Tertiary Formations in the Yuya-wan (bay) District, Southwest Japan, with References to the Tertiary Geologic History of West Chugoku

By

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with 2 Tables, 6 Text-figures and 1 Plate

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ABSTRACT: This paper treats of the problems concerned with the geology of the Cenozoic strata developed in the Yuya-wan (bay) district of West Chugoku, the Inner side of Southwest Japan. On the basis of the data obtained through his study the writer summarizes the stratigraphy and structure of this district, and gives the correlation among the Tertiary formations of the Saikai, in which the Yuya-wan district is included, Setouchi and San-in sedimentary provinces. As a result of the study, the writer remarks the Mid-Tertiary geologic history and paleogeography of West Chugoku.

CONTENTS

I. INTRODUCTION AND ACKNOWLEDGEMENTS

The Yuya-wan (bay) district, where the Cenozoic strata are well developed, is situated on the northwest coast, facing the Sea of Japan, of West Chugoku in the

Inner side of Southwest Japan (Pl. VI). To the southwest of this district the Tertiary coal fields of the Saikai sedimentary province (CENOZOIC RESEARCH GROUP of SOUTHWEST JAPAN, 1960) are distributed in the Sea of Japan side of North and Northwest Kyushu. To the northwest across the Sea of Japan the Tertiary strata are exposed in the environs of Yŏngil-bay, South Korea. Moreover, to the east-northeast of the district the Neogene formations of the Setouchi and San-in sedimentary provinces (IKEBE, 1957) are scattered in Chugoku district. Therefore, the Tertiary strata of this district play paleogeographically the part of a bridge among the different sedimentary provinces. Further in the standpoint of discriminating the boundary between the Paleogene and Neogene of Japan, the Tertiary strata of this district are remarkably interested like those of Kyushu, because they range from Oligocene to Miocene in age. As a step of researching the Tertiary geology of Chugoku district the writer summarizes here the stratigraphy and structure of the Tertiary formations of the Yuya-wan district investigated by him during the last decade, and gives the notes of the Tertiary geologic history of West Chugoku. Micropaleontological study based on this work is now being provided by him.

Brief notes of previous works: It has long been known that the Tertiary formations are distributed in the Yuya-wan district (TÔJÔ, 1891; KOCHIBE, 1903; SUZUKI, T., 1906). Since the discovery of the so-called *Lithothamnium ramosissium* from the limestone inserted in the formations (OGURA, 1918, 1919; YABE, 1920), the age of them had become considered to be Miocene. After that, SUDÔ (1942) reported the occurrence of the Ashiya faunule, which was regarded as an index of Oligocene at that time, from Kiwado of the same district.

In 1950, Prof. IMAMURA and his collaborators of the Hiroshima University started to investigate the Tertiary formations there as one of researches of the Cenozoic geology in the San-in district, and some data on the stratigraphy and paleontology have often been made public by WADA (1955), OKAMOTO (1960, 1961), NAKANO and OKAMOTO (1962), OKAMOTO and NAKANO (1963), and others. Detailed description of the stratigraphy has very recently been given by OKAMOTO and IMAMURA (1964).

In addition to the studies by IMAMURA and his collaborators, there are many studies and reports concerned with the Cenozoic formations. The followings are very important among them. ASAMI (1954, 1964) studied on the paleomagnetism of the Olivine-trachybasalt at Kawashiri-misaki (cape). MATSUMOTO, T. (1951, 1962) explained the fundamental geologic structure in North Kyushu and West Chugoku, and gave his opinion on the Cenozoic geologic history of these districts. ISHIJIMA (1954, 1962) reported the paleontological studies of the algae from the so-called *Lithothamnium* limestone. KURASAWA and TAKAHASHI, K. (1960), and ŌJI (1961a, b) researched the andesitic and basaltic rocks of this district with the view of petrology of the Cenozoic volcanic rocks in West San-in and North Kyushu. TAKAHASHI, K. (1963a, b) made the palynological studies of the Hioki group in the district.

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II. OUTLINE OF STRATIGRAPHY OF THE YUYA-WAN DISTRICT

The outline of the Cenozoic stratigraphy of the Yuya-wan district, West Chugoku is summarized as shown on Table 1.

III. NOTES OF BASEMENT ROCKS

The basement rocks of the Tertiary formations in this district are classified into the Kwanmon group (the Wakino and Shimonoseki subgroups), the Yahata formation, the "Rhyolite and quartz-porphyry", and others (HASE, 1960) in ascending order. They are assigned to Cretaceous in age.

The Kwanmon group is made up of sandstone, shale, and lavas and pyroclastics of altered (hornblende?-) andesite and rhyodacite. It is developed from Tsuô, through Kiwadoguchi and Kiwado, to Jûraku, having the strike of WNW direction and dip of about 15° to the south. The major part of these strata may correspond to the Shimonoseki subgroup, the upper of the typical Kwanmon. A shale bed intercalated in the rhyodacitic tuff at Kiwado yields *Euestheria* sp., *Estherites* sp., *Cyclestheria* sp., and ostracods.* The Wakino subgroup, the lower of the group, is distributed in the area of Kottoi.

The Yahata formation of acid volcanic origin is exposed in the area south of Kaikawa, and it extends widely into the southward. Moreover, the rhyodacite cropping out at the north point of Ima-misaki (cape) is probably the correlative with a part of the Yahata formation.

The "Rhyolite and quartz-porphyry" and their pyroclastics are developed extensively in the south of the Kaisaku and Jûraku-Kaikawa faults and in the area north of Kottoi. In the latter area they are mainly composed of welded tuff.

Besides the rocks mentioned above, a shale with sandstone intercalations is found

* Discriminated by KUSUMI, H.

TABLE 1 STRATIGRAPHY OF THE YUYA-WAN DISTRICT AND THE NISHIICHI AREA, WEST CHUGOKU, SOUTHWEST JAPAN.

Age	Stratigraphy: Nishiichi Area	Kottoi Area	Yuya-Hioki Area	Kiwado Area	Rock Facies	Fossils: Molluscs·Echinoids	Fossils: Smaller Foraminifera · Plants
Pleistocene		Ovama gravel bed 3m	Furuichi gravel bed 20m	Furuichi gravel bed 10?m	gravel and sand		
Pliocene		Olivine-trachybasalt 50	Olivine-trachybasalt 150	Olivine-trachybasalt 120	lavas with lapilli tuff and Cgl intercalations		
		? Mukatsuku gravel bed 3?	? Mukatsuku gravel bed 5		gravel		
Miocene			Rhyolite Quartz-dolerite		(dikes)	e *Batillaria tateiwai*, *Crassostrea* cf. *sakitoensis*, *Tellina* cf. *notoeneis* *Echinolampas yoshiwarai* d *Siphonaria osawanoensis*, *Propeamussium tateiwai*, *Cuspidaria* cf. *osawanoensis* c *Polinices* cf. *meisensis*, *Chlamys* cf. *arakawai*	e Limestone···*Discorbis*? sp., *Cibicides* sp., Sh···*Haplophragmoides* sp., *Gyroidina orbicularis* *Eponides haidingerii* d Sh···*Haplophragmoides* sp., SS···*Eponides* cf. *praecinctus* *Cibicides lobatulus* c SS···*Eponides praecinctus*, *Cibicides* cf. *refulgens*
			Bronzite-augite-andesite	Augite-andesite			
		Yuya-wan group: Kawashiri formation e 60+	Yuya-wan group: Igami formation c 425; Kawashiri formation e 400; Kadoyama f. ? d 300	Yuya-wan group: Kawashiri formation e 50?	e alternation of SSand Sh with an algal limestone layer d Cgl, SS, Sh and alt. of SS and Sh c Cgl, SS, Sh and alt. of SS and Sh		
		ft Hioki group: Tsuno-shima m. b 22+	Hioki group: Hitomaru formation a 500+		b Cgl and SS, a SS, Sh and alt. of SS and Sh	b *Batillaria takeharai* *Cyclina japonica* a *Corbicula matsusitai*	b SS··· *Elphidium* cf. *etigoense* a Daibō florule
		ft Hioki group: Taoyama f. ? 60+	Hioki group: Taoyama formation 500?	Hioki group: Taoyama f. 200+	SS, Sh, alt. of SS and Sh and tuffaceos rocks	*Turritella infralirata* *Chlamys ashiyaensis* *Crassatellites yabei* *Venericardia subnipponica*, *Pitar ashiyaensis*, *Dosinia chikuzenensis*, *Echinodiscus chikuzenensis*	Sh··· *Cyclammina pussilla*
		Hioki group: Sakagawa formation: Kiwado member 70; Jūraku member 30?	Hioki group: Sakagawa formation: Kiwado member 200; Jūraku member 260	Hioki group: Sakagawa formation: Kiwado member 70; Jūraku member 30	Cgl, SS, Sh and tuffaceous rocks Cgl, SS, Sh and tuffaceous rocks		Sh··· *Gyroidina soldanii* *Baggina saitoi* Noda florule
Eocene-Oligocene	"Nishiichi formation" m 60?		Olivine-andesite		alternation of lava and volcanic Cgl	f. : formation m. : member ft : fault	
		Augite-andesite 40+	Hypersthene-bearing pigeonite-augite-olivine-andesite 230				
				Hypersthene-olivine-basalt 50	lava with volcanic breccia		
Cret. | Jura.	Wakino subgroup Toyora group	"Rhyolite and quartz-porphyry" Wakino subgroup	"Rhyolite and quartz-porphyry" Yahata formation Kwanmon group	"Rhyolite and quartz-porphyry" Yahata formation			

In this paper Miocene includes Aquitanian.

The stratigraphy of the Nishiichi area is summarized from the data of HASE (1954), ONO (1952) (MS), and TAKAHASHI, K. (1961).

at the hill east of Ôuchiyama, enclosed by the Tertiary Hioki group like a *Fenster*.

IV. Description of the Cenozoic formations

A. Paleogene basalt and andesites

1. Hypersthene-olivine-basalt (Kurasawa and Takahashi, K., 1960)

This basalt rests unconformably on the Yahata formation, and is exposed at Ima-misaki. This basalt, 50 m thick, is composed of lava with volcanic breccia. Ôji (1961a, b) called it the Bronzite-augite-olivine-basalt.

2. Hypersthene-bearing pigeonite-augite-olivine-andesite and Olivine-andesite (Ôji, 1961a, b)

These andesites overlie unconformably the Kwanmon group, and are developed in the area from Tsuô to Kiwadoguchi. The exact stratigraphic relationship between the basalt mentioned above and these andesites is unknown, because both are separately distributed. According to the petrological studies by Kurasawa and Takahashi, K. (1960) and Ôji (1961a, b), however, the former activity seems to precede the latter. The Augite-andesite correlated with a part of these andesites (Ôji, 1961a, b; Okamoto, 1961) occupies the west of Tsuno-shima. These andesites, 230 m thick, are composed of volcanic conglomerate and alternation of lava and pyroclastics.

B. Hioki group (Okamoto and Imamura, 1964)

The Hioki group lies unconformably upon the basement rocks and the Paleogene basalt and andesites, and is overlain disconformably by the Yuya-wan group. It is distributed in Hioki-mura, the east areas of Yuya-machi, and the environs of Kottoi, Hôhoku-machi. This group, about 1,400 m in total thickness, consists of the sediments of a megacyclothem, and is accumulated in three different sedimentary basins, i.e., the Kiwado, Yuya-Hioki and Kottoi bays (Figs. 3b–c). It is lithologically divided into the Sakaigawa, Taoyama and Hitomaru formations in ascending order. The lithofacies of the group are, as a whole, similar to those of the Ôtsuji and Ashiya groups in North Kyushu.

1. Sakaigawa formation

This formation is subdivided into two members, the Jûraku in the lower and the Kiwado in the upper, and each of them is composed of a cyclothem.

1a. Jûraku member

This member is exposed at Ima-misaki of the Kiwado bay, in Kiwadoguchi and Jûraku of the Yuya-Hioki bay, and in the environs of Kottoi of the Kottoi bay. In the Yuya-Hioki bay this member is thick, about 260 m thick, while in the Kiwado and Kottoi bays it is thin, about 30 m thick. This member is chiefly composed of conglomerate, sandstone, greenish black shale inserted with a few coaly shale layers,

and white tuff in upward succession. Reflecting the characters of the basement rocks, the kind of pebble of the basal conglomerate are different among the sedimentary basins. The conglomerate of the Yuya-Hioki bay contains pebbles of altered andesite and rhyodacite, "rhyolite and quartz-porphyry", etc., the one of the Kiwado bay has pebbles and cobbles of Paleogene basalt, rhyodacite, dacite, etc., and the one of the Kottoi bay comprises pebbles of "rhyolite and quartz-porphyry" etc. derived from the basement rocks. Thus the differences of the rock characters and thickness of this member in three areas will evidently verify that the accumulation of the Hioki group had commenced in the three different sedimentary basins (Fig. 1). The basal conglomerate is purplish to reddish colored in a part of Jûraku and whole of the Kottoi bay, as well as in the basal part of the Ôtsuji group of North Kyushu (MATSUSHITA, 1949).

This member yields no marine fossils, but often the so-called Matsuiwa (silicified wood) and fragments of plant leaves. At the point 800 m west of Kiwado there is a small outcrop of sandstone and shale, overlying the basement, which may be the correlative with a part of the Jûraku member. This outcrop yields fossil plants such as *Equisetum* sp., *Quercus* sp., *Dryophyllum* sp., *Planera Ungeri* KOVATS, *P.* sp. (abundant), *Liquidambar*? sp., *Diospyros* sp. (abundant), etc.*

1b. Kiwado member

This member is developed along the coast from Niigahama, through Kayakari and Kiwado, to Kaisaku of the Kiwado bay, in the areas from Tsuô to Ôuchiyama of the Yuya-Hioki bay, and in the environs of Kottoi of the Kottoi bay. In the Yuya-Hioki bay this member is 200 m thick, while in the Kiwado and Kottoi bays it is about 70 m thick. This member is chiefly composed of pebble conglomerate, coarse-grained sandstone, alternation of conglomerate and sandstone, black fine-grained sandstone to shale, and alternation of the so-called Honeishi (tuff) and conglomerate or sandstone in ascending order. Most pebbles of volcanic rocks in conglomerate are brought in from the basement rocks. Sandstone includes often a kind of dark green mineral. The horizon of the iron-sand deposit at Kiwado (SUDÔ, 1942; KOMATSU, 1956; TAKEDA et al., 1958) seems to be upper than the uppermost molluscan fossil bed K_3 described below. A coaly shale layer of 1 m thick rests directly on the iron-sand deposit at Kiwado. The tabular and lenticular cross-laminations are well preserved.

This member yields the fossil marine molluscs belonging to the Ashiya faunule named under the Ashiya group in North Kyushu (NAGAO, 1928a, b; OTUKA, 1939). They are as follows:

Fossil bed K_1 (coarse-grained sandstone)

Crassostrea cf. *sakitoensis* (NAGAO), *Ostrea* sp., etc., with an echinoid *Echinodiscus chikuzenensis* NAGAO (WADA, 1955).

* Fossil plants in this paper were discriminated by ENDÔ, S.

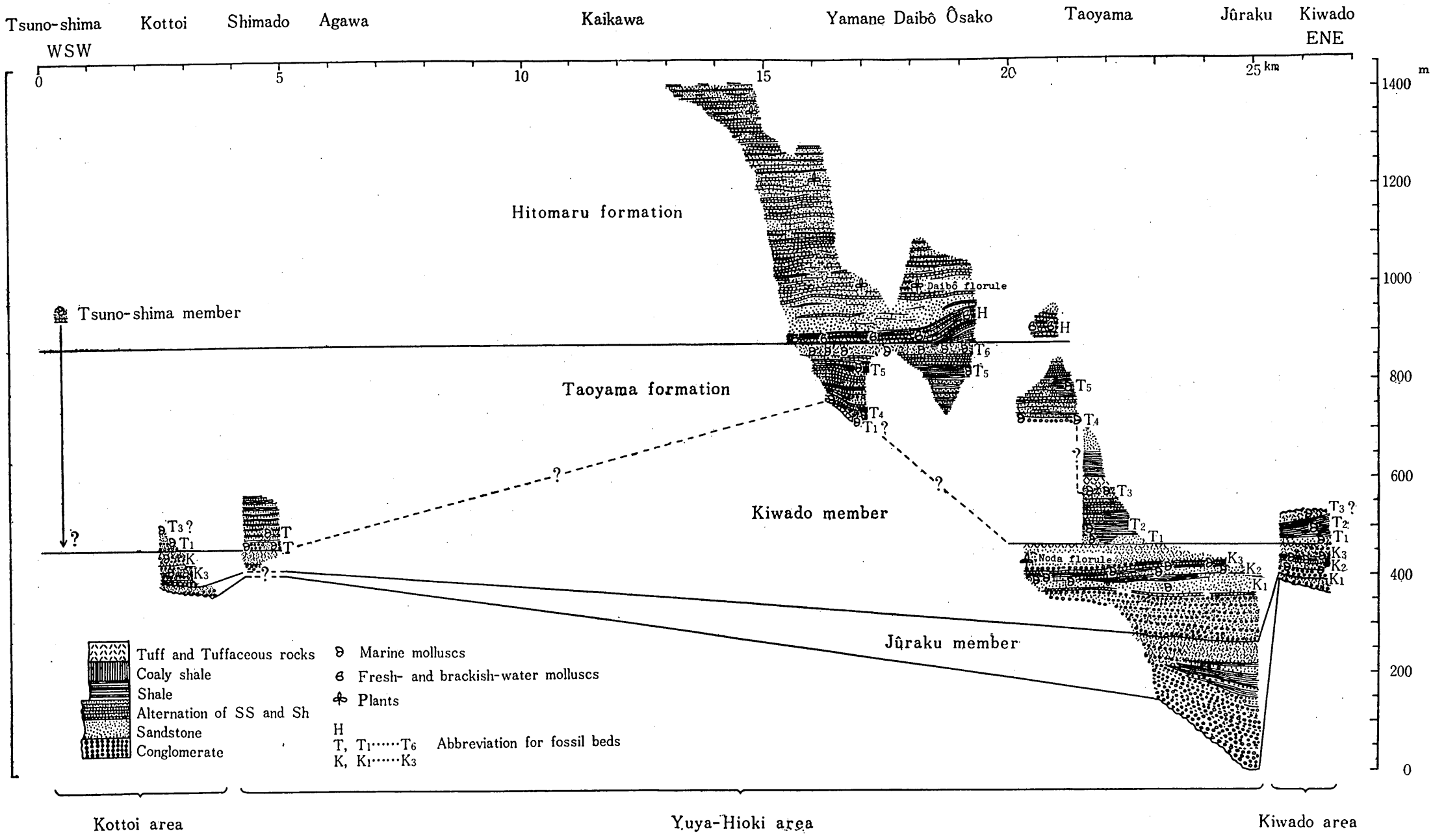

Fig. 1 Diagrammatic cross section of the Hioki group.

Fossil bed K_2 (pebble conglomerate to pebble-bearing coarse-grained sandstone)
Turritella infralirata NAGAO, *Euspira ashiyaensis* (NAGAO), *Molopophorus denselineatus* (NAGAO), *Glycymeris cisshuensis* MAKIYAMA (very abundant), *Chlamys ashiyaensis* (NAGAO), *Crassatellites yabei* NAGAO, *Venericardia subnipponica* NAGAO, *Pitar ashiyaensis* (NAGAO), *Callista hanzawai* (NAGAO), *Dosinia chikuzenensis* NAGAO (abundant), etc.

Fossil bed K_3 (coarse-grained sandstone to shale)
Euspira ashiyaensis (NAGAO), *Saccella* sp., *Portlandia scaphoides* (NAGAO), *Acila ashiyaensis* (NAGAO) (abundant), *Venericardia subnipponica* NAGAO (very abundant), *Dosinia chikuzenensis* NAGAO (common), *Angulus maximus* (NAGAO) (common), *Spisula* sp. (NAGAO's *Spisula* sp. a, 1928), *Cultellus* cf. *izumoensis* YOKOYAMA, *Periploma besshoense* (YOKOYAMA), etc.*

The fossil beds K_1 and K_2 have not been found out in the Kottoi bay.

The following fossil plants were obtained from the sandy shale layers of the uppermost of the member at the south-southwest of Noda. These plants were called the Noda florule** by IMAMURA (1958).

Populus Zaddachi HEER?, *Engelhardtia* cf. *Brongniarti* ETTINGSHAUSEN, *Jugulans nigella* HEER?, *J.*? sp. (Cf. *J. acuminata* BRAUN), *Betula Brongniarti* ETTINGSHAUSEN?, *Castanea Kubinyi* KOVATS, *C. Ungeri* HEER, *Fagus Antipofi* HEER, *Quercus Lyallii* HEER?, *Q.* cf. *groenlandica* HEER, *Broussonetia* cf. *Imaii* ENDÔ, *Ficus tiliaefolia* HEER, *Cercidiphyllum eojaponicum* ENDÔ, *Platanus aceroides* GOEPPERT, *Acer arcticum* HEER, *A. pictum* THUNBERG, *Celastrophyllum* cf. *crenatum* HEER, *Rhamnus* cf. *Rossässleri* UNGER, *Viburnum Nordenskiöldi* HEER?, etc.

The preliminary report of the smaller foraminifera from the fossil bed K_3 was given by OKAMOTO (1960), and the palynological study of this member at Kiwado and Waku was also carried out by TAKAHASHI, K. (1963a).

2. Taoyama formation

This formation is distributed in the area northwest of Kiwado, and Sakaigawa of the Kiwado bay, in the west areas of Hioki-mura, and Hisatomi and Ôe of the Yuya-Hioki bay, and along the coast of Kottoi of the Kottoi bay. As shown in Fig. 1, the successive stratigraphic column of this formation could not be made up in an area. Accordingly, the writer infers that the upper column of the Ôe area succeeds to the lower of Taoyama, with a question as to the correlation between them. In the Yuya-Hioki bay this formation is about 420 m+ thick, but in the Kiwado and Kottoi bays the thickness can not be estimated because the upper part is thought to be eroded out. This formation is chiefly composed of coarse-grained sandstone, gray shale, alternation of sandstone and shale, tuffaceous pebble-bearing coarse-grained sandstone, tuff, gray shale, fine- to medium-grained sandstone, pebble conglomerate, fine-

* Fossil molluscs belonging to the Ashiya faunule are discriminated by MIZUNO, A., WADA, T., OKAMOTO K., and NAKANO, M.

** TAKAHASHI, E. (1959b) named it the Ashiya fossil flora.

grained sandstone with shale intercalations, and tuff in upward succession. In this respect, the formation is considered to be made up of two or three imperfect cyclothems. Sandstone includes also often a kind of dark green mineral.

The fossil marine molluscs gathered from the formation are as follows:

Fossil bed T_1 (coarse-grained sandstone)

Crassostrea cf. *sakitoensis* (NAGAO) etc.

Fossil bed T_2 (shale)

Saccella sp., *Portlandia* sp., *Venericardia subnipponica* NAGAO (common), *Lucinoma* sp., *Angulus maximus* (NAGAO), *Cultellus* cf. *izumoensis* YOKOYAMA, *Peripoloma besshoense* (YOKOYAMA) (common), etc.

Fossil bed T_3 at the type area (coarse-grained sandstone)

Acila ashiyaensis (NAGAO), *Chlamys ashiyaensis* (NAGAO), *Crassatellites yabei* NAGAO (abundant), *C.* sp. (abundant), *Venericardia subnipponica* NAGAO, *Pitar ashiyaensis* (NAGAO) (common), *Callista* sp., *Dosinia chikuzenensis* NAGAO (common), etc.

Fossil bed T_3 at the point northwest of Kiwado (coarse-grained sandstone)

Turritella sp., *Acila* sp., *Mytilus* sp., *Callista* sp., *Dosinia* sp., etc.

Fossil bed T_3? on the coast west of Hijû (pebble-bearing coarse-grained sandstone)

Turritella infralirata NAGAO, *Batillaria takeharai* MIZUNO (MS) (common), *Euspira ashiyaensis* (NAGAO) (common), *Phyllonotus ashiyaensis* (NAGAO), *Glycymeris cisshuensis* MAKIYAMA (abundant), *Mytilus* sp., *Crassatellites yabei* NAGAO, *Venericardia subnipponica* NAGAO, *Pitar ashiyaensis* (NAGAO) (abundant), etc.

Fossil bed T_4 (pebble conglomerate)

Euspira ashiyaensis (NAGAO), *Acila ashiyaensis* (NAGAO), *Glycymeris cisshuensis* MAKIYAMA, *Crassatellites yabei* NAGAO, *Venericardia subnipponica* NAGAO (very abundant), *Dosinia chikuzenensis* NAGAO, etc.

Fossil bed T_5 (shale)

Saccella sp., *Portlandia* sp., *Nucula* sp., etc.

Fossil bed T_6 (tuff to tuffaceous sandstone)

Turritella infralirata NAGAO, *Euspira ashiyaensis* (NAGAO), *Glycymeris cisshuensis* MAKIYAMA, *Solamen subfornