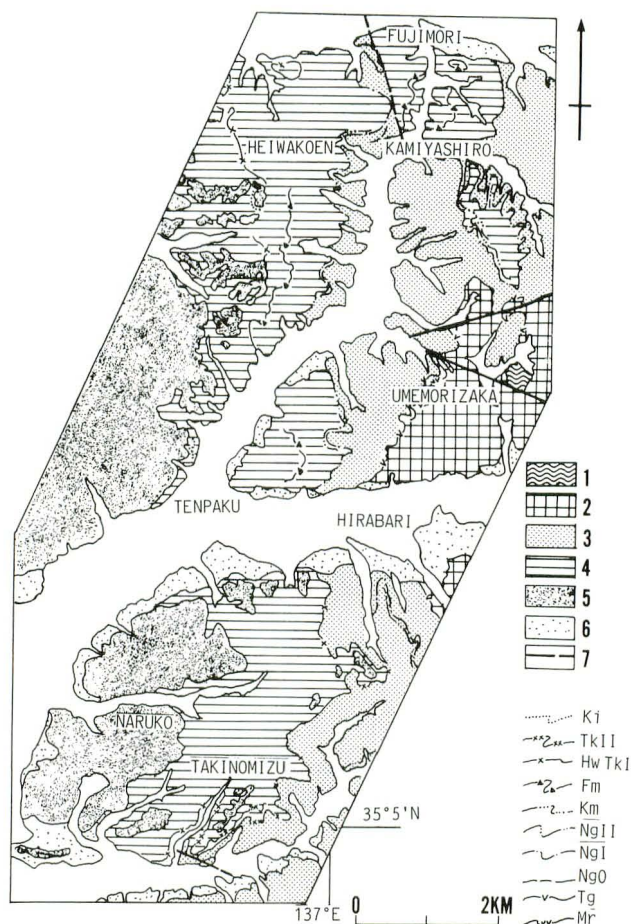


Fig. 17. Geological map of southeastern Nagoya.

The map is based on MORI (1971b) and FURUSAWA (1988). 1: Mesozoic-Paleozoic formation, 2-4: Yadagawa Formation, 2: Nisshin Member, 3: Takabari Member, 4: Idaka Member, 5: Yagoto and Karayama Formations, 6: Middle-Low terrace deposits, 7: Fault, Ki: Kameiri volcanic ash layer, TkII: Takinomizu II volcanic ash layer, Hw Tk I: Heiwakoen and Takinomizu I volcanic ash layer, Fm: Fujimori volcanic ash layer, Km: Kumanomae volcanic ash layer, NgII: Nagakute II volcanic ash layer, NgI: Nagakute I volcanic ash layer, Ng0: Nagakute 0 volcanic ash layer, Tg: Togo volcanic ash layer, Mr: Marune volcanic ash layer.

Thickness: 40 m at the type locality, generally 30-80 m; locally 30-50 m in the Komaki-Kasugai area, 50-80 m in the Owariasahi-Seto area, and 40 m in the Fujioka-Nisshin area.

Stratigraphical relations: The member extends from the bottom of the Yadagawa Formation up to the first alternating beds of sand and mud. At the type locality, it overlies the Seto Porcelain Clay Formation with paraconformity, and in general, it unconformably overlies that formation. In some areas, however, the member

unconformably overlies basement rocks.

Lithofacies: The member is composed mainly of gravel beds with mud and sand lenses. Clasts are typically subrounded to rounded pebbles, and consist mainly of chert. The matrix is medium to coarse arkose sand. Along the periphery of the sedimentary basin, poorly sorted gravel beds are locally present (Fb3, Fb4 in Fig. 6, Ca1 in Fig. 10 and others). Mud lenses consist of massive gray mud with plant remains. The sand lenses consist of well sorted medium to coarse arkose sand with cross laminations. Detailed description of each area follows.

At the type locality, the member is composed mainly of chert-bearing gravel beds. Sand beds with 1.5 m thickness are intercalated in the upper part.

In the Komaki-Kasugai area, the member is well exposed at Takamoridai (Fb7 in Fig. 6). Around Kozoji, gravel beds are dominant, but around eastern Komaki City, sand and mud lenses increase in number, and the gravel beds contain more matrix. The discontinuous Ohyama volcanic ash layer is intercalated at southern Ohyama (Da13 in Fig. 6). In the Owariasahi-Seto area, the member is well exposed at Seto Civil Park (Ea11 in Fig. 10). An exceptional lithofacies of gravel beds with quartz grains and pale gray to white mud matrix is observed at Jinya. The Jinya volcanic ash layer, also discontinuous, is intercalated at Jinya (Ea12 in Fig. 10), and the Nishiiba volcanic ash layer at Nishiiba (Eb10 in Fig. 10). In the Fujioka-Nisshin area, the Tamomi volcanic ash layer is intercalated in the lower part of the member.

Nisshin Member (NAKAYAMA, 1987)

Type locality: Hilly land to the north of Aichi Pond in Nisshin-cho (C32' in Fig. 14).

Distribution: The member is widely distributed from Okusa of Komaki City to Nisshin-cho, and occurs at Tenno and Teiho of Toyota City.

Thickness: 25 m around the type locality, generally 20–40 m, but 5–20 m in the Owariasahi-Seto area.

Stratigraphical relations: The member extends from the alternating beds of sand and mud above the Fujioka Member to the Togo volcanic ash layer. At several places including the type locality, its lower part intertongues with the Fujioka Member, but in general, it conformably overlies the Fujioka Member.

Lithofacies: The member is composed of alternating beds of sand and mud with intercalations of sandy gravel and lignite beds. The beds vary in thickness from 50 to 200 cm. The sand beds consist of medium to coarse arkose sands, commonly with pebbles to granules. The mud beds contain plant remains. The sand beds are thicker and more continuous than the mud beds. Mud beds dominate in the upper part of the member. Detailed descriptions of each area follow.

Outcrop at the type locality comprises the lower part of the Fujioka Member (5 m thick), and the upper part of the Nisshin Member (25 m thick). The lower

part is a gravel bed containing two mud lenses up to 1.7 and 1.1 m thick, respectively. Alternating beds of gravelly sand, sand, and mud form the upper part.

In the Komaki-Kasugai area, the member is well exposed at Komakigaoka (Da8 in Fig. 6). Tree trunks more than 1.5 m in diameter are found at Da9 in Fig. 6. The Taroike 1 and Taroike 2 volcanic ash layers, correlative with the Marune volcanic ash layer, occur in the upper part of the member. The Ueno volcanic ash layer, which corresponds to the Togo volcanic ash layer, is found near the top of the member. In the Owariasahi-Seto area, the member is well exposed at Minamihishino (Dd9 in Fig. 10). There the Marune and Togo volcanic ash layers occur intercalated in the upper and uppermost part of the member, respectively.

Takabari Member (MORI, 1971b)

Type locality: Eastern Takabari of Nagoya City (MORI, 1971b).

Distribution: The member is widely distributed from Shinooka of Komaki City to southeastern Nagoya, and occurs also at Teiho of Toyota City.

Thickness: 50 m at the type locality, generally 40–60 m, but thinner (20 m) in the Fujioka-Nisshin area.

Stratigraphical relations: The member overlies the Togo volcanic ash layer and its top is at the first sandy gravel beds above the Nagakute I volcanic ash layer. It conformably overlies the Nisshin Member, as observed at the type locality.

Lithofacies: Apart from the Komaki-Kasugai area, the member is composed mainly of sand beds and mud beds with plant remains. The sand beds consist of medium to coarse sands, with common 3D dunes. The lower part of the member is dominated by sandy gravel beds. The clasts of the sandy gravel beds are generally subrounded to rounded pebbles and cobbles consisting mainly of chert from the Mesozoic-Paleozoic formations. The matrix consists of medium to very coarse, well sorted sands. Detailed descriptions of each area follow.

At the type locality, the column consists of alternating beds of gravelly sand, sand, and mud (MORI, 1971b).

In the Owariasahi-Seto area, the member is well exposed at Shiroyama (Bb13 in Fig. 10). The member in this area consists of alternating sand and mud beds, 10 to 50 cm thick (for example Bb13 in Fig. 10), and alternating sand-rich beds, 1 to 5 m thick (for example Ab10 in Fig. 10). The Nagahazama volcanic ash layer, correlative with the Nagakute I & II volcanic ash layer, is intercalated around Nagahazama (Ab7, Ab3 in Fig. 10). In the Fujioka-Nisshin area and southern Nagoya, the member is well exposed at eastern Togo (C37 in Fig. 14). The Nagakute 0, Nagakute I & II, Kumanomae, Issha, Fujimori, and Takinomizu I (Heiwakoen) volcanic ash layers are found in the member. The last two layers are occasionally intercalated in the Idaka Member.

In the Komaki-Kasugai area, the member can be divided into a lower member comprising sand and mud beds, 30 m in thick, and an upper member comprising

sand, sandy gravel, and gravel beds, 20–30 m in thickness. The lower member, distributed from Shinooka to western Ohkusa, is well exposed at Shinooka Junior High School (Cb2 in Fig. 6). The upper member, distributed from the Ohyama River to Shinooka, is well exposed at southern Shinooka (Cb9 in Fig. 6). The Shinooka volcanic ash layer, which corresponds to the Nagakute I & II volcanic ash layer, is intercalated in the upper member.

Idaka Member (MORI, 1971b)

Type locality: Agematsu of Komaki City (Bb13 in Fig. 6). Because extensive engineering work is being carried out around Idaka, outcrops in this area are disappearing rapidly.

Distribution: The member is found around eastern Nagoya.

Thickness: Over 20 m at the type locality, generally over 30 m, but more than 70 m in southeastern Nagoya.

Stratigraphical relations: The member extends from the first sandy gravel beds above the Nagakute I & II volcanic ash layer to the top of the Seto Group. In the Komaki-Kasugai area, including the type locality, the member conformably overlies the Shinooka (the same as the Nagakute I & II) volcanic ash layer. In general, it conformably overlies the Takabari Member, but locally the two members interdigitate.

Lithofacies: The member is composed mainly of sandy gravel and gravel beds. The clasts are generally subrounded to rounded pebbles and cobbles, and consist mainly of chert and rhyolites. The clasts of rhyolites are derived from the Miocene Shidara Group. The Shidara Group is distributed about 50 km to the east of the study area. At the type locality, the member consists mainly of chert-bearing gravel beds, along with a very coarse sand bed, 1.5 m thick.

In the Komaki-Kasugai area, the gravel beds contain a remarkable amount of hornfels clasts, and mud beds are occasionally intercalated in the upper part of the member (Bb11, Bb12 in Fig. 6). Rhyolites clasts of the Miocene Shidara Group are not recognized in this area. In the Owariasahi-Seto area, the member is well exposed at Nagoya Nursery College (Bb10 in Fig. 10). The member contains mud lenses in this area. In the Fujioka-Nisshin area, it is well exposed at Kannokura of Nagoya (C55 in Fig. 14). The clast size of gravel beds in this area is generally smaller than in the Komaki-Kasugai area. The Kameiri and Takinomizu II volcanic ash layers occur as intercalations.

4.1.2. Lithostratigraphy of the Tokoname Group

The lithostratigraphy of the Tokoname Group was summarized by MAKINOUCHI (1988). Geological maps of the Tokoname Group are shown in Figs. 18 & 19.

Toyooka Formation (MAKINOUCHI, 1975)

Type locality: Along the road from Naifukuji of Minamichita-cho to Ko(u)wa

Interchange.

Distribution: The formation is distributed from Toyooka to Noma.

Thickness: Approximately 85 m.

Stratigraphical relations: The formation includes the beds from the bottom of the Tokoname Group to the beds below the medium sand beds at northern Kofu of Mihama-cho. It unconformably overlies the Morozaki Group.

Lithofacies: The formation is composed of sandy gravel and gravel beds with intercalations of mud and granular sand layers. Chert clasts are dominant at southern Ko(u)wa, whereas sand and mudstone clasts from the Miocene Morozaki Group and the Mesozoic-Paleozoic formations dominate in other areas. Clast size is generally in the cobble to granule range.

Ko(u)wa Formation (MAKINOUCHI, 1975)

Type locality: Along the road from Ko(u)wa to Aoyama Pond.

Distribution: The formation is distributed from Ko(u)wa of Mihama-cho to Sakai of Tokoname City.

Thickness: Approximately 180 m.

Stratigraphical relations: The formation extends from granular medium sand beds above the Toyooka Formation to the beds just below Sakai volcanic ash layer. It conformably overlies the Toyooka Formation.

Lithofacies: The formation is composed of irregular alternating beds of sand and mud with intercalations of lignite. The sand beds consist mainly of pale gray to gray medium arkose sands. The mud beds consist mainly of bluish gray mud. Generally, sand beds are abundant along the east coast of the peninsula. The lignite beds are mainly formed in the middle and uppermost parts of the formation. The Kofu and Ko(u)wayama volcanic ash layers occur in the lower part of the formation. The Chita pink, Shirasawanoike, Kaminoma, and Sakai volcanic ash layers occur in the upper part of the formation. MAKINOUCHI *et al.* (1983) reported a fission-track age of 5.3 ± 0.4 Ma for the Kaminoma volcanic ash.

Futto Formation (lower) (MAKINOUCHI, 1988)

Type locality: The valley at the western Futto of Mihama-cho.

Distribution: The formation is distributed on the surface around Tokoname City and southern Ohbu City, and below the ground surface between Tokoname and Ohbu.

Thickness: 100–200 m.

Stratigraphical relations: The formation extends from the Sakai volcanic ash layer to the beds 5–20 m below from the Koba volcanic ash layer. It conformably overlies the Ko(u)wa Formation.

Lithofacies: The formation is composed of sand and mud beds with intercalations of lignite and sandy gravel beds. The lowermost part of the formation consists

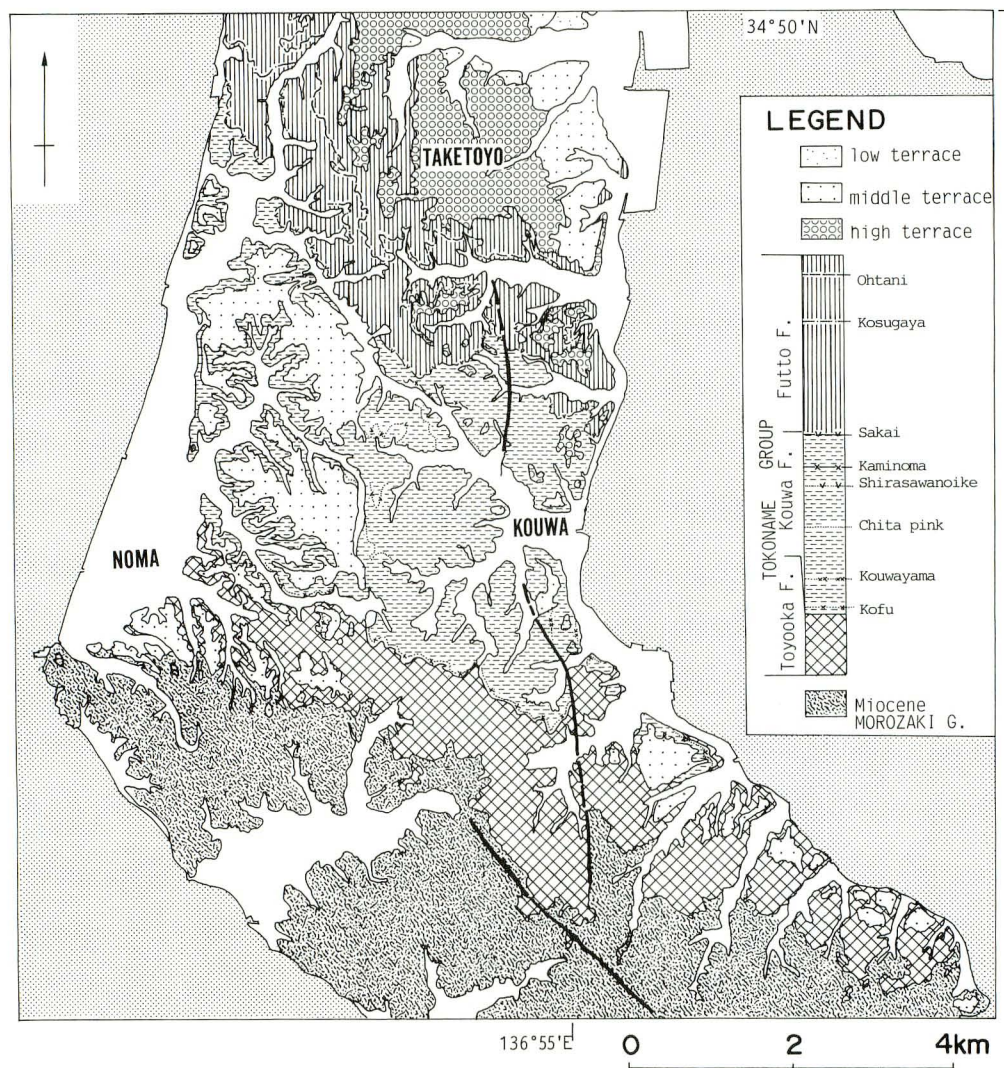


Fig. 18. Geological map of the southern Chita Peninsula (after MAKINOCHI, 1975).

of sandy gravel beds with mud balls. The gravel beds eroded the Ko(u)wa Formation throughout the region. Coarse sand beds typically grade upward into mud beds. The sand beds consist of well sorted arkose sand. Very coarse to coarse sands are dominant in Higashiura-cho, in contrast to the sands in Tokoname City. The lignite beds are 5–200 cm in thickness. Sandy gravel beds are common in the lowermost part of the formation and in the horizon between the Ohtani and Koba volcanic ash layers. The clasts in the sandy gravel beds are generally rounded to subrounded pebbles of chert, rhyolites, and sandstone. The volcanic ash layers in the formation are the Kosugaya, Ohtani, and Kariya in ascending order. MAKINOCHI *et al.* (1983) presented fission-track age for the

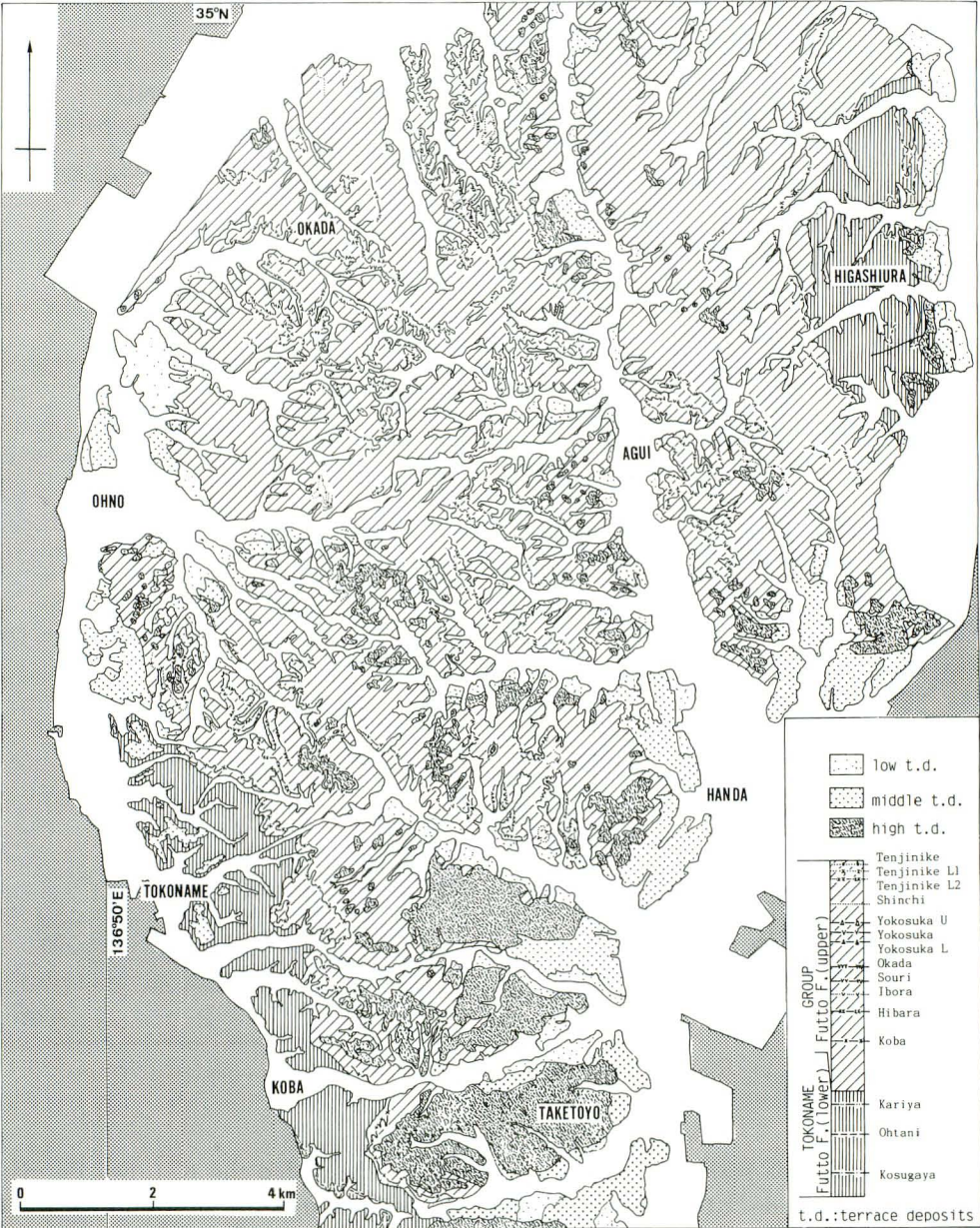


Fig. 19. Geological map of the northern Chita Peninsula (after YOSHIDA & OZAKI, 1986).

Kosugaya and Ohtani volcanic ashes of 4.0 ± 0.5 Ma, and 4.3 ± 0.6 Ma, respectively.

Futto Formation (upper) (MAKINOUCHI, 1988)

Type locality: 500 m south of Chita Higashi Senior High School.

Distribution: The formation is widely distributed in northern Chita Peninsula.

Thickness: Over 300 m.

Stratigraphical relations: The formation extends from the top of the Futto Formation (lower) to the top of the Tokoname Group. It conformably overlies the Futto Formation (lower).

Lithofacies: The formation is composed of sand and mud beds with intercalations of lignite and sandy gravel beds. Sand and sandy gravel beds are dominant, and there are fewer mud and lignite beds than in the Futto Formation (lower). The clasts are mainly chert and volcanic rocks. The lignite beds are 5–50 cm in thickness, and are common in the lower part of the formation. The sand beds are widespread in the upper part of the formation. The sandy gravel beds are extensive above the Koba volcanic ash layers and around Higashiura-cho and Ohbu City. Clast size is in the cobble to granule range, but cobbles are restricted to the vicinity of Ohbu City. The clasts are mainly chert and rhyolites, and the rhyolites clasts increase in abundance upward. The volcanic ash layers found in the formation are, in ascending order, the Koba, Hibara, Ibora, Souri, Okada, Yokosuka, Shinchi, Tenjinike L2, Tenjinike L1, and Tenjinike.

4.2. Tephrostratigraphy

Volcanic ash layers are common in the Tokai Group around the east coast of Ise Bay (Fig. 4). The representative volcanic ash layers in the Seto Group are the Hirohata, Tamomi, Marune, Togo, Nagakute 0, Nagakute I & II, Kumanomae, Takinomizu I, and Takinomizu II ones in ascending order. In the Tokoname Group, the representative volcanic ash layers are the Kofu, Ko(u)wayama, Chita pink, Shirasawanoike, Kaminoma, Sakai, Kosugaya, Ohtani, Kariya, Koba, Hibara, Ibora, Souri, Okada, Yokosuka, Shinchi, and Tenjinike ones in ascending order.

Correlation of the volcanic ash layers between the Seto and Tokoname Groups is based on their lithology, stratigraphical position, and their petrographical similarities. The Marune, Togo, Nagakute 0, Nagakute I & II, Kumanomae, and Takinomizu I volcanic ash layers in the Seto Group can be correlated with the Kosugaya, Ohtani, Ibora, Souri, Okada, and Tenjinike volcanic ash layers in the Tokoname Group, respectively (NAKAYAMA & FURUSAWA, 1989). Also, the Tamomi volcanic ash layer in the Seto Group may be correlated with the Kofu (Kofu L) volcanic ash layer in the Tokoname Group (MAKINOCHI & NAKAYAMA 1990). I confirmed all of these correlations, using the descriptions of NAKAYAMA & FURUSAWA (1989). Correlation between the volcanic ash layers of the Seto and Tokoname Groups is shown in Fig. 20.

4.3. Magnetostratigraphy

I have added magnetic measurements of 4 beds in the Seto Group to the previous data of OTOFUJI *et al.* (1975) and NAKAYAMA & YOSHIKAWA (1990). Sampl-

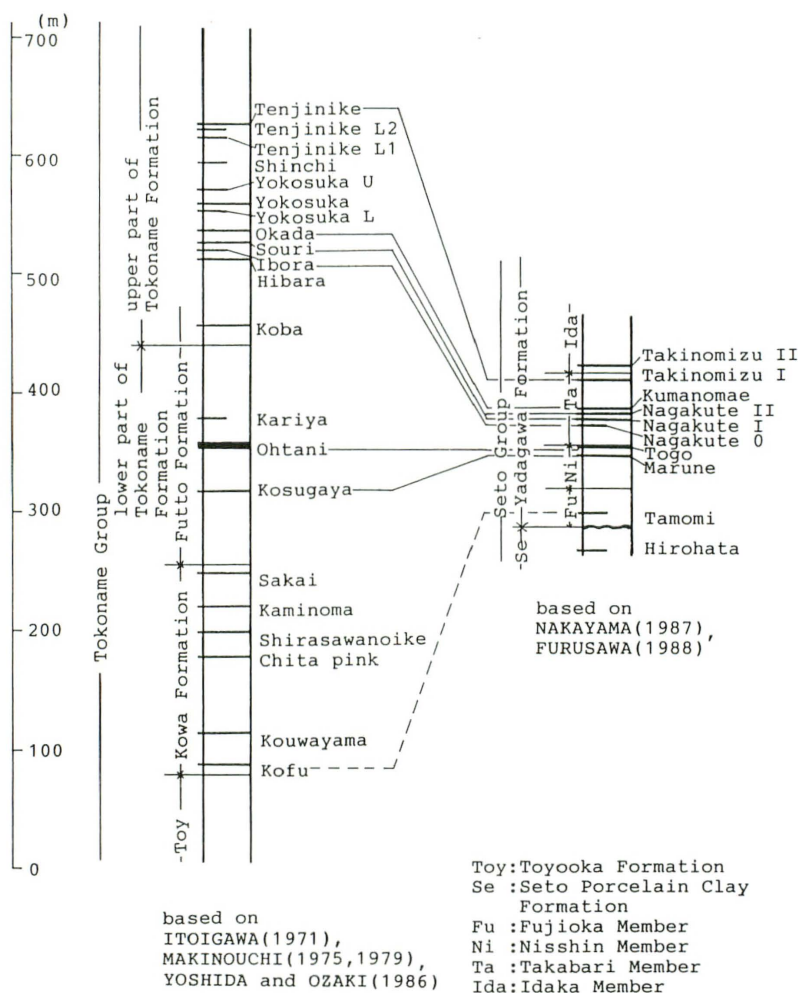


Fig. 20. Tephrochronology and correlation between the Seto and Tokoname Groups (after NAKAYAMA & FURUSAWA, 1989).

ing points and magnetic data are shown in Fig. 21 and Table 1. The magnetostratigraphy of the Tokai Group around the east coast of Ise Bay is divided into five magnetopolarity zones: the TO-A Reverse, TO-B Normal, TO-C Reverse, TO-D Normal, and TS-E Normal Magnetopolarity Zones in descending order. This division is based on the tephrostratigraphy and its correlations. Magnetostratigraphy is summarized in Fig. 22.

TO-A Reverse Magnetopolarity Zone

This magnetozone is the uppermost one in the Tokai Group around the east coast of Ise Bay. It lies above the Shinchi volcanic ash layer in the Tokoname Group and above the Kumanomae volcanic ash layer in the Seto Group. The zone has a maximum thickness of more than 150 m in the Futto Formation (upper) in the Tokoname Group, and more than 30 m in the Idaka Member and the upper

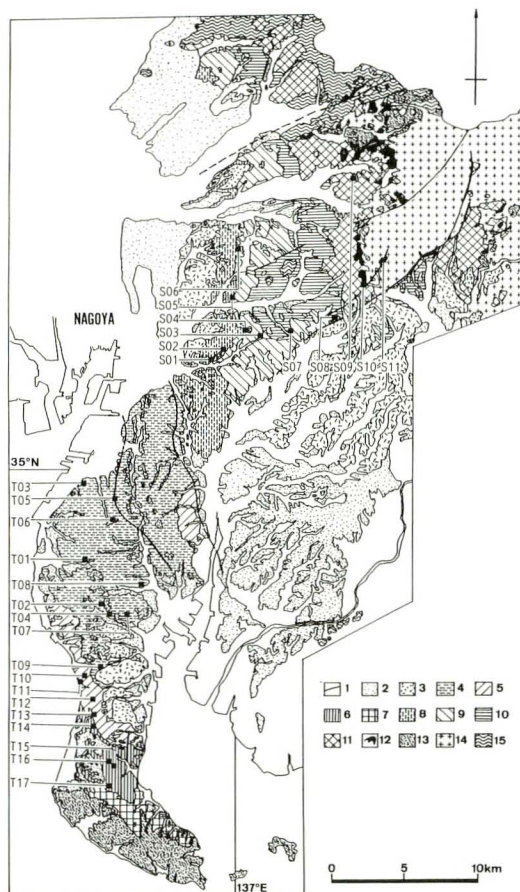


Fig. 21. Sampling points for paleomagnetism.
1-15 are the same as in Fig. 3.

part of the Takabari Member in the Seto Group.

TO-B Normal Magnetopolarity Zone

This zone lies above the Koba volcanic ash layer and below the Tenjinike L2 volcanic ash layer in the Futto Formation (upper) in the Tokoname Group, and above the Togo volcanic ash layer and below the Takinomizu I volcanic ash layer in the Takabari Member in the Seto Group. Its thickness is about 150 m in the Tokoname Group and 40–60 m in the Seto Group.

TO-C Reverse Magnetopolarity Zone

This zone is situated around the Futto Formation (lower) and the Nisshin Member. It is above the Kaminoma volcanic ash layer and below the Hibara volcanic ash layer in the Tokoname Group, and above the Tamomi volcanic ash layer and below the Nagakute 0 volcanic ash layer in the Seto Group. Its thickness is about 200 m in

Table 1. Paleomagnetic data from the Tokai Group around the east coast of Ise Bay.

Volcanic ash layer	Site No.	N	Pol.	N R M				after Demagnetization			
				D	I	K	A ₉₅	D	I	K	A ₉₅
Takinomizu II	S01	8	R	-117.60	-48.10	60.14	16.80	-171.60	-52.80	139.50	10.50
Takinomizu I	S02	7	R	-114.10	-49.00	31.03	12.00	-171.60	-59.30	60.73	8.70
Kumanomae	S03	8	N	-4.30	52.90	48.01	8.10	-5.80	53.30	97.80	5.60
Nagakute II	S04	8	N	3.80	45.20	224.76	5.20	4.10	43.30	331.96	3.00
Nagakute I	S05	8	N	14.80	46.30	105.74	8.40	12.30	47.50	122.05	6.10
Nagakute 0	S06	8	N	3.50	45.10	380.78	2.80	3.40	43.60	639.73	2.70
Togo	S07	7	R	-56.70	42.40	5.21	26.80	-175.50	-48.70	50.94	7.50
Marune	S08	8	R	-177.20	-39.20	45.66	8.30	179.40	-41.51	93.60	6.30
Nishiiba	S09	9	R	11.40	53.50	96.24	5.70	-166.40	-38.50	42.82	8.80
Tamomi	S10	8	N	3.80	43.90	9.41	60.20	-5.70	54.20	39.60	9.80
Hirohata	S11	8	N	0.70	54.80	130.22	4.90	1.30	60.00	141.28	4.70
Tenjinike	T01	8	R	-152.30	-69.20	121.44	5.00	-159.60	-69.70	132.99	5.30
Tenjinike L1	T01	7	R	15.40	-8.60	19.60	11.20	-175.60	-57.50	85.97	6.50
Tenjinike L2	T01	8	R	-161.40	-31.20	51.80	7.80	159.00	-30.10	49.35	8.00
Shinchi	T02	9	N	24.00	48.60	188.37	3.80	20.10	48.60	450.03	2.98
Yokosuka	T03	9	N	-12.90	34.60	36.60	8.60	-19.30	34.60	46.71	7.60
Yokosuka L	T04	8	N	-33.60	42.40	71.40	6.60	-21.50	41.40	113.50	5.60
Okada	T05	8	N	13.50	55.00	37.72	8.50	13.80	54.90	42.99	8.50
Souri	T06	8	N	-3.90	51.30	16.94	13.90	1.60	44.00	47.82	9.80
Ibora	T07	8	N	7.40	43.00	166.85	4.00	5.80	42.90	199.06	3.90
Hibara	T08	7	N	84.50	87.70	7.37	20.30	-10.20	51.90	43.75	18.90
Koba	T09	8	R	170.00	-47.70	1.51	74.80	164.80	-40.30	36.51	9.30
Kariya	T10	7	R	-170.90	-53.30	3.61	29.70	168.90	-56.20	113.77	5.70
Ohtani	T11	-	R	175.80	-49.80	---	13.60	-169.20	-55.40	---	6.00
Kosugaya	T12	-	R	-165.20	-55.60	---	8.50	-173.10	-52.60	---	9.40
Sakai	T13	-	R	-177.00	-37.90	---	6.70	-170.00	-41.70	---	8.10
Kaminoma	T14	-	N	34.20	16.90	---	27.50	32.20	10.50	---	18.00
Shirasawanoike	T15	-	N	1.40	54.90	---	7.10	4.40	52.20	---	7.40
Chita pink	T16	-	N	24.00	44.10	---	46.10	-42.00	9.10	---	52.50
Kofu	T17	-	N	-21.40	29.00	---	2.70	0.40	48.10	---	5.00

N:the number of samples, Pol.:geomagnetic porality (N:normal, R:reverse), NRM: natural remnant magnetization, D:declination in degrees, I:inclination in degrees, K:the precision parameter (Fisher, 1953), A₉₅:the radius of the cone around the mean direction drawn at the 95% confidence level in degrees.

the Tokoname Group and 50–80 m in the Seto Group.

TO-D Normal Magnetopolarity Zone

This zone lies above the lowest part of the Tokoname Group (the Toyooka and the lower part of Ko(u)wa Formations) below the Sakai volcanic ash layer in the Tokoname Group, and around the lowest part of the Yadagawa Formation (the

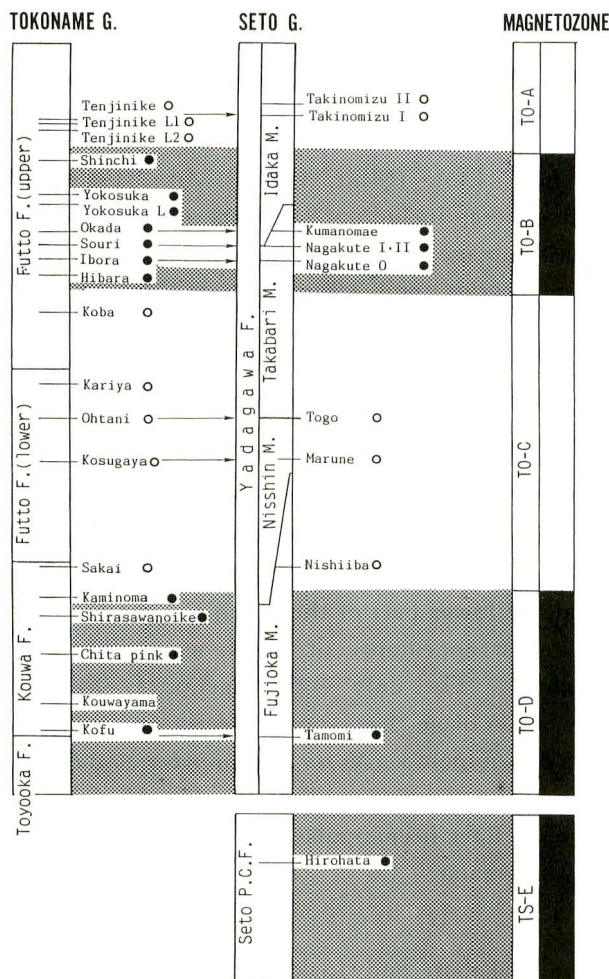


Fig. 22. Magnetostratigraphy of the Tokai Group around the east coast of Ise Bay. Open circles show reversed polarity, solid circles show normal polarity, and arrows show the correlative volcanic ash layers.

Fujioka Member) below the Nishiiba volcanic ash layer in the Seto Group. Its thickness is 200–250 m in the Tokoname Group and 60–80 m in the Seto Group.

TS-E Normal Magnetopolarity Zone

This zone is recognized only in the Seto Group, and is the lowest one in the Tokai Group. The Seto Porcelain Clay Formation belongs to this zone, which is 20–30 m thick.

4.4. Biostratigraphy

This biostratigraphy comprises the TB1, TB2, and TB3 biozones in ascending

order. The list of plant and pollen fossils of the Seto Group, and the list of plant fossils of the Tokoname Group, are shown in Figs. 23 and 24, respectively.

TB1 biozone

This biozone is situated in the Seto Porcelain Clay Formation. It is known as the “*Pinus trifolia* bed” Flora (MIKI, 1948). MIKI (1963) described 116 species in 41 families and 89 genera, including 9 extinct genera and 66 extinct species in its flora. The plant assemblage, which is characterized by *Pinus trifolia*, *Hemitrapa trapelloidea*, *Sinomenium aetum*, and *Viburnum japonicum*, indicates a warm climate with a low annual temperature range. In this flora, NASU (1972) noted that *Cyclobalanopsis* pollen grains predominate (more than 75%), and conifer pollen grains are rare (less than 10%). The flora consists of many Tertiary-type plants.

TB2 biozone

The TB2 biozone stretches from the bottom of the Yadagawa Formation to the Togo volcanic ash layer (the Fujioka and Nisshin Member), and from the lowermost part of the Tokoname Group to the Ohtani volcanic ash layer (the Toyooka, Ko(u)wa, and the lower part of the Futto Formations). Its plant assemblage is characterized by the first appearance of *Trapa mammillifera*, *T. dolichocarpa*, and *Sparganium protojaponicum*. The only extinct genus is *Protosequoia* (TSUKAGOSHI, 1992). However, the assemblage has some species in common with the “*Pinus trifolia* bed” Flora. Its pollen includes *Nyssa*, *Liquidamber*, and *Carya*, 12% *Glyptostrobus*, with other conifer pollen grains making up less than 10% (NASU, 1972). The climate of the biozone is considered to have been similar to that of the TB1 biozone, but the annual range of temperature was greater.

TB3 biozone

This zone lies the Takabari and Idaka Members of the Yadagawa Formation and the upper part of the Futto Formation; from the Togo and Ohtani volcanic ash layers to the top of the Tokai Group around the east coast of Ise Bay. Its pollen content is characterized by abundant *Glyptostrobus*, *Fagus*, *Alnus*, *Metasequoia*, and *Tsuga*, deciduous *Quercus*, *Nyssa*, and *Liquidamber*, but no *Carya* (YOSHINO, 1971). This appears to indicate a cooling climate with wide annual fluctuation of temperature. The flora of this biozone is considered to correlate with the “*Metasequoia* Flora flourish” of ITIHARA (1960).

4.5. Summary of stratigraphy

The Tokai Group around the east coast of Ise Bay comprises the Seto and Tokoname Groups. Lithostratigraphical divisions are reported for each group (Fig. 4). Tephrostratigraphy and correlation between the ash layers of the Seto Group and those of the Tokoname Group are shown in Fig. 20. Magnetostratigraphy and biostratigraphy are based on litho- and tephrostratigraphy. The former contains

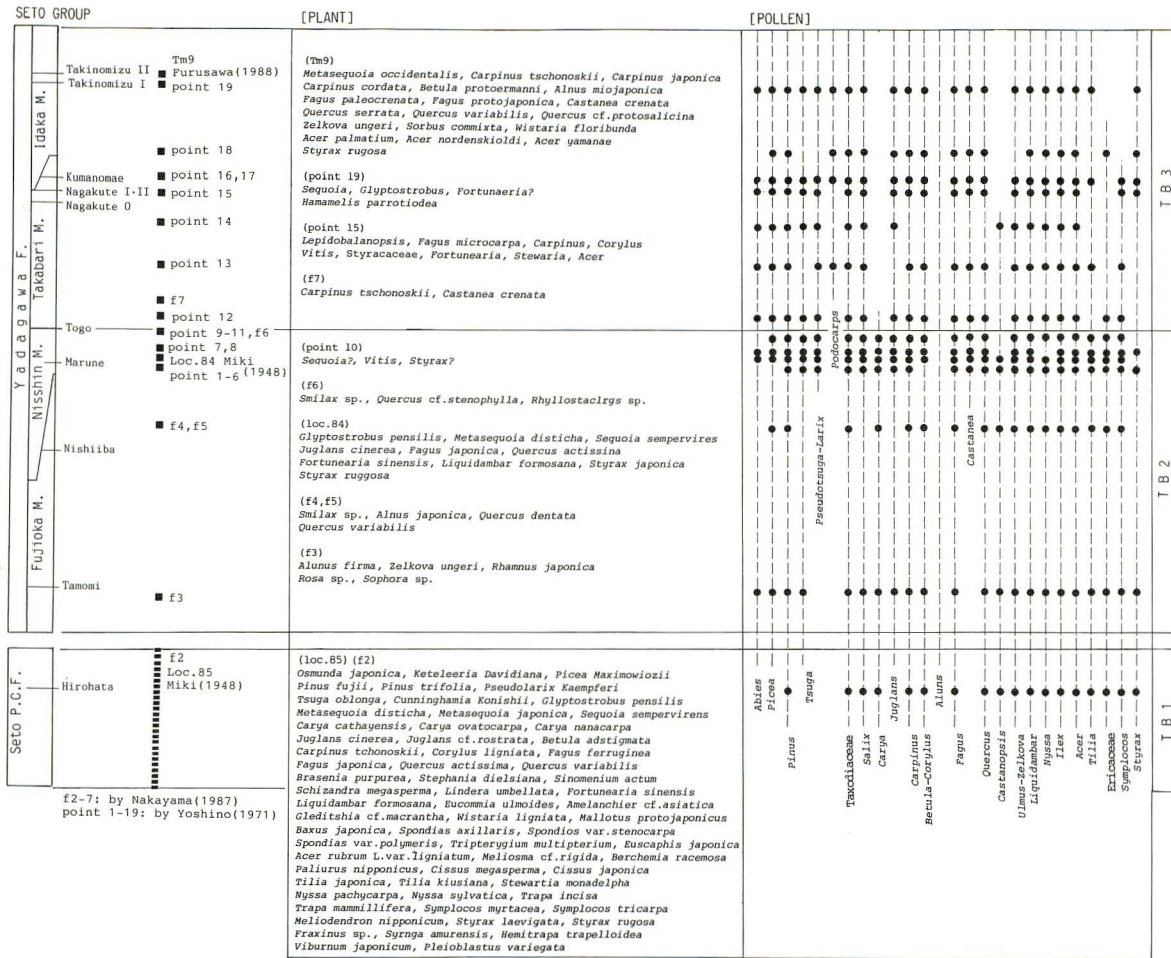


Fig. 23. Biostratigraphy of the Seto Group.

TOKONAME GROUP		[PLANT]	
Futto F. (upper)	Tenjinike		TB3
	Tenjinike L1		
	Tenjinike L2	■ Loc.82	
	Shinchi	■ Miki(1948)	
	Yokosuka		
	Okada	■ MU1	
	Souri	■ Matsuzawa & Uemura (1957)	
	Ibora		
	Hibara		
	Koba		
Futto F. (lower)	Kariya	■ Loc.81	TB2
	Ohtani	■ Miki(1948)	
		■ Loc.1,2	
	Kosugaya	■ Onoe et al. (1986)	
Kouwa F.	Sakai		
	Kaminoma	■ Loc.80A,80B	
	Shirasawanoike	■ Miki(1948)	
	Chita pink		
	Kouwayama		
Toyooka F.	Kofu		
		(loc.82) <i>Metasequoia disticha</i> , <i>Brasenia purpurea</i> <i>Trapa incisa</i>	
		(MU) <i>Metasequoia</i> sp., <i>Fagus cf. ferruginea</i> <i>Fagus</i> sp., <i>Quercus</i> sp.	
		(loc.81) <i>Glyptostrobus pensilis</i> , <i>Sequoia sempervirens</i> <i>Sabia japonica</i> , <i>Berchemia racemosa</i>	
		(loc.1) <i>Salix cf. subfragilis</i> , <i>Quercus protoaliene</i> <i>Quercus protoserrata</i> , <i>Cladrastis cf. platycarpa</i> <i>Wisteria fallax</i> , <i>Paliurus protonipponicus</i> "Alangium aequalifolium", <i>Pleioblastus</i> sp. <i>Carex</i> sp.	
		(loc.2) <i>Salix cf. subfragilis</i> , <i>Quercus sinomiocenicum</i> <i>Lindera miyataensis</i> , <i>Liquidambar protopalmata</i> <i>Cladrastis cf. platycarpa</i> , <i>Cladrastis cf. shikokiana</i> <i>Wisteria fallax</i> , <i>Acer</i> sp. Vitaceae gen. et sp. indet., "Alangium oequalifolium" <i>Pleioblastus</i> sp., <i>Carex</i> sp.	
		(loc.80A,80B) <i>Podocarpus macrophylla</i> , <i>Pseudolarix kaempferi</i> <i>Cunninghamia</i> sp., <i>Metasequoia disticha</i> <i>Sequoia sempervirens</i> , <i>Sciadopitys verticillata</i> <i>Myrica rubra</i> , <i>Castanopsis cuspidata</i> <i>Quercus stenophylla</i> , <i>Aphananthe aspera</i> <i>Zelkova ungeri</i> , <i>Brasenia purpurea</i> <i>Cinnamomum camphora</i> , <i>Nuphar japonicum</i> <i>Illicium anisatum</i> , <i>Mallotus japonicus</i> <i>Buxus japonica</i> , <i>Berchemia racemosa</i> <i>Vitis cf. thunbergii</i> , <i>Camellia japonica</i> <i>Trapa incisa</i> , <i>Symplocos glauca</i> <i>Symplocos prunifolia</i> , <i>Trapella antennifera</i>	

Fig. 24. Biostratigraphy of the Tokoname Group.

the TO-A, TO-B, TO-C, TO-D, TS-E Magnetopolarity Zones in descending order (Fig. 22). The latter comprises the TB1, TB2, and TB3 biozones in ascending order (Figs. 23 & 24). Figure 25 shows a synthesis of these divisions. Their correlation will be discussed in chapter 7.

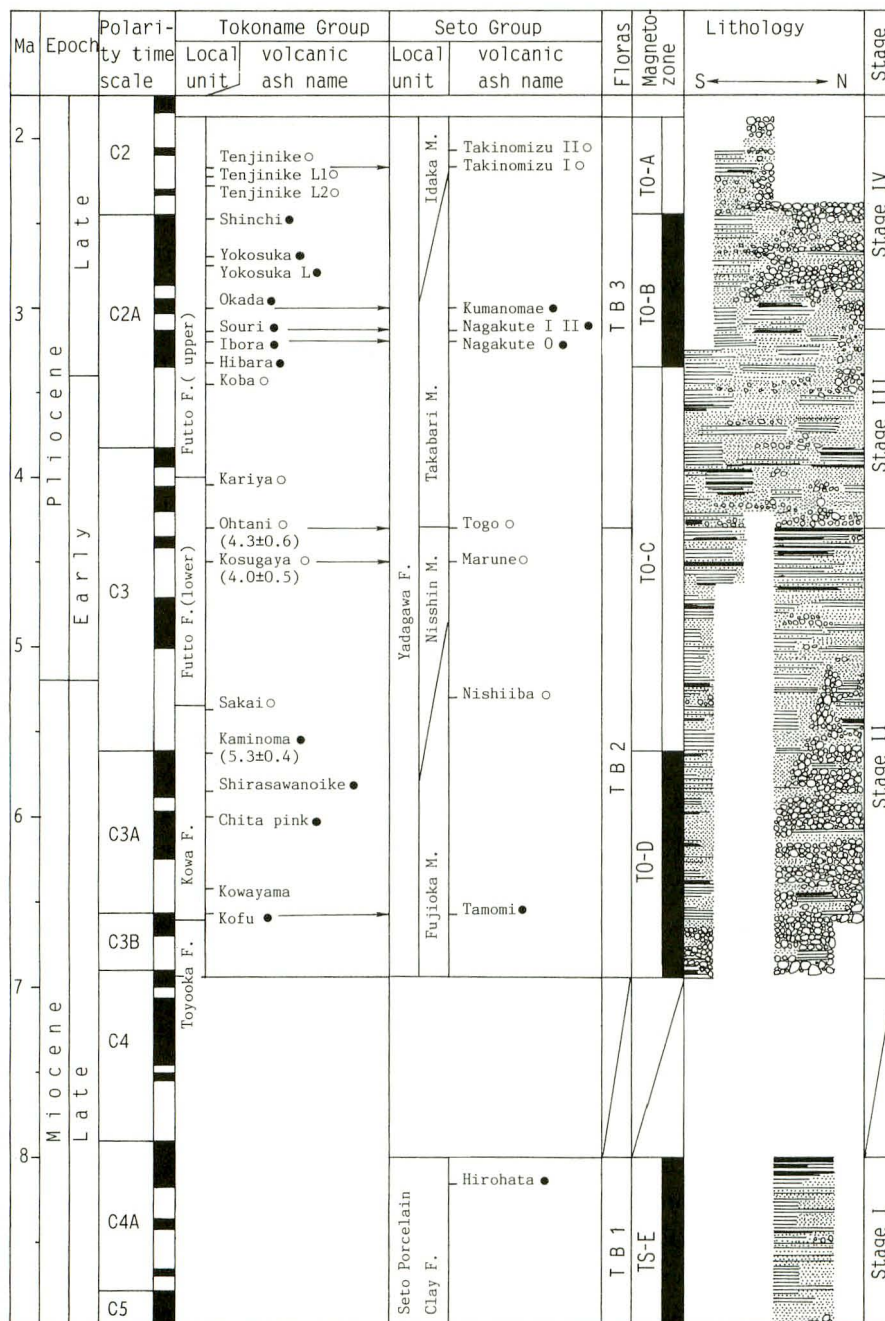


Fig. 25. Stratigraphy of the Tokai Group around the east coast of Ise Bay. Relationships between the standard geological time scale and the stratigraphy of the Tokai Group are discussed in Chapter VI. Open circles show reversed polarity, solid circles show normal polarity, and an arrow shows correlative volcanic ash layers. Geomagnetic polarity time scale is based on BERGGREN *et al.* (1985).

4.6. Stage units

On the basis of the lithofacies and the geological time horizon as a whole, the Tokai Group around the east coast of Ise Bay can be divided into 4 stages, stage I to IV in ascending order. Stage I contains the Seto Porcelain Clay Formation, which is absent in the Tokoname Group. Stage II extends from the bottom of the Yadagawa Formation to the Togo volcanic ash layer (the Fujioka and Nisshin Members), and from the lowermost horizon of the Tokoname Group to the Ohtani volcanic ash layer (the Toyooka, Ko(u)wa, and the lower part of the Futto Formations). Stage III extends from the top of the Togo volcanic ash layer up to the Nagakute I & II volcanic ash layer (mainly Takabari Member), and from the top of the Ohtani volcanic ash layer up to the Sourì volcanic ash layer (the middle part of the Futto Formations). Stage IV lies above the Nagakute I & II and Sourì volcanic ash layers (mainly the Idaka Member of the Yadagawa Formation, and the upper part of the Futto Formation). The relationship between the stratigraphical divisions and the stages is shown in Fig. 4 and Fig. 25. Geological age of each stage will be discussed in chapter 7.

5. Some sedimentological data

Sedimentological data in this section comprises mainly gravel composition, mean size of chert clasts, paleocurrent directions, and distribution of particular fragments. The method of gravel bed analysis follows the line method used by the TODO COLLABORATIVE RESEARCH GROUP (1982) and NAKAYAMA (1985). Features of gravel and sandy gravel beds are summarized in Table 2 and Fig. 26. Paleocurrent directions are deduced from channel with grain fabric of channel-fill deposits, and 3D dunes. Paleocurrent direction of 3D dunes is calculated as a vector mean direction based on ten or more measurements at each point. Paleocurrent directions and distribution of the mean size of chert clasts are shown in Fig. 27.

5.1. Features of gravel

In stage I of the Seto Porcelain Clay Formation, the formation is deficient in gravel or sandy gravel beds. Particular types of gravel are exposed along the periphery of the basin; one is poorly sorted angular to subangular hornfels breccia with mud matrix (G101=Ea4 in Fig. 10), the other is poorly sorted gravel comprising subrounded granite boulders.

The sediments of stage II are dominated by gravel. In the Seto Group, the clast size is the greatest in northern Komaki, Kasugai, and Fujioka, and becomes finer toward the southeast (Fig. 27). Both the mean size and the content of chert and Nohi rhyolites clasts decrease from Komaki to the south, whereas the mean size of the volcanic rock clasts of the Miocene Shidara Group decreases from

Table 2. Characteristics of gravel beds in the Tokai Group around the east coast of Ise Bay.
Localities of G101-453 are shown in Fig. 26.

Locality		G101	G201	G202	G203	G204	G205	G206	G207	G208	G209	G210	G211	G301	G302	G303	G351	G352	G353	G354	G355	G401	G402	G403	G404	G405	G406	G451	G452	G453
Proportion of rock type (%)	chert	8.6	56.2	64.4	72.4	89.7	71.2	82.9	77.4	85.0	87.0	71.3	45.9	82.5	77.3	77.7	61.1	65.2	78.8	70.6	75.5	52.5	70.4	80.2	78.4	77.4	88.6	72.4	86.7	88.3
	sand'mud(P+M)		20.4	13.0	5.4	3.8	10.7	5.8			10.8	14.4	18.5	10.5	8.4	4.9	18.6	14.6	7.2	6.7	6.4	28.0	14.2	7.8	6.2	7.2	3.5	3.8	0.8	1.6
	hornfels	91.4	10.6	3.2	2.7		1.6	0.9	0.9	2.7							3.7			0.8		14.3	4.5	4.2	5.0					
	granite		2.0	7.7	3.3	2.2	3.8	6.2						5.0	4.7	2.7	4.2	6.2	8.0	8.0	5.2		0.9					2.8		
	schist											4.2	14.2																	
	rhyolite I		10.8	10.8	10.5	3.4	9.3	2.1	2.8			2.0	4.4	2.4	11.3	9.2	2.5	7.2	2.7	5.3	10.0	4.2	2.2		2.4			2.4		0.9
rhyolite II					0.9	3.4	2.1	10.5	5.6			4.9		5.2	12.3		4.8	3.5	6.6	10.2			3.6	8.2	15.4	7.9	18.6	12.5	9.2	
andesite			0.9														1.1													
sand'mud(Mio.)					5.6				8.4	6.6	2.2	10.1	16.5																	
Mean size of each rock (mm)	chert	45	126	68	46	32	35	42	24	32	20	28	38	20	34	35	42	24	20	38	36	62	40	32	24	34	22	31	22	20
	sand'mud(P+M)		105	74	35	32	34	40			20	28	36	26	38	32	38	28	22	40	33	71	38	28	26	35	20	28	20	19
	hornfels	155	128	35	45		26	45	40	36							32			50		78	38	40	25					
	granite		83	59	42	28	32	26						22	30	43	34	25	20	41	33		40					28		
	schist											23	28																	
	rhyolite I		122	67	35	34	30	38	40					28	32	33	38	22	20	34	28	42	36	33	24			25		12
rhyolite II					37	23	36	38	35				29	38	45		26	23	32	30			33	28	32	20	28	18	20	
andesite			50														35							33	28					
sand'mud(Mio.)					44			50	38	26	32	30																		
Maximum size of each rock (mm)	chert	185	300	255	230	165	130	220	100	95	55	155	150	50	45	80	100	75	70	105	65	105	100	65	65	60	32	75	40	35
	sand'mud(P+M)		220	225	95	85	105	120			40	60	65	65	40	45	85	65	45	95	55	120	120	50	55	55	25	60	40	30
	hornfels	370	205	90	180		50	45	125	65							45			60		130	85	60	80					
	granite		165	270	155	70	55	85						40	45	75	90	70	40	65	40		40					45		
	schist											40	140																	
	rhyolite I		180	145	110	85	90	45	75					65	45	45	105	50	50	55	40	85	75	45	45			45		20
rhyolite II					52	50	40	65	55				60	40	65		45	50	50	45			40	45	40	25	40	35	35	
andesite			50														55													
sand'mud(Mio.)					80			80	75	55	55	190																		
Roundness	chert	Sr-sa	Sr-sa	Sr-sa	Sr-sa	Sr-sa	Sr-sa	Sr-sa	Sr-sa	R-sr	Sr-sa	Sr-sa	Sr-sa	Sr-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa	R-sa
	sand'mud(P+M)		R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sa	R-sa	R-sa	R-sa	R-sa	R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sr	R-sa	R-sr	R-sa	R-sa	R-sa
	hornfels	sa-a	R-sr	R-sr	R-sr		Sr	R-sr	R-sr	R-sr							R			R		R	R	R-sr	R-sr	R-sa	R-sr	R-sa	R-sa	R-sr
	granite		R-sa	R-sr	R-sr	R-sa	Sr	Sr-sa						R-sr	R-sr	R-sa	R-sr	R-sr	R-sr	R-sr	R-sr		Sr						R-sr	
	schist											Sr-sa	Sr-a																	
	rhyolite I		R	R-sr	R-sr	R-sr	Sr-sa	Sr-sa	Sr-sa	R-sr				R-sa	R-sr	R-sr	R-sr	R-sr	R-sa	R-sa	R-sa	R-sa	R-sr	R-sr	R-sr	R-sr			R-sa	
rhyolite II					R-sa	Sr-sa	Sr-sa	Sr-sa	R-sa	R-sa			R-sr	R-sa	R-sa		R-sa	R-sa	R-sa	R-sa			Sr-sa	R-sa	R-sr	R-sr		R-sa		R-sr
andesite			R														R-sr													
sand'mud(Mio.)					R-sr			R-sr	R-sa	R-sa	R-sa	R-sa																		
Gravel content (%)		76.5	52.5	57.8	56.4	60.5	49.5	62.5	57.2	68.4	21.6	38.2	75.5	22.4	25.3	40.5	48.4	40.5	20.8	40.8	44.5	54.3	60.4	38.4	40.5	35.4	25.6	44.2	28.3	20.3

sand'mud(P+M):sandstone and mudstone of Paleo-Mesozoic, graniteincludes aplitic rock, sand'mud(Mio.):sandstone and mudstone of Miocene, rhyolite I may be Nohi rhyolites, rhyolite II may be Shidara volcanic rocks(Miocene),| r:rounded, sr:subrounded, sa:subangular, a:angular

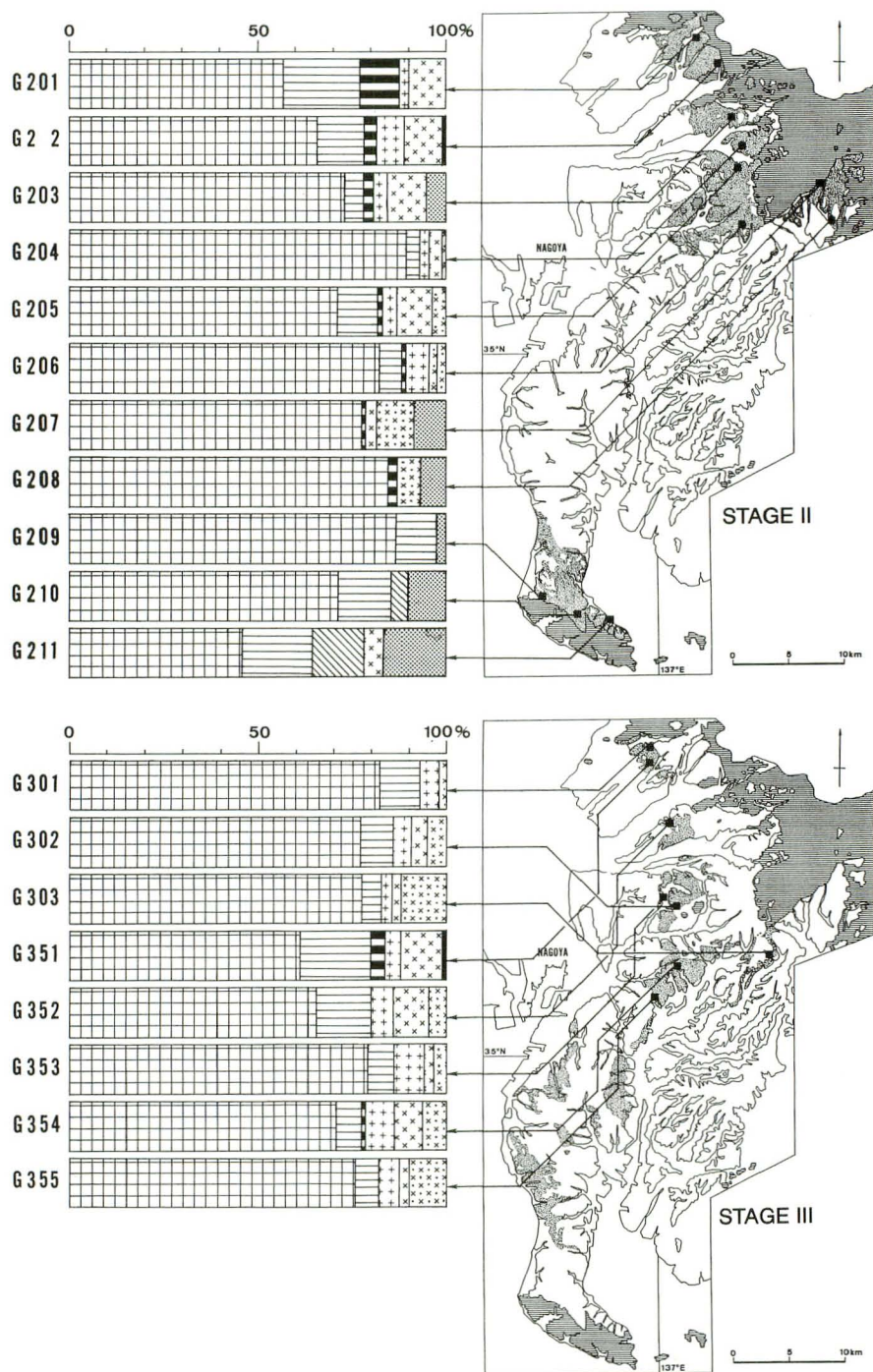


Fig. 26. Gravel composition (continued).

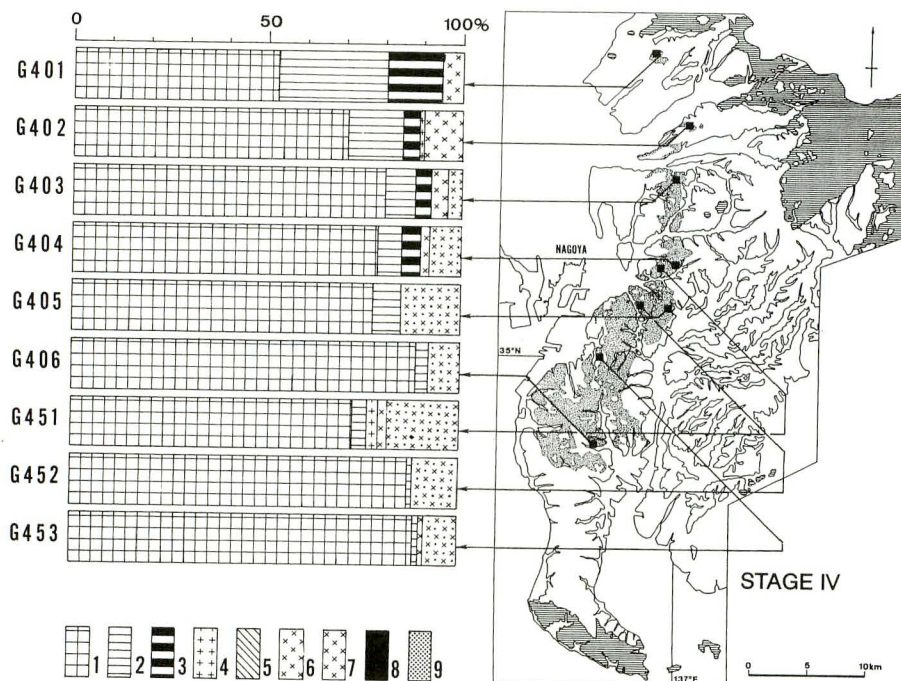


Fig. 26. Gravel composition.

Dotted areas show the distribution of each bed during each stage. 1: Chert, 2: Sandstone & mudstone (Mesozoic-Paleozoic formations), 3: Hornfels, 4: Granites, 5: Schist, 6: Nohi rhyolites, 7: Shidara volcanic rocks (Miocene), 8: Andesite, 9: Sandstone & mudstone (Miocene).

Toyota and Fujioka westward. Clasts of the Shidara Group are not recognized at Komaki. In the Tokoname Group, the mean size of chert clasts is the largest at Toyooka, and decreases to the northwest. The Toyooka Formation includes schist clasts derived from the Outer Zone of Southwest Japan. Along the periphery of the basin, particular type of gravel beds are observed (Fig. 28). One comprises well sorted pebbly gravel beds with superimposed boulders at Tamomi, Ohyama, and Hokusogi. NAKAYAMA (1992) described the gravel bed at Ohyama. The other type comprises poorly sorted gravel beds composed of angular to subangular clasts with mud matrix, found at Kano and eastern Kozoji.

In stage III, gravel beds are distributed mainly in the lowermost part of the stage. The gravel beds in the lowermost part of the stage consist mainly of pebbly gravel, which includes volcanic rock clasts of the Shidara Group. Along the periphery of the basin at Komaki, poorly sorted gravel beds with mud matrix occur.

In earlier stage IV, the gravel content rapidly decreases southward from Komaki. The clasts in the gravel consist of chert and hornfels. The gravel in later stage IV, distributed around southern Nagoya, is dominated by volcanic rock clasts

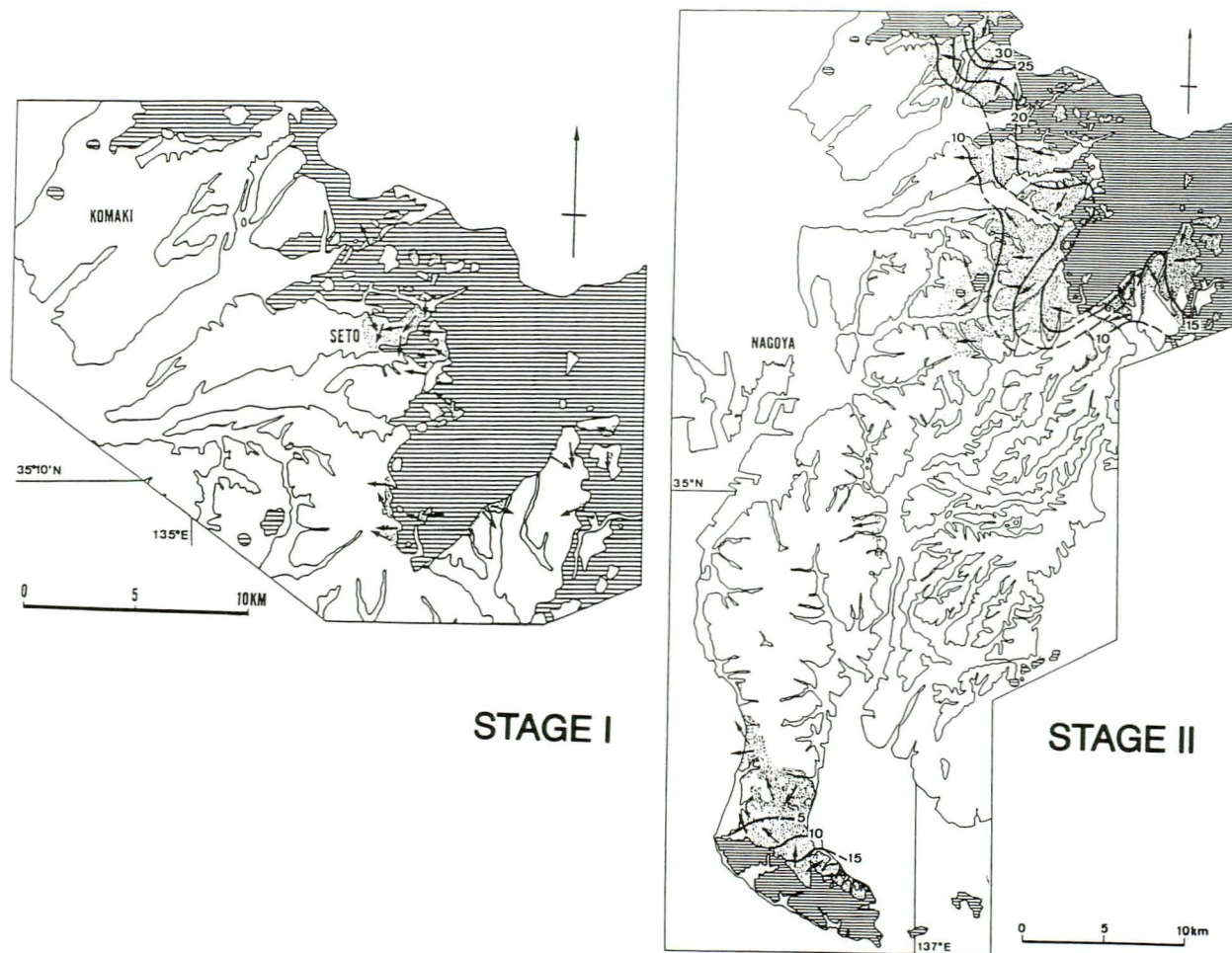


Fig. 27. Paleocurrent directions and mean size of chert clasts (continued).

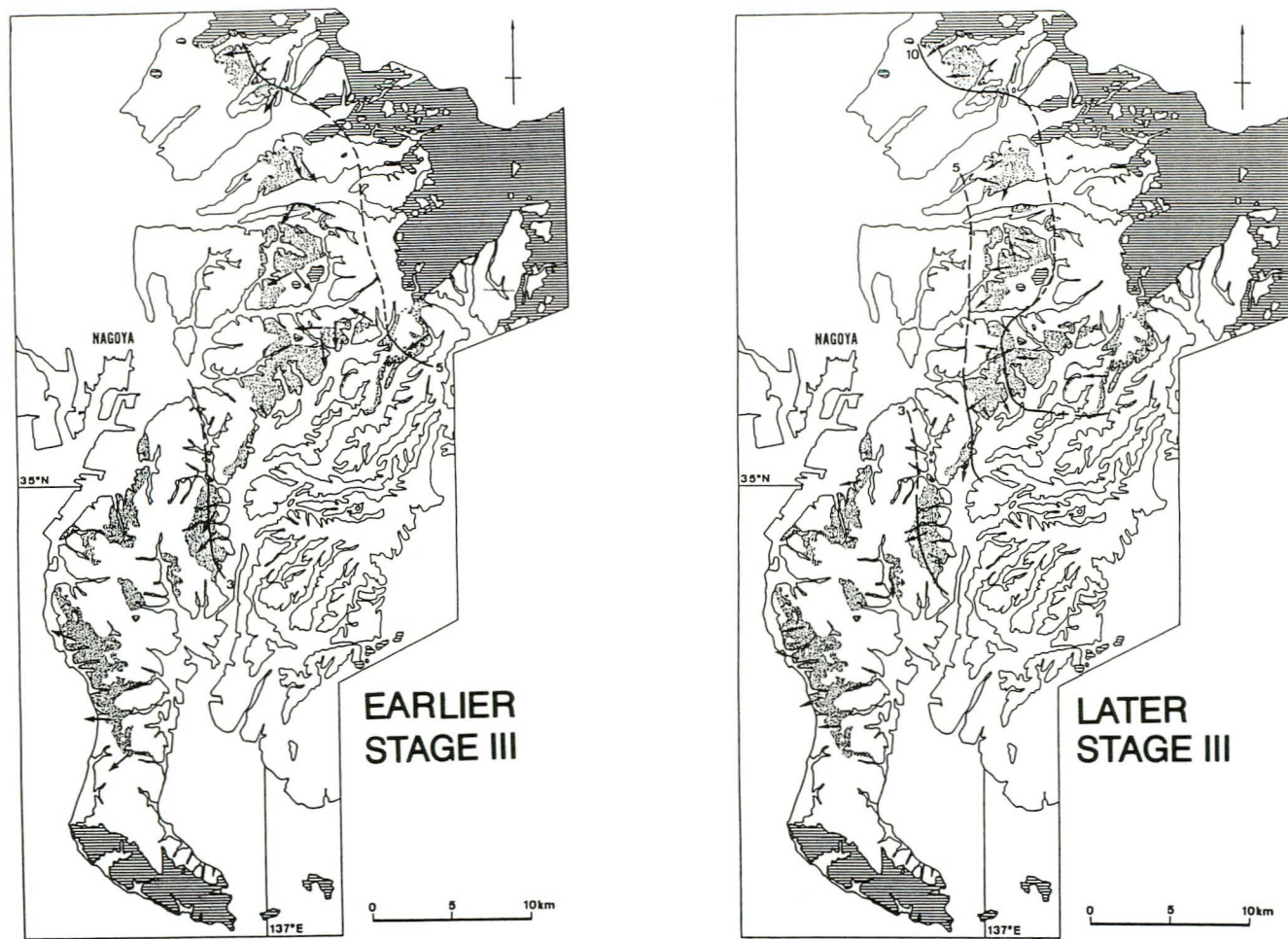


Fig. 27. Paleocurrent directions and mean size of chert clasts (continued).

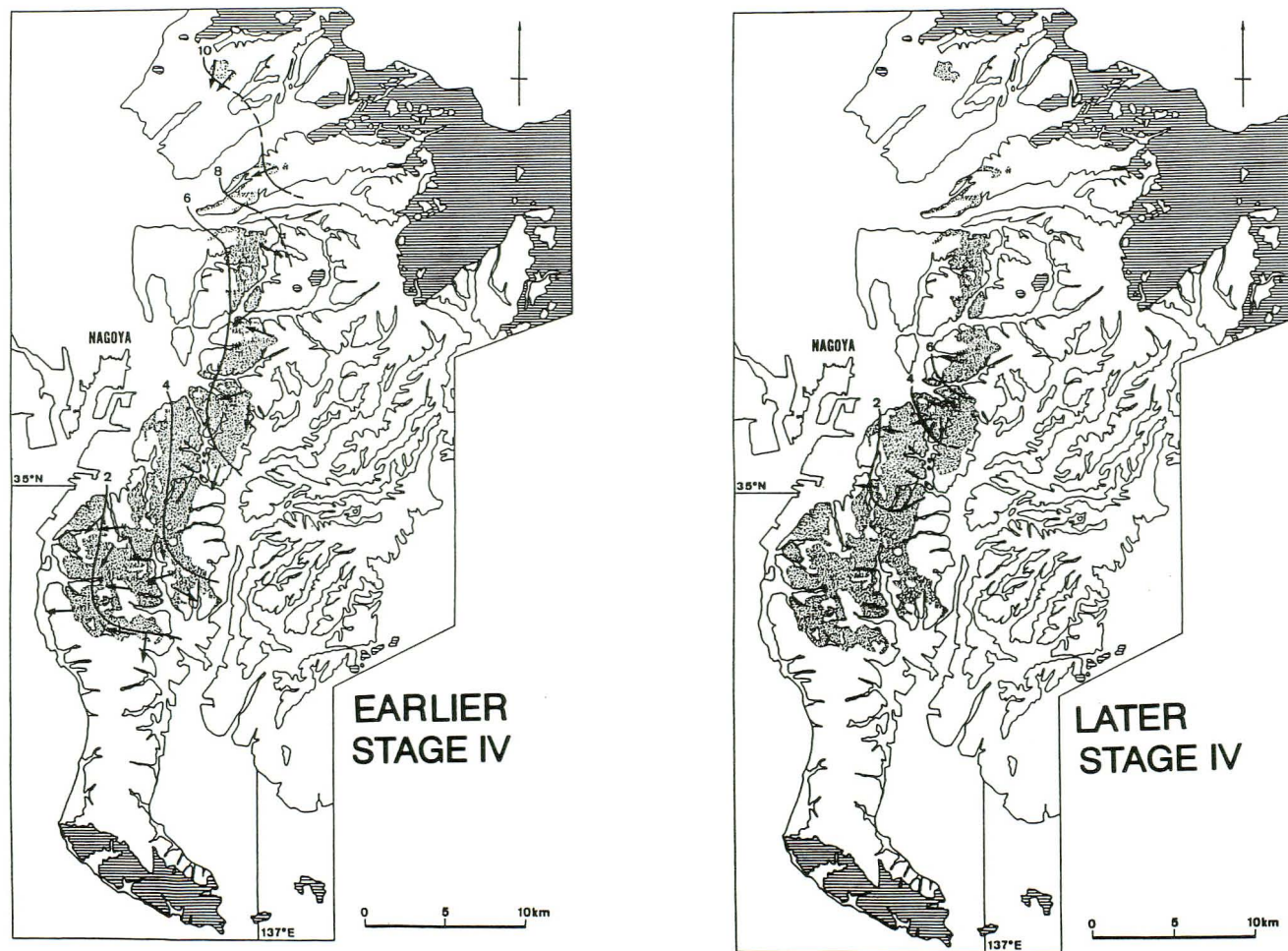


Fig. 27. Paleocurrent directions and mean size of chert clasts

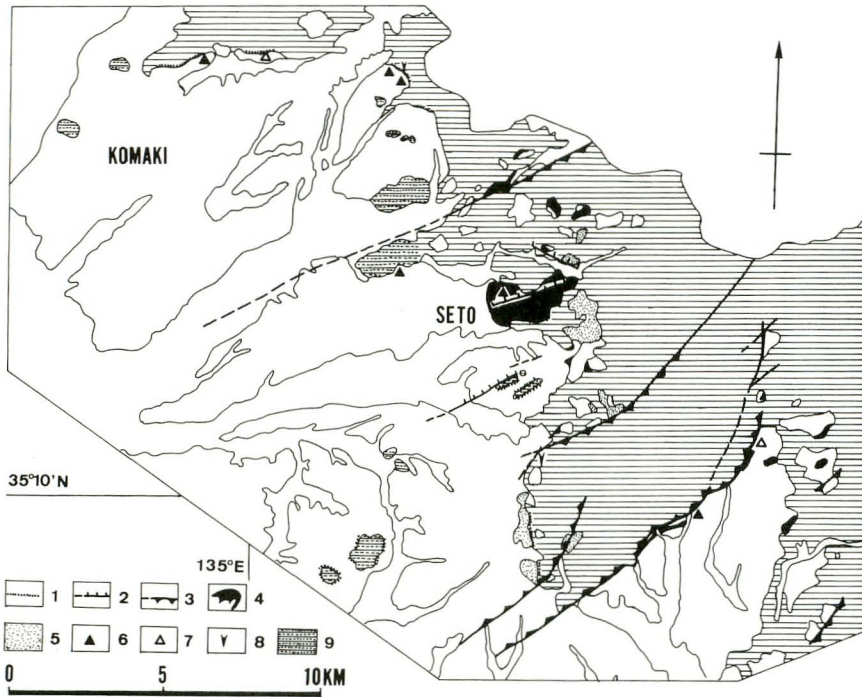


Fig. 28. Characteristics of the peripheries of the sedimentary basins in the Seto Group area. 1: High angle unconformity, 2: Normal fault, 3: Thrust, 4: Seto Porcelain Clay Formation (coarse part), 5: Seto Porcelain Clay Formation (fine part), 6: Poorly sorted gravel bed (matrix-supported), 7: Well sorted gravel bed with superimposed granite boulders (NAKAYAMA, 1992); 8: Wedge shaped breccia beds (YOSHITANI & YAMAUCHI, 1981), 9: Micro-ridge.

from the Shidara Group.

5.2. Paleocurrent directions

In stage I, NAKAYAMA (1991) described the distribution of paleocurrents around northern Seto City. These data, along with the new measurements made here in stage I, show paleodispersal to the east around Yagusa, and to the south around Fujioka-cho (Fig. 27).

In earlier stage II, paleocurrent measurements indicate a southward- or westward-directed flow around Fujioka-cho, and northerly or westerly flow around southern Chita Peninsula. In later stage II, directions appear to be to the west or to the north, but overall they are rather ambiguous.

In the earliest stage III, paleocurrent measurements indicate a southward- and westward-directed flow in the region of the Seto Group and the northern Chita Peninsula. In middle stage III, paleocurrents are indistinct around eastern Nagoya, but in the Chita Peninsula, paleocurrent directions are to the south and southwest. In

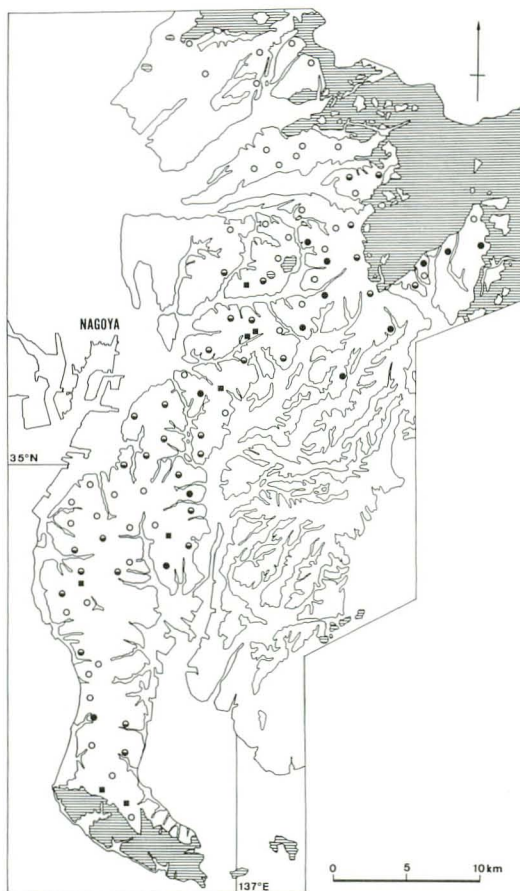


Fig. 29. Distribution of zircon grains of the Busetsu granite.
 Circles: number of all zircon grains more than 10, open circles: none of the Busetsu granite zircon, half open circles: less than 3 grains of the Busetsu granite, solid circles: more than 4 grains of the Busetsu granite, solid squares: number of all zircon grains less than 3 grains.

later and partly middle stage III, paleocurrent directions are to the west and southwest.

In earlier stage IV, paleocurrent directions suggest flow to the southwest and east, but the evidence is rather ambiguous in the central Chita Peninsula. In later stage IV, paleocurrent directions are from east to west.

5.3. Distribution of particular fragments

The content of zircon grains of the Busetsu granite (see Fig. 1) in the sediments of the Tokai Group was measured at 94 sites. The Busetsu granite is limited in area to 20 km to the east of the study area (Fig. 1). These zircon grains are readily distinguished from those originating in other granites around the Tokai Group, due to their acute angled top. Samples were obtained from fine sand beds.

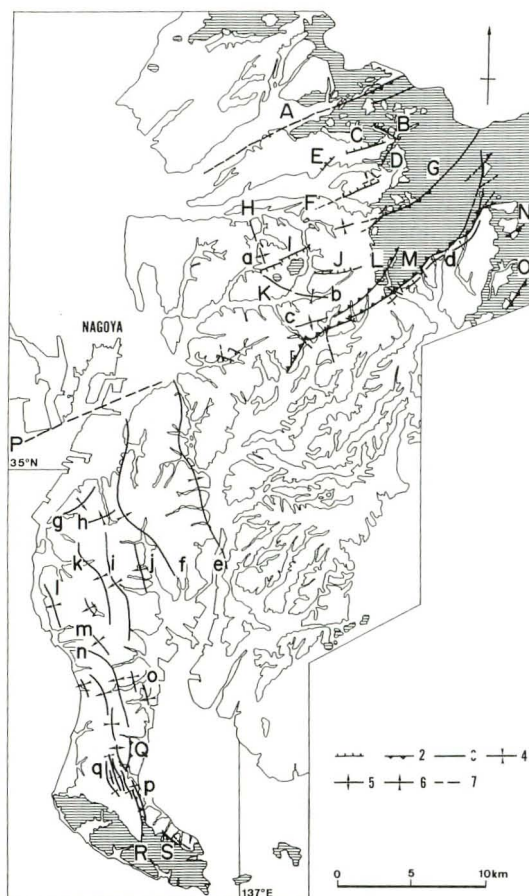


Fig. 30. Geological structures around the east coast of Ise Bay.
 1: Normal fault, 2: Reverse fault, 3: Vertical fault, 4: Syncline, 5: Anticline,
 6: Flexure, 7: Inferred fault.

Each sample weighted 500 g. Zircon grains were separated by water washing, sieving (1/4 – 1/8 mm), and panning, followed by counting under the microscope. Measurements are summarized in Fig. 29.

These data suggest three points; (1) the zircon grains from the Busetsu granite dominate around the south-eastern Nagoya and the Fujioka-Nisshin areas, (2) a small number of the grains exists in Chita Peninsula area, (3) the zircon grains are absent around the Komaki-Kasugai area.

6. Geological structure

Geological structures around the east coast of Ise Bay and their characteristics are shown in Fig. 30 and Table 3. Level maps of the Togo-Ohtani, Nagakute I & II-Souri, and Takinomizu I-Tenjinike volcanic ash layers are shown in Fig. 31.

6.1. Geological structure of the Seto Group

In the Seto Group, northeast to southwest faults are well exposed. Representative ones are the Kasahara, Sanageyamakita, Hirohara, and Sanage-Sakaigawa Faults, all of which can be traced over 7 km. The Kasahara Faults and west margins of the other three faults are deeply buried and only flexures are observed. Each fault consists of a number of short faults (Fig. 30). The vertical slip of each fault is more than 50 m, but decreases southwestward into a flexure. The Sanage-Sakaigawa Faults raised the base of the Yadagawa Formation 150 m at Fujioka-cho and 80 m at Togo-cho, the Togo volcanic ash layer 90 m at Miyoshi-cho and 50 m in Togo-cho, and the Miyoshi Formation 30 m (NAKAYAMA, 1987). The uplifted area from the northwest side of the Sanage-Sakaigawa Faults to the southeast side of the Sanageyamakita Faults corresponds to the northern half of the Sanage-Chita Uplift Zone.

Numerous faults are recognized in the exposed basement rock near the boundary between the basement rock and the Seto Group.

6.2. Geological structure of the Tokoname Group

In the Tokoname Group, the north-northwest to south-southeast flexures are well exposed. Representative ones from southwest to northeast are the Hibara, Hongusan, Souri, Handaike, Hirai, Nawa-Kagiya, and Ohdaka-Ohbu Flexures. The latter two flexures raised the west side more than 200 m vertically. The first five flexures raised the east side up to 70 m. Altogether these seven flexures formed the Handa Syncline, the axis of which is the same as that of the Nawa-Kagiya Flexure. The Chita Peninsula forms the southern part of the Sanage-Chita Uplift Zone. The boundary between the Seto and Tokoname Groups is the Ohdaka-Ohbu Flexure, east of which the Tokai Group is thickest around the east coast of Ise Bay.

7. Discussion

7.1. Stratigraphical position

7.1.1. Stratigraphical position of the Seto Porcelain Clay Formation

MATSUZAWA *et al.* (1960) considered that the Seto Porcelain Clay Formation was unconformably overlain by the Yadagawa Formation in the eastern hills, but the contact could be conformable in the western basin under the Nobi Plain. MAKINOUCHI (1983) postulated that the unconformity between them represented a hiatus of several million years. NAKAYAMA (1987) regarded it as only locally unconformable with a hiatus of about one million years. His reasons were given below.

At some outcrops (e.g., Fa4 in Fig. 10, C02 in Fig. 14), the Yadagawa Formation overlies the Seto Porcelain Clay Formation with a slightly dipping erosional surface. At other outcrops (e.g., Ea5, 6, and 7 and Fa5, 6, and 7 in Fig. 10), the

Table 3. Characteristics of each geological structure around the east coast of Ise Bay.

Mark on map	Name	Locality	Length (km)	Direction of fault plane	Net slip (m)	T*	Df ⁺	Reference
A	Kasahara	Shidami-(Kasahara)	17	ENE-WSW	100-150	R	NNW	Akamine(1954)
B	Shinano	Shinano	2.5	WNW-ESE	70	N	SWS	Tanemura(1964)
C	Akatsuki	Mizuno	2.5	N70°E70°N	2- 3	N	SES	Mizuno(1986)
D	Konyada	Shinano-Shinmichi	2	NNE-SSW	5- 10	N	ESE	Tanemura(1964)
E	(unnamed)	Yamate	1.5	N40°E56°W	3- 4	N	SE	
F	Hishino	Hishino-Yamanota	5	N48°W70°W	10- 20	N	SE	Mizuno(1986)
G	Sanageyamakita	Yoshino-(Tsurusato)	20	N40°E90°	10-200	-	NW	R.G.A.F.** (1980)
H	(unnamed)	Fujimori	1.5	NNW-SSE	10- 30	N	SW	Mori(1971b)
I	(unnamed)	Makinogaike-Nagakute	4	N58°W50°S	5- 10	N	NW	Nakayama(1987)
J	(unnamed)	Goshikien	2.5	E-W80°N	4	N	S	Nakayama(1987)
K	(unnamed)	Makinogaike-Iwasaki	2	N70°W90°	20	-	SWS	Nakayama(1987)
L	Hirohata	Hirohata-Tamomi	7	N25°E74°N	1-150	R	SE	Nakayama(1987)
M	Sanage·Sakaigawa	Fujioka-Toyoake	23	N50°E72°N	1-150	R	SE	Nakayama(1987)
N	(unnamed)	Tamodaira	2	N40°E80°S	20	R	NW	Nakayama(1987)
O	(unnamed)	Narai	2	N40°E82°S	5	R	NW	Nakayama(1987)
P	Tenpakukako	Ohdaka-Nagoya Port	10	ENE-WSW	1-300	-	NNW	Kuwahara(1976)
Q	(unnamed)	Kowa-Futto	2.5	N-S	10+	-	W	Kondo·Kimura(1987)
R	Kofu	Kowa-Iwaya	5	N8°W55°E	20+	R	WSW	Kondo·Kimura(1987)
S	(unnamed)	Yanashi-Hongo	2	N10°W68°W	20+	R	ENE	Kondo·Kimura(1987)

Mark on map	Name	Locality	Length (km)	Direction of axis	V.D. (m)	T*	Df ⁺	Deformation Width Dmax.	Reference
a	(unnamed)	Takabari	1	NNW-SSE	--	A	--	5°-8°W[W] 8°-15°E[E]	Mori(1971b)
b	Tenpakugawa	Fujieda-Komenogi	1.5	WNW-ESE	--	S	--	5°S[N] 5°-8°N[S]	Nakayama(1987)
c	Togo	Aichiike-Wago	1.5	ENE-WSW	--	A	--	5°-15°N[N] 5°S[S]	Nakayama(1987)
d	Sanage	Iino-Homi	10	NE-SW	--	S	--	50°-80°S[N] 8°-15°N[S]	Nakayama(1987)
e	Ohdaka-Ohbu	Ohdaka-Kariya	11	NNW-SSE	300	F	ENE	300 85°E	Matsuzawa·Uemura(1957)
f	Nawa-Kagiya	Nawa-Handa	15	NNW-SSE	200	F	ENE	800 60°E	Matsuzawa·Uemura(1957)
g	(unnamed)	Okada	3	NE-SW	10	F	SE	50 20°E	Yoshida·Ozaki(1986)
h	(unnamed)	Souri	2	ENE-WSW	25	F	NNW	100 30°N	Yoshida·Ozaki(1986)
i	Hirai	Aoyama-Okada	10	NNW-SSE	60	F	SW	200 22°W	Yoshida·Ozaki(1986)
j	Agui	Agui	3.5	NNW-SSE	40	F	WSW	100 25°W	Yoshida·Ozaki(1986)
k	Handaie	Itayama-Handa	8	NNW-SSE	70	F	WSW	250 28°W	Yoshida·Ozaki(1986)
l	Chiyoogaoka	Chiyoogaoka-Hara	3	NNW-SSE	50	F	WSW	100 24°W	Yoshida·Ozaki(1986)
m	Hongusan	Hibara-Okuei	6	NW-SE	45	F	SW	150 28°W	Yoshida·Ozaki(1986)
n	Hibara-Rokkanyama	Rokkanyama	7	NNW-SSE	30	F	WSW	300 30°W	Okada(1979)
o	Higashodaka	Taketoyo	1.5	NNW-SSW	--	F	WSW	--- ---	Okada(1979)
p	Kowa	Kowa-Iwaya	3	NNW-SSW	--	A	--	55°W[W] 10°E[E]	Makinouchi(1975)
q	(unnamed)	Mihama	2.5	NNW-SSW	--	A,S	-	5°-10°W 5°-10°E	Makinouchi(1975)

T*: Type of geological structure (N: Normal fault, R: Reverse fault, F: Flexure, A: Anticline, S: Syncline), Df⁺: Direction of footwall, V.D.: Maximum vertical displacement, Deformation Width: Deformation width of flexure in meters, D_{max}: Maximum dip in degrees, []: Wing, R.G.A.F.: The Research Group for Active Faults. Locality name in parenthesis indicates the outside of the study area.

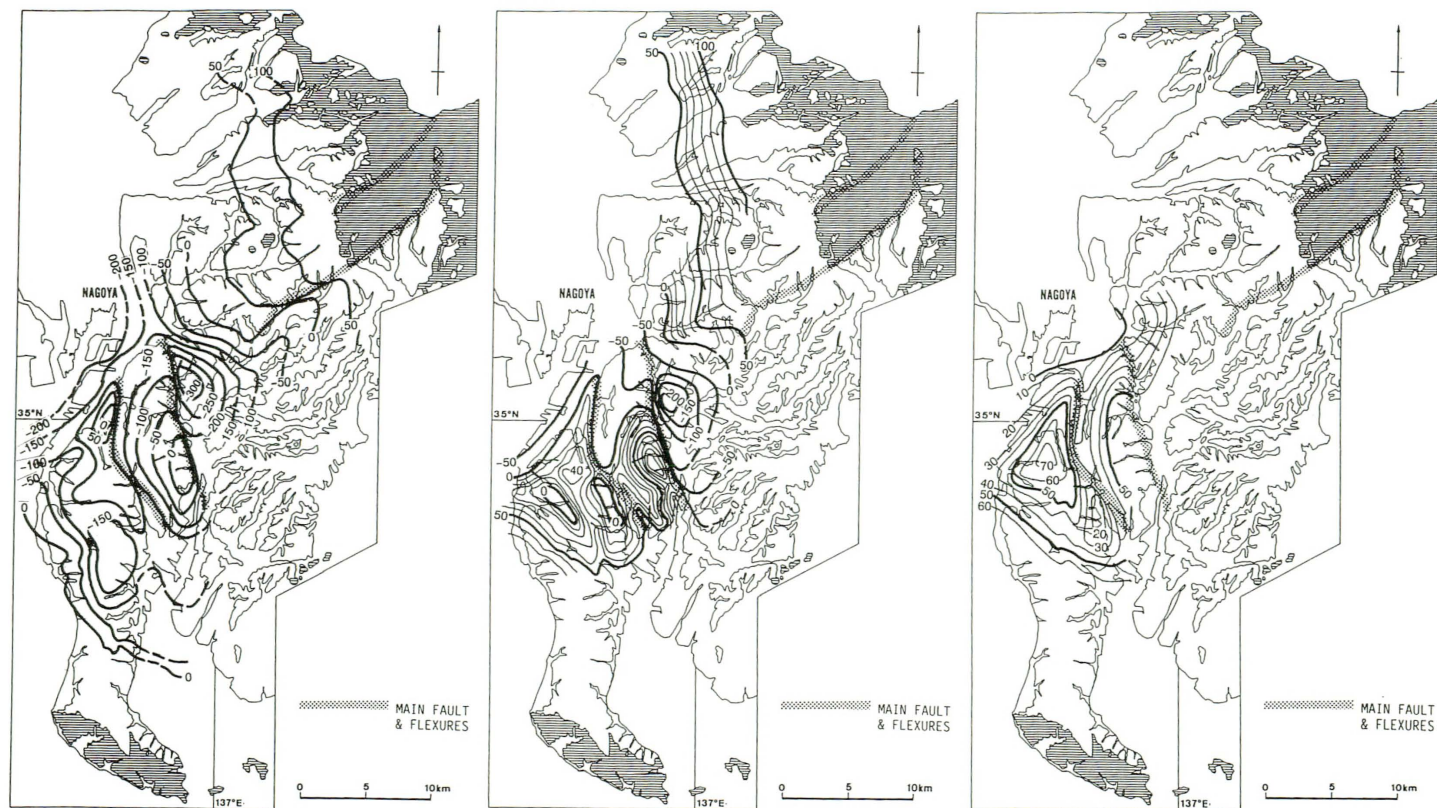


Fig. 31. Level of volcanic ash layers.

Left map represents the Togo-Ohtani volcanic ash layer, central one the Nagakute I & II-Souri volcanic ash layer, and the right one the Takinomizu I-Tenjinike volcanic ash layer. The numbers are the altitude above sea level in meters.

Yadagawa Formation seems to overlie the Seto Porcelain Clay Formation conformably. However, thick sandy gravel or gravel beds of the Yadagawa Formation, which are not observed in the Seto Porcelain Clay Formation, overlie mud and sand beds of the Seto Porcelain Clay Formation. The sedimentary systems, at least, clearly changed between deposition of the two formations. Moreover, sedimentary basins of the Seto Porcelain Clay Formation are very small, less than 2 km across, and are sporadically distributed, whereas those of the Yadagawa Formation are noticeably larger, more than 10 km across (see Fig. 33). The difference in geological structure suggests a time interval between the deposition of these formations. A new wider sedimentary basin evidently was reformed by structural movements before deposition of the Yadagawa Formation.

On the other hand, nine extinct genera and 66 extinct species of plants were reported from the "*Pinus trifolia* bed" Flora of the TB1 biozone (MIKI, 1948). The plant assemblage of the TB2 biozone has some species common to one of the TB1 biozone. However, in the TB2 biozone, *Trapa mammillifera*, *T. dolichocarpa*, *Sparganium protojaponicum* and others first appeared (NASU, 1972). This indicates a time interval between these two biozones.

The Seto Porcelain Clay Formation unconformably overlies the marine Miocene. Its age is considered to be greater than 14 Ma on the evidence of planktonic foraminifers (SHIBATA & ITOIGAWA, 1980), whereas the basal part of the Yadagawa Formation is dated at about 7 Ma (see following chapter). Furthermore, there is a distinct unconformable relationship and difference in consolidation observed between the Seto Porcelain Clay Formation and the marine Miocene. This indicates a longer interval between them than that between the Seto Porcelain Clay Formation and the Yadagawa Formation. The Seto Porcelain Clay Formation is 20–30 m thick, which is considered to indicate a period of about 1 m.y. to deposit. Because the sedimentation rate of the Yadagawa Formation is calculated as 0.020–0.037 m/10³ years (see Fig. 35). From the above, the Seto Porcelain Clay Formation is inferred to have been deposited in a period of 1 m.y. at about 9 Ma.

7.1.2. Stratigraphical position of the Tokai Group around the east coast of Ise Bay

The tephrostratigraphy and radiometrical data from the volcanic ash layers provide a means of correlating the magnetozones to the standard polarity time scale. The results indicate that the TO-A Magnetopolarity Zone correlates with the Matuyama Reversal Epoch, the TO-B Magnetopolarity Zone with the Gauss Normal Epoch, the TO-C Magnetopolarity Zone with the Gilbert Reversal Epoch, the TO-D Magnetopolarity Zone with the Chron 3 Epoch, and TS-E Magnetopolarity Zone with the Chron 4-5 Epoch (after NAKAYAMA & YOSHIKAWA, 1990).

The uppermost horizon of the Tokai Group around the east coast correlates with the Matuyama Reversal Epoch. The Second Setouchi Supergroup, except for the Tokai Group around the east coast of Ise Bay, contains the Fukuda volcanic

ash layer and its correlatives. The fission-track age of the Fukuda volcanic ash layer was calculated as 1.59 ± 0.22 , 1.60 ± 0.25 Ma (ITIARA *et al.*, 1984). The ash layer correlative with the Fukuda volcanic ash layer occurs in the Tokai Group around the west coast, but it is above the Tokai Group around the east coast of Ise Bay, according to the geological structure. Moreover, no horizon correlative with the Olduvai Event has been recognized in the Tokai Group around the east coast of Ise Bay. These facts suggest that the uppermost part of the Tokai Group around the east coast is restricted to below the Olduvai Event. It can be inferred, therefore, that the deposition there of the Tokai Group ended between 2.4 Ma and 1.9 Ma. This age estimate is supported by pollen fossil evidence, as *Nyssa* pollen grains are still present in the upper part of the Tokai Group around the east coast, which indicates a stratigraphical position below the Fukuda volcanic ash layer.

The upper part of the Tokoname Group can be assigned to the Gauss Normal Epoch. It can be used to determine the rate of sedimentation, because abundant paleomagnetic data are available for the Gauss Normal Epoch. As the TO-B Magnetopolarity Zone in the Tokoname Group is 150 m thick, the sedimentation rate is estimated at 160 m/m.y. This rate agrees well with the rate of 0.15–0.17 m/10³ years (MAKINOCHI *et al.*, 1983) based on fission-track dating of volcanic ash layers. The Matuyama Reversal Epoch in the Tokoname Group is 150 m thick, and its deposition is estimated to have required at least 0.83 m.y, assuming a constant sedimentation rate. The sedimentation apparently ended at about 1.59 Ma, and the somewhat coarser facies of the uppermost part may indicate that sedimentation ended earlier than 1.59 Ma because in the Tokai Group such coarse facies suggest a faster sedimentation (MAKINOCHI *et al.*, 1983). Altogether, sedimentation ended at 1.9 Ma which is a little before the beginning of the Olduvai Event.

Sedimentation of the Yadagawa Formation and the Tokoname Group is considered to have begun at 6.5 Ma (MAKINOCHI *et al.*, 1983) on the basis of fission-track dates from the Kaminoma and Ohtani volcanic ash layers. The sedimentation rate during the Gauss Epoch (160 m/m.y.) indicates that the lowest horizon of the Ko(u)wa Formation is at least 6.0 Ma. The Toyooka Formation (overlain by the Ko(u)wa Formation), is 85 m thick, and its gravelly facies indicates a high sedimentation rate. Its deposition is inferred to have required 0.5 Ma. From these data, the age of the lowest horizon of the Tokoname Group is inferred to be 6.5 Ma which is the same as that given by MAKINOCHI *et al.* (1983). The paleomagnetic data, however, suggest that the normal geomagnetic polarity of the Kofu volcanic ash layer should be assigned to the C3B Epoch rather than to the C3A. If that is correct, deposition of the Tokoname Group and the Yadagawa Formation started about 7.0 Ma. In connection with the sedimentation rate during the Gauss Normal Epoch, the age of the Souri volcanic ash layer can be estimated at about 3.1 Ma.

These discussions indicate a period of each stage (stage I-IV) to be 9–8 Ma, 7.0–4.3 Ma, 4.3–3.1 Ma, and 3.1–1.9 Ma, respectively.

A summary of the stratigraphical data for the Tokai Group is shown in Fig. 25. Its correlation with the Second Setouchi Supergroup, based on stratigraphy is given in Fig. 32.

7.2. Structural movement

7.2.1. Sedimentary basins of the Seto Porcelain Clay Formation

The sedimentary basins of the Seto Porcelain Clay Formation are very small basins, all being less than 4 km² in area. They were formed by small block movements, as is shown by the following evidence.

Debris flow and alluvial fan deposits, which are exposed along the peripheries of the basin, overlie the marginal rocks with steep-angled unconformities, and numerous faults are observed in the basement rock around the peripheries. These suggest that small basement blocks dropped to cause structural basins with steep cliffs along the peripheries. The steep cliffs were rapidly covered with debris flow or alluvial fan deposits which protected the steep unconformities. Due to this preservation and good exposures of their margins, the size of the basins is readily determined.

7.2.2. Sedimentary basin of the Tokai Group

The sedimentary basin of the Tokai Group, except for the Seto Porcelain Clay Formation, was formed by block movements. The blocks, 5–10 km in circumference, are outlined from geological structures and the altitudes of volcanic ash layers (Figs. 31 & 33). Some particular sediments, such as debris flow deposits and the gravel with superimposed boulders, along with unconformities, are observed along the margins of the blocks, where the sediments are in contact with basement rocks. Movements of each block can be estimated by the altitude maps of volcanic ash layers (Fig. 31), and are summarized in the following (Fig. 34).

During stage II, the S1-S4, T4, and Sanage Uplift B Blocks collapsed. Along these blocks except for the Sanage Uplift B Block, poorly sorted gravel was deposited. This means the basin formed rapidly.

During stage III, the S4, T4, and Sanage Uplift B Blocks changed from subsiding to uplifting blocks. The others still subsided. Generally, the amount of subsidence in the Seto Group is small. The T1 - T3 Blocks in the Tokoname Group area show much subsidence, along with tilting toward Handa. The S5 Block dips westward. The different subsidence between the S5 and T1 blocks marked the beginning of the Ohdaka-Ohbu Flexure.

During stage IV, subsiding and tilting blocks were limited to the central part of the east coast of Ise Bay. The S5 Block maintained the same activity as in

stage III, but the T1 and T2 Blocks changed their direction of tilt. After that, all blocks rose.

The sedimentary basin of the Tokai Group existed for more than 6 m.y., a long time in such an active arc area. It contained the above mentioned depressed areas caused by block movements. Such block movements are observed in the Tono district of Gifu Prefecture (NAKAYAMA & TODO COLLABORATIVE RESEARCH GROUP, 1989a, 1989b) and the Kobiwako Group (KAWABE, 1989). The Late Cenozoic intra-arc basin in Southwest Japan may consist of several blocks, rather than one large one.

7.2.3. Characteristics of the Sanage-Chita Uplift Zone

The Sanage-Chita Uplift Zone can be divided into the Sanage Uplift Zone (southwest trend), and the Chita Uplift Zone (south-southeast trend). The former formed since stage II, the latter since stage III. KAWABE (1989) documented that the Sanage-Chita Uplift Zone might comprise two different structural zones. This paper clarifies the characteristics of the uplift zone on the basis of geological structure and stratigraphical position.

Sanage Uplift Zone

The Sanage Uplift Zone is bounded by the Sanage-Sakaigawa Faults. NAKAYAMA (1987) showed that the faults became active after deposition of the Seto Group, and calculated their overall vertical velocity as $0.01\text{--}0.04\text{ m}/10^3\text{ years}$, but $0.01\text{--}0.02\text{ m}/10^3\text{ years}$ during deposition of the Tokai Group. The deposition of the Seto Group was two or three times as fast as the vertical velocity of the faults.

The altitude difference of three volcanic ash layers (Fig. 31) on both walls of the Sanage-Sakaigawa Faults decreases to the southwest. This indicates that activity on the faults began at the northeast part and spread from there southwestward.

The Sanage Uplift Zone is considered to comprise the Sanage Uplift A, B, and C Blocks. The Sanage Uplift A Block has the largest vertical movements outside the Seto Group. The Sanage B Block is associated with the Hirohata Faults which elevated the block after the Togo volcanic ash layer was deposited. The Sanage Uplift C Block was only slightly raised by the Hirohata Faults, and there is only a small difference in thickness between both walls of the Sanage-Sakaigawa Faults.

The Sanage Uplift A Block, formed by the Sanage-Sakaigawa and Hirohata Faults, existed as a topographic barrier before deposition of the Yadagawa Formation. The Sanage Uplift B Block, bounded by the Sanage-Sakaigawa Faults and the Hirohata Faults, was uplifted during deposition of the Seto Group. The Sanage Uplift C Block was uplifted mainly after deposition of the Togo volcanic layer, but it rose less than the other blocks. These three blocks at least were hilly land before deposition of the Middle Pleistocene Miyoshi Formation. Distribution of the Miyoshi Formation is limited by the Hirohata Faults and by its contact with the Seto Group, where there are no faults

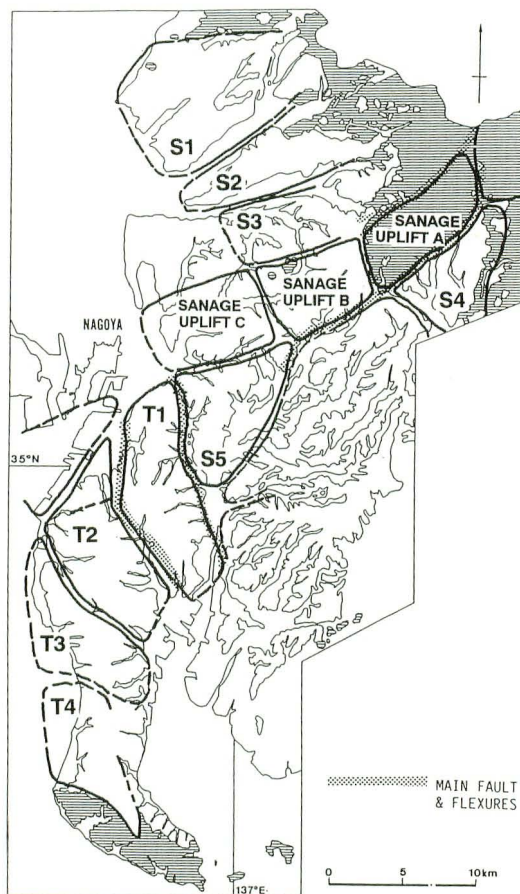


Fig. 33. Map showing the distribution of basement blocks.

(Fig. 16).

Chita Uplift Zone

The Chita Uplift Zone embraces the whole of the Chita Peninsula, and is characterized by south-southeast flexures. Subsidence of the Tokoname Group spread northwards from the southwestern area at a rate of $0.15\text{--}0.17\text{ m}/10^3\text{ years}$ (Fig. 35). The culmination of the Ohdaka-Ohbu Flexure, whose vertical velocity was $0.070\text{--}0.100\text{ m}/10^3\text{ years}$, was greater than that of the Sanage-Sakaigawa Fault. The main activity of these flexures began after stage II because the difference of bed thickness of the blocks on either side of these flexures occurred after deposition of the Ohtani volcanic ash layers. Also, terrace deposits occurring along the flexures (Fig. 19) indicate that each block was hilly land before terrace deposition started.

The Chita Uplift Zone was formed rapidly by block movements since stage

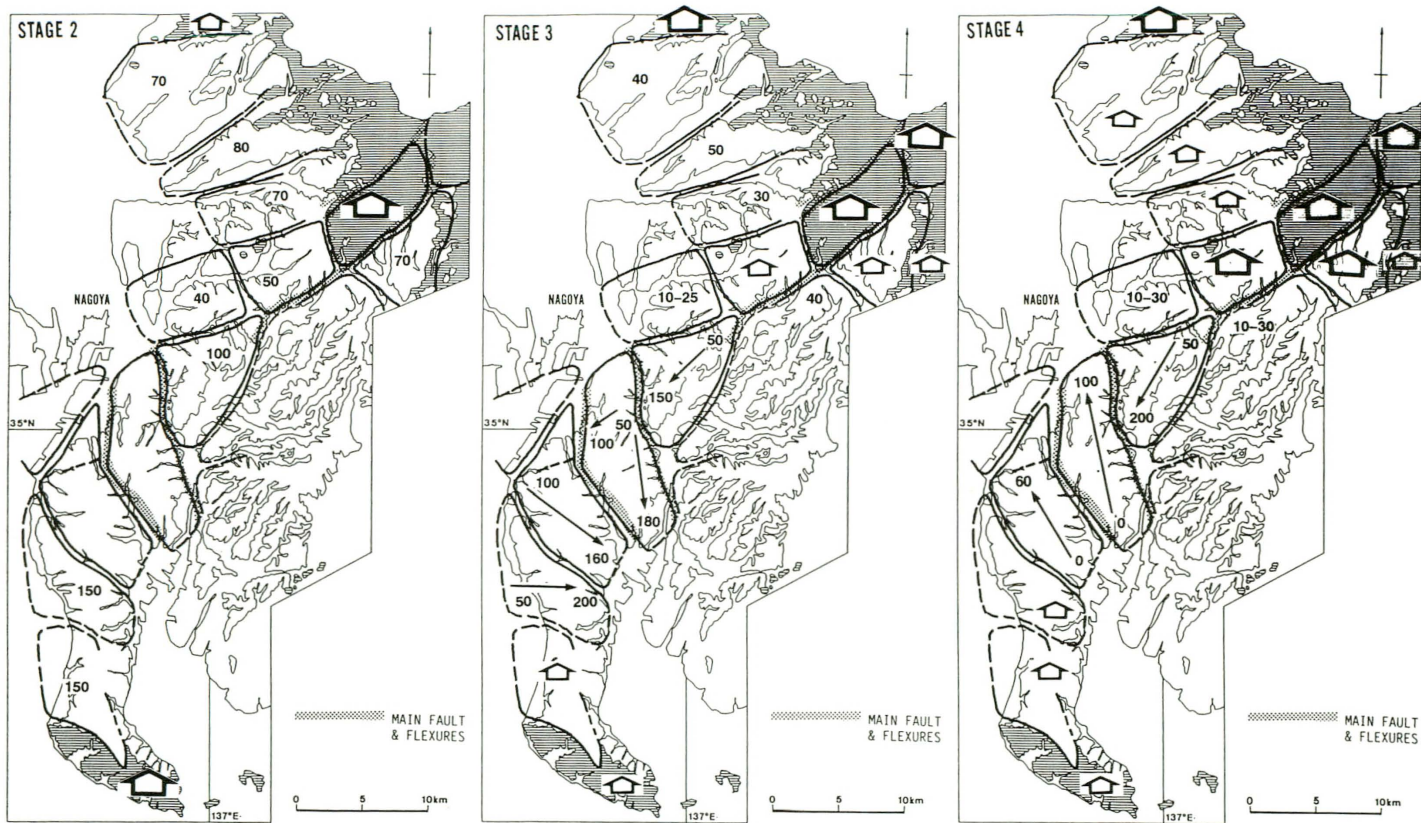


Fig. 34. Kinematic movement of basement blocks. Solid arrows show tilting directions, open arrows show uplifted areas. Numbers show the amount of subsidence or collapse.

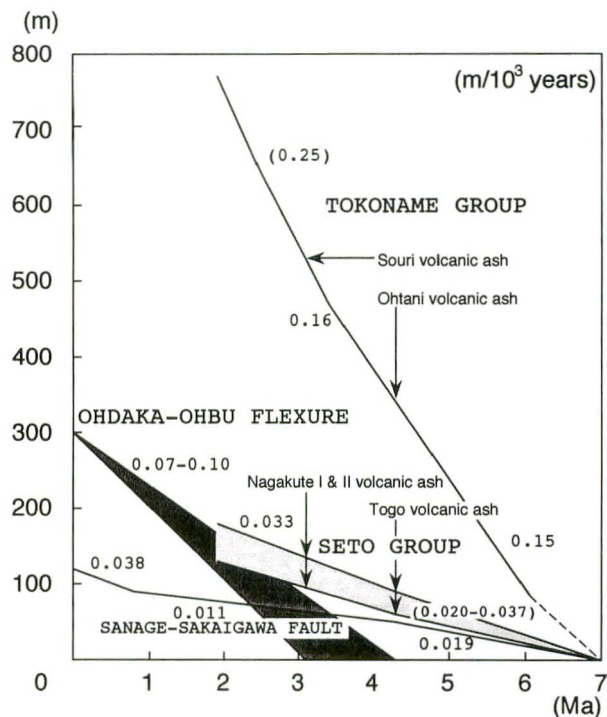


Fig. 35. Vertical velocity of movement and rate of sedimentation.

Numbers beside line show velocity in meters per 1000 years. Sedimentation rate is drawn on the basis of the relationship between bed thickness and the period of the TO-B Normal Magnetopolarity Zone, and the age of Ohtani volcanic ash layers. The Ohtani volcanic ash (correlative with the Togo volcanic ash) was dated as 4.3 Ma. The Souri volcanic ash (correlative with the Nagakute I & II volcanic ash) can be estimated as 3.1 Ma.

III, before terrace deposition.

The vertical movement velocity and change of block tilting are noteworthy. For the Osaka and Kobiwako Groups, acceleration of vertical movement was shown by HUZITA (1983) and KAWABE (1989). The latter clarified the change of block tilting in the Kobiwako Group. On the basis of data in this paper and of the Quaternary in the Nobi Plain area (KUWAHARA, 1975), vertical movement has accelerated since the Middle Pleistocene, which is characteristic of Japanese Island arc tectonics. Drastic change of block tilting such as is found in the T1 and T2 Blocks, may be a feature of the intra-arc basin in Southwest Japan.

7.3. Paleogeography

Paleogeography of the Tokai Group around the east coast of Ise Bay can be reconstructed using stratigraphy, block movements, and river systems. Gravel compositions indicate that three river systems formed the group with exception of the Seto Porcelain

Systems. The Mikawawan River System flowed from the Outer Zone of Southwest Japan, the Toyota from the Miocene Shidara Group and Busetsu granite, and the Komaki from the Nohi rhyolites and Mesozoic-Paleozoic formations of the Mino Belt which were partly altered to hornfels.

Climate changed from warm in stages I, II and III to cool in stage IV, but this did not play an important role in the paleogeography of the Tokai Group. The only aspect that it may have affected was the change from dominantly fine sediments in the uppermost part of stage II and stage III to dominantly coarse sediments in stage IV.

Reconstructed paleogeographical maps are shown in Fig. 36, and Figure 37 provides a summary of the stratigraphy, sedimentation and tectonic movements of the Tokai Group around the east coast of Ise Bay. These paleogeographical maps differ markedly from those by KUWAHARA (1975), ADACHI & KUWAHARA (1980), TAKEMURA (1985), NAKAYAMA & TODO COLLABORATIVE RESEARCH GROUP (1989b), and YOSHIDA (1990). The present maps are characterized by the following two points: (1) the Sanage-Chita Uplift Zone is divided into the Sanage and Chita Uplift Zones. (2) the sedimentary basin was formed by block movements, each block being 30–80 km² in area.

7.3.1. Stage I (9–8 Ma ?)

NAKAYAMA (1991) found two depositional systems in the Seto Porcelain Clay Formation in northern Seto City; alluvial fan and very small lacustrine systems. The same depositional systems are observed at Yagusa and Fujioka-cho. But in the coarse-grained area (Fig. 26) small lacustrine system is not observed. Paleocurrents indicate that fine sediments in the central Seto City area originated in the coarse sediments near eastern Seto City.

The basins were formed by very small block movements, with each block less than 4 km² in area. Immature rivers flowed around the basins judging from the composition of sediment, but some of the rivers are inferred to have linked several very small basins. Immature rivers and small lacustrine deposited the Seto Porcelain Clay Formation during stage I.

7.3.2. Stage II (7.0–4.3 Ma)

Earlier stage II (7.0–5.5 Ma)

During earlier stage II, a large sedimentary basin was formed by block movements, and all three river systems existed. According to sediment composition, the Mikawawan River System deposited the Toyooka Formation, whereas the Toyota and Komaki River Systems deposited the Fujioka Member. The Sanage Uplift A Block formed a sedimentary barrier, but a branch of the Komaki River System was able to flow down to Fujioka.

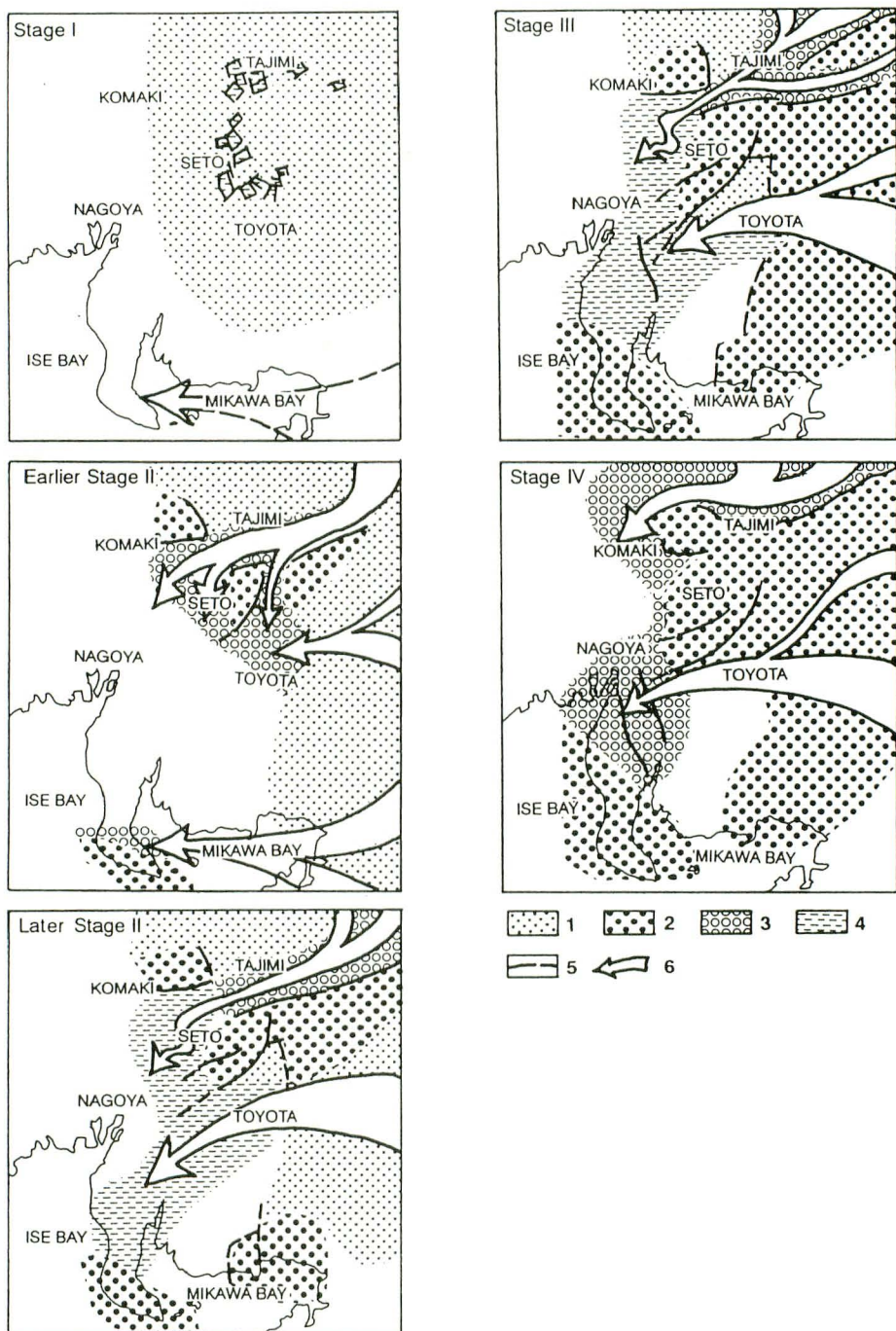


Fig. 36. Paleogeographical map around the east coast of Ise Bay.

1: Land area without sedimentation, 2: Upheaval land area without sedimentation, 3: Depositional area of coarse sediments, 4: Depositional area of fine sediments, 5: Fault, 6: River system.

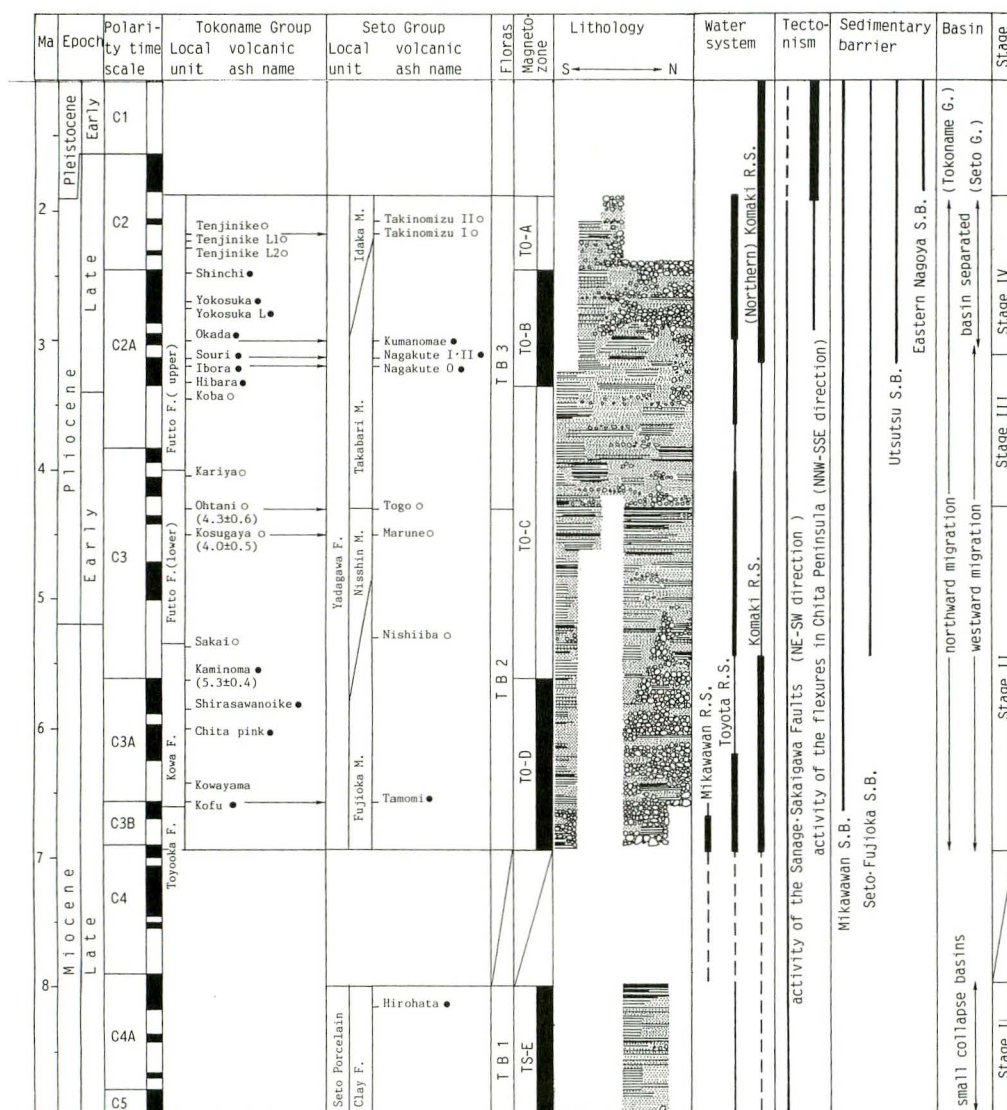


Fig. 37. Summary diagram of the stratigraphy, sedimentation, and tectonic movements of the Tokai Group around the east coast of Ise Bay.

Later stage II (5.5–4.3 Ma)

During later stage II, especially the last part, fine clastics were deposited. Their composition indicates they were deposited by the Toyota and Komaki River Systems. The change of paleocurrents from southeast to northeast and the absence of schist gravels from the Outer Zone indicates that there was no Mikawawan River System in this stage. Furthermore, the rise of the Sanage Uplift A Block blocked the branch of the Komaki River System flowing to Fujioka. In particular,

during the last part of later stage II, a great amount of mud was deposited.

7.3.3. Stage III (4.3–3.1 Ma)

In the lowermost part of stage III, gravel and sand were deposited in the northern half of the study area, and mud and sand were deposited in the middle part of Chita Peninsula. Sediment composition indicates that the Toyota and Komaki River Systems deposited most of the sediments of Stage III. But during the middle horizon, the rise of the Sanage Uplift B block separated the Toyota and Komaki River Systems around eastern Nagoya, and caused a decline of the Komaki River Systems. As a result, mud beds were dominant and paleocurrents were indistinct in Nagakute-cho, which means the Komaki River Systems flowed around Nagakute-cho as a meandering. In the upper part of stage III, around Komaki, hornfels gravel beds were dominant, showing that the Komaki River System had been rejuvenated. The rejuvenated Komaki River System then shifted westward. The central part of the sedimentary basin was in eastern Chita Peninsula (Fig. 34).

7.3.4. Stage IV (3.1–1.9 Ma)

Around Komaki, gravel beds had been deposited since the upper part of stage III. In the area from eastern Nagoya to the Chita Peninsula, deposition of gravel occurred later than near Komaki. The gravels around Komaki include chert and hornfels, whereas those of other areas consist mainly of chert and volcanic rocks of the Shidara Group (Fig. 23). These compositions indicate that gravel beds around Komaki were deposited by the rejuvenated Komaki River System, and in the others by the Toyota River System. At that time, the Komaki River System could not flow into the Chita Peninsula, because uplift of the Sanage Uplift B and C Blocks had completed the Sanage Uplift Zone.

The beds in the upper part of stage IV, which were formed solely by the Toyota River System, are restricted in eastern Nagoya to the northern Chita Peninsula. As block tilting in the Chita Peninsula changed from southeast to northwest, the central part of the sedimentary basin shifted from the eastern to the northwestern part of the Chita Peninsula, and this might have controlled the river system.

Towards the end of Stage IV, block movements in the Chita Peninsula rapidly completed the Chita Uplift Zone. The Sanage and Chita Uplifts ended the Toyota River System, whereas the Komaki River System formed the beds under the Nobi Plain.

The difference in thickness of the Seto and Tokoname was mainly a result of the subsidence of the block. The fact that the uplift was slow, however, played an important role in preserving the beds, because it allowed much fluvial erosion on the exposed area. On the other hand, block uplift in the Tokoname Group,

such as the Ohdaka-Ohbu Flexure, is considered to have been so rapid that the sediments were not significantly eroded by rivers. The beds on the Sanage Uplift B and C Blocks are thinner than those elsewhere in the Seto Group, indicating that they were partly eroded by rivers during their deposition.

8. Conclusions

The Tokai Group around the east coast of Ise Bay has been geographically divided into "the Seto and Tokoname Groups." The Seto Group is divided into the Seto Porcelain Clay and Yadagawa Formations in ascending order and is a maximum 250 m thick. The Yadagawa Formation is, in turn, subdivided into the Fujioka, Nisshin, Takabari, and Idaka Members in ascending order. The Tokoname Group is divided into the Toyooka, Ko(u)wa, and Futto Formations and reaches 770 m in thickness. At least 14 volcanic ash layers are intercalated within the Seto Group, and 28 in the Tokoname Group. Among them, the Tamomi, Marune, Togo, Nagakute 0, Nagakute I & II, Kumanomae, and Takinomizu I volcanic ash layers in the Seto Group can be correlated with the Kofu, Kosugaya, Ohtani, Ibora, Souri, Okada, and Tenjinike ones in the Tokoname Group, respectively. Magnetostratigraphy is the TO-A Reverse, TO-B Normal, TO-C Reverse, TO-D Normal, and TS-E Normal Magnetopolarity Zones in descending order. Biostratigraphy contains the TB1, TB2, and TB3 biozones in ascending order. The TB1 and TB2 biozones suggest a warm climate, but the plant assemblage of the TB1 biozone contains abundant extinct genera and species. The TB3 biozone suggests cooling but with a high annual range of temperature. From these data, it is concluded that the Seto Porcelain Clay Formation was deposited in a period of 1 m.y. around 9 Ma. The other part of the Tokai Group around the east coast of Ise Bay was deposited from 7.0 to 1.9 Ma (Fig. 37).

The paleogeography of the Tokai Group on the east coast is discussed in 4 stages; stage I (9.0–8.0 Ma ?), stage II (7.0–4.3 Ma), stage III (4.3–3.1 Ma), and stage IV (3.1–1.9 Ma). The paleogeography can be explained by block movements, and river systems. Stage I was a time of very small collapse basins of less than 4 km² in area. Fine clastics were deposited in these basins. At that time, river systems were insufficiently developed with small drainage basins. From stage II to stage IV, sediments were transported by three river systems; the Mikawawan, Toyota, and Komaki River Systems. These systems were controlled by small basement blocks which were about 30–80 km² in area. During earlier stage II (7.0–5.5 Ma), the Komaki, Toyota, and Mikawawan River Systems deposited coarse sediments such as gravel and very coarse sand. The south margin of the Chita Peninsula had already been uplifted. The basement block around Mt. Sanage (the Sanage Uplift A Block) formed a topographic barrier, but a branch of the Komaki River System was able to flow southward down around Fujioka-cho. During later stage II (5.5–4.3 Ma), the

Mikawawan River System disappeared. The Sanage Uplift A Block rose and blocked the branch of the Komaki River System around Fujioka-cho. During stage III, sediments were transported mainly by the Toyota River System. The rise of the Sanage Uplift B Block separated the Toyota River System from the Komaki River System around eastern Nagoya. The central part of the sedimentary basin formed in the eastern Chita Peninsula. During stage IV, the Sanage Uplift B and C Blocks were uplifted further to complete the Sanage Uplift Zone, which prevented the Komaki River System from flowing into the Chita Peninsula. The central part of the sedimentary basin shifted to the northwestern Chita Peninsula, and this change controlled the river system in the Chita Peninsula. After stage IV, block movements in the Chita Peninsula rapidly completed the Chita Uplift Zone and the Toyota River System disappeared. In general, sedimentation of the Tokai Group around the east coast of Ise Bay was controlled by basement blocks. The Sanage-Chita Uplift Zone is divided into the Sanage Uplift Zone and the Chita Uplift Zone.

The Tokai Group is the type group for Upper Cenozoic sediments in Japan. It lies in the intra-arc region of the Southwest Japan. Its sedimentary basin included several blocks, whose movement controlled the sedimentary environment. Block movement accelerated during the Late Cenozoic, with some blocks greatly changing their direction of tilt. It shares these general features with other intra-arc basins of Southwest Japan.

Acknowledgments

I would like to express my sincere thanks to Prof. Hisao KUMAI of Osaka City University for his valuable advice as well as constant guidance with this work. I wish to thank Dr. S. YOSHIKAWA of Osaka City University, former Prof. Y. FUJITA of Niigata University, and Prof. I. KIMURA and Dr. Y. KAWAMURA of Aichi University of Education for their useful suggestions and encouragement. Grateful acknowledgment is due to Dr. A. STALKER of the University of Lethbridge for his helpful comments on an earlier version of the manuscript. My sincere gratitude is also extended to the members of Todo Collaborative Research Group, Osaka City University, and Shimane University.

References

- ADACHI, M. and KUWAHARA, T. (1980): Petrographical study of sediments from a 600 m well, Southern Nobi Plain of Central Japan: Research on a tectonically controlled Plio-Pleistocene sedimentary basin. *Jour. Sci. Nagoya Univ.*, **28**, 33–55.
- AKAMINE, H. (1954): Geology of environs of Seto, with special reference to the sedimentary condition of the formation containing ceramic clay and lignite. *Misc. Rep. Inst., Natur. Resouces*, **34**, 25–39.*
- BERGGREN, W. A., KENT, D. V., and VAN COUVERING, J. A. (1985): Neogene geochronology and chronostratigraphy. in *The Chronology of Geological Record* (ed. SNELLING, N. J.), 211–250, Blackwell Scientific Pub., Oxford.
- FISHER, R. A. (1953): Dispersion on a sphere. *Proc. R. Soc.*, A217, 295–305.

- FUJITA, Y. (1990): *Nihon rettou no seiritu* (Materialization of Japanese Island). Chikujii Pub., Tokyo, 259 pp.**
- FURUSAWA, A. (1988): The Yadagawa Formation of the Seto Group in the Naruko Hill, east of Nagoya, Central Japan. *Earth Sci. (Chikyu Kagaku)*, **42**, 257-266.*
- HIROOKA, O. (chief ed.) (1978): Geological Map of Japan, 1:1,000,000 (2nd Ed.). *Geol. Sur. Japan*.
- HUZITA, K. (1983): *Nihon no sanchi keisei ron* (Construction of Japanese Mountains). Souju Pub., Tokyo, 466 pp.**
- IKEBE, N. (1957): Cenozoic sedimentary basin in Japan, with special reference to the Miocene sedimentary basin. *Cenozoic Res. (Shinseidai no Kenkyu)*, no. 24-25, 1-10.*
- 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.*
- ITIHARA, M. (1960): Some problems of the Quaternary sedimentaries, Osaka and Akashi area. *Earth Sci. (Chikyu Kagaku)*, no.49, 15-25.*
- ITIHARA, M., YOSHIKAWA, S., and KAMEI, T. (1984): The Pliocene-Pleistocene boundary in Osaka Group Japan. *Proceed. the 27th IGC, section C*, 22-33.
- 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 Takemura Mem. vol.*, 83-98.*
- KAWABE, T. (1989): Stratigraphy of the lower part of the Kobiwako Group around the Ueno basin, Kinki district, Japan. *Jour. Geosci. Osaka City Univ.*, **32**, 39-90.
- KOBIAWAKO RESEARCH GROUP (1981): The Kobiwako Group in the Seta-Ishibe area, southern part of Shiga Prefecture, Japan. *Earth Sci. (Chikyu Kagaku)*, **35**, 26-40.*
- KOMAKI RESEARCH GROUP (1971): The Yadagawa Formation in the vicinity of Komaki City, Research on the Seto Group-1. *Prof. Heiichi Takehara Mem. vol.*, 69-82.*
- KONDO, Y. and KIMURA, I. (1987): *Geology of Morozaki district*, with geological sheet map at 1:50,000. *Geol. Surv. Japan*, 93 pp.*
- KUWAHARA, T. (1975): Occurrence of the Nobi tilted basin and the Quaternary in the basin. *Ground Subsidence Research Group of Aichi Prefecture (Aichi Prefecture Jiban Chinka Kenkyu-kai)*, 111-182.**
- MAKINOUCHI, T. (1975): The Tokoname Group in the southern part of the Chita Peninsula, central Japan. *Jour. Geol. Soc. Japan*, **81**, 67-80.*
- MAKINOUCHI, T. (1988): Tokoname Group. In *Regional Geology of Japan Part 5 CHUBU II (Nihon no chishitu Chubu II)* (ed. Editorial Committee of CHUBU II), 134-136, Kyoritsu, Tokyo.**
- 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.*
- MAKINOUCHI, T. and NAKAYAMA, K. (1990): Tokai Group around the east coast of Ise Bay. *Urban Kubota*, no. 29, 2-12.**
- MAKIYAMA, J. (1950): *Chubu District* (Chubu chiho). Asakura, Tokyo, 233pp.**
- MATSUZAWA, I., and UEMURA, T. (1957): Geologic maps of environs of Handa City and the Northwestern Part of the Chita Peninsula (2 sheets). Aichi Prefecture.
- MATSUZAWA, I., KATO, R., KUWAHARA, T., KIMURA, T., UEMURA, T., and TSUZUKI, Y. (1960): *Geology of southeastern areas of Sanageyama*, with geologic map. Aichi Prefecture, 35 pp.**
- MIKI, S. (1948): Floral remains in Kinki and adjacent district since the Pliocene with descriptions 8 new species. *Kobutu to Chishitsu (Mineralogy and Geology)*, **9**, 105-144.*
- MIKI, S. (1963): Further study of plant remains in *Pinus trifolia* beds, Central Hondo, Japan. *Chigaku Kenkyu*, Special Vol., 80-93.**
- MIYAMURA, M., MIMURA K., and YOKOYAMA, T. (1976): *Geology of the Hikonetobu district*, with geological sheet map at 1:50,000. *Geol. Surv. Japan*, 49 pp.*
- MIYAMURA, M., YOSHIDA, S., YAMADA, N., SATO, T., and SANGAWA, A. (1981): *Geology of the Kameyama district*, with geological sheet map at 1:50,000. *Geol. Surv. Japan*, 128 pp.*
- MIZUNO, O. (1986): *Nature in Seto City* (Seto no shizen). Seto City, 460 pp.**
- MORI, S. (1971a): 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, S. (1971b): The Yadagawa Formation of the Seto Group in the east of Nagoya City, Aichi Prefecture (in Japanese with English abstract). *Jour. Geol. Soc. Japan*. **77**, 635-644.*

- MORI, Y., and KIMURA, I. (1973): Tephrochronology of the Plio-Pleistocene in Inabe district, Mie Prefecture. *Nagoya Chigaku (Nagoya Earth Science)*, no. 28-29, 26-33.**
- NAKAMURA, S. (1929): Subdivision of Diluvium in Japan. *Annual Report of Gakujutsu Ass. (Gakujutsu Kyokai Houkoku)*, no. 5, 115-117.**
- NAKAYAMA, K. (1985): Sedimentary basins of the Seto Group in the southern part of Toki City, Gifu Prefecture, Central Japan. *Monog. Assoc. Geolog. Collab. (Chidanken Senpo)*, no. 29, 119-130.*
- NAKAYAMA, K. (1987): The Seto Group and the Sanage-Chita uplift zone in the vicinity of Mt. Sanage, Aichi Prefecture, Central Japan. *Earth Sci. (Chikyu Kagaku)*, **41**, 114-130.*
- NAKAYAMA, K. (1991): Depositional process of the Neogene Seto Porcelain Clay Formation in the northern part of Seto City, central Japan. *Jour. Geol. Soc. Japan*, **97**, 945-958.*
- NAKAYAMA, K. (1992): Fluvial gravel beds with superimposed boulders: deposits developed along periphery of a sedimentary basin. *Jour. Sed. Soc. Japan*, no.37, 79-84.
- NAKAYAMA, K. (1993): Depositional process of the lignite bed in the Upper Miocene Seto Porcelain Clay Formation, Central Japan. *IPPCCE News Lett.*, no. 7. (in press)
- NAKAYAMA, K., and FURUSAWA, A. (1988): Volcanic ash layers in the Seto and Tokoname Groups, Aichi Prefecture, Japan. *Jour. Geol. Soc. Japan*, **95**, 189-208.*
- NAKAYAMA, K., and TODO COLLABORATIVE RESEARCH GROUP (1989a): Porcelain clay in small collapse basins, Gifu Prefecture, Japan. *Monog. Assoc. Geolog. Collab. (Chidanken Senpo)*, no. 36, 237-246.*
- NAKAYAMA, K., and TODO COLLABORATIVE RESEARCH GROUP (1989b): Sedimentary basins of the Seto Group. *Earth Sci. (Chikyu Kagaku)*, **43**, 392-401.*
- NAKAYAMA, K., and YOSHIKAWA, S. (1990): Magnetostratigraphy of the Tokai Group (in Japanese with English abstract). *Jour. Geol. Soc. Japan*, **96**, 967-976.*
- NASU, T. (1972): Floral and faunal changes during the Quaternary Period in Japan. *Jour. Biol. Sci.*, **24**, 1-10.**
- OKADA, A. (1979): Active faults -Active faults and historical earthquakes around Aichi Prefecture (in Japanese). *Aichi Geology and Foundation Rep (Aichi Jiban Cyousakai Houkoku)*, no. 4, 1-122.**
- OGAWA, T. (1919,1920): Tertiary strata of Ise. *Annual Report of Shimazu (Shimazu-jihou)*, no. 6-7, 1-6.**
- ONOE, T., OZAKI, M. and YOSHIDA, F. (1986): Plant fossils from the Tokai Group in the Chita Peninsula, Aichi Prefecture, Japan. *Bull. Geol. Surv. Japan*, **37**, 201-206.**
- OSAKA GROUP RESEARCH GROUP (1951): Osaka Group and the related Cenozoic Formations (in Japanese with English abstract). *Earth Sci. (Chikyu Kagaku)*, no. 6, 49-60.*
- OTSUKA, T., KONDO, Y., SASAKI, M., TAKADA, Y., and SHIMOSAKA, Y. (1968): *Quartz sands and fireclay in the vicinity of Seto in Central Japan*, Aichi Prefecture, 43 pp.**
- OTOFUJI, Y., MAKINOCHI, T., and NISHIDA, J. (1975): Preliminary report of 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.**
- THE RESEARCH GROUP FOR ACTIVE FAULTS (1980): *Nihon no katsudansou (Active faults in Japan)*. Univ. Tokyo Press., Tokyo, 363 pp.*
- SAKAMOTO, T., KUWAHARA, T., ITOGAWA, J., TAKADA, Y., WAKITA, K., and ONOE, T. (1984): *Geology of Nagoyananbu district*, with geological sheet map at 1:50,000. *Geol. Surv. Japan*, 64 pp.*
- SHIBATA, H. and ITOGAWA, J. (1980): Miocene Paleogeography of the Setouchi Province, Japan. *Bull. Mizunami Fossil Mus.*, **7**, 1-49.
- SUGIYAMA, Y. (1992): The Cenozoic tectonic history of the forearc region of southwest Japan, based mainly on the data obtained from the Shizuoka district. *Bull. Geol. Surv. Japan*, **43**, 91-112.*
- TANAKA, K., YAMADA, N., SAKAMOTO, T., YOSHIDA, F., and MIYAMURA, M. (1982): Geological map of Kyoto at 1:500,000. *Geol. Surv. Japan*.
- TANEMURA, M. (1964): Geological and mineralogical studies of clay and silica sand deposits in Seto district, Aichi Prefecture. *Geol. Surv. Japan Rep.*, **203**, 40 pp.*
- TAKEMURA, K. (1983): Pliocene-Pleistocene sequence in the northern part on the west coast of Ise Bay, central Japan. *Monog. Assoc. Geolog. Collab. (Chidanken Senpo)*, no. 25, 139-150.*
- 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 (in Japanese with English abstract). *Jour. Geol. Soc. Japan*, **90**, 709-813.*
- TAKEMURA, K. (1985): The Plio-Pleistocene Tokai Group and the tectonic development around Ise Bay of Central Japan since Pliocene. *Mem. Fac. Sci. Kyoto Univ., ser. Geol. Mineral.*, **51**, 21-96.
- TAKEMURA, K., and TORII, M. (1978): Magnetostratigraphy of the Plio-Pleistocene Age Group in the northern part of Mie Prefecture, Japan. *Rock Mag. Paleogeophys.*, **5**, 72.
- TODO COLLABORATIVE RESEARCH GROUP (1982): The Seto Group in the southern part of Mizunami

- City, Gifu Prefecture -A study on occurrence and development of the Seto sedimentary basin (2)-. *Monog. Assoc. Geolog. Collab. (Chidanken Senpo)*, no. 24, 143-155.*
- TODO COLLABORATIVE RESEARCH GROUP (1985): A collapse basin in the eastern margin of the Lake Tokai -Seto Group around Nakatsugawa City, Gifu Prefecture. *Monog. Assoc. Geolog. Collab. (Chidanken Senpo)*, no. 29, 101-117.*
- TSUKAGOSHI, M. (1992): Plant fossils from the Seto Group in the eastern Nagoya. *I. F. Rep.*, no. 19, 175-184.**
- TSUCHI, R. (1990): Accelerated evolutionary events in Japanese endemic mollusca during the Latest Neogene. in *Pacific Neogene Events* (ed. TSUCHI, R.), 85-97. Univ. Tokyo Press, Tokyo.
- WADA, Y. (1982): The Age Group in the vicinity of Kameyama City, Mie Prefecture, Central Japan. *Jour. Geol. Soc. Japan*, **88**, 121-139.*
- YOKOYAMA, T. (1971): Upheaval of 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 Takemura Mem. vol.*, 55-67.*
- YOSHIDA, F. (1987): *Geology of Tsutoubu district*, with geological sheet map at 1:50,000 (in Japanese with English abstract). *Geol. Surv. Japan*. 72 pp.*
- YOSHIDA, F. (1988): Plio-Pleistocene Tokai Group between the Suzuka and Yoro Mountains, central Japan -latest sediments of the Tokai Sedimentary Basin-. *Earth Sci. (Chikyu Kagaku)*, **42**, 1-16.*
- YOSHIDA, F. (1990): Stratigraphy of the Tokai Group and paleogeography of the Tokai sedimentary basin in the Tokai region, central Japan. *Bull. Geol. Surv. Japan*, **41**, 303-340.*
- YOSHIDA, F. (1992): Geologic development of the Setouchi Geologic Province since Early Miocene. *Bull. Geol. Surv. Japan*, **43**, 43-67.*
- YOSHIDA, F., and OZAKI, M. (1986): *Geology of Handa district*, with geological sheet map at 1:50,000. *Geol. Surv. Japan*. 98 pp.*
- YOSHIKAWA, S. (1984): Volcanic ash layers in the Osaka and Kobiwako Groups, Kinki District, Japan. *Jour. Geosci. Osaka City Univ.*, **27**, 1-40.
- YOSHIKAWA, S., YOSHIDA, S., and HATTORI, T. (1988): Volcanic ash layers of the Tokai Group in Inabe area, Mie Prefecture, central Japan. *Bull. Geol. Surv. Japan*, **39**, 615-633.*
- YOSHIKAWA, S., and YOSHIDA, S. (1989): Volcanic ash layers of the Tokai Group in the Kameyama area, Mie Prefecture, central Japan. *Bull. Geol. Surv. Japan*, **40**, 285-298.*
- YOSHIKAWA, S., YOSHIDA, F., and SUGAWA, E. (1991): Volcanic ash layers of the Tokai Group and their correlation. *Earth Sci. (Chikyu Kagaku)*, **45**, 453-467.*
- YOSHINO, M. (1971): Palynological study of the Yadagawa Formation in the environs of Nagoya, Japan. *Prof. Heiichi Takehara Mem. vol.*, 129-136.*
- YOSHITANI, A., and YAMAUCHI, Y. (1981): Fracture systems distributed in the basement of Green-Tuff sedimentary basin in the earliest stage of basin formation. *Mem. Fac. Edu. Tottori Univ.*, **30**, 85-95.*

*: in Japanese with English abstract

**: in Japanese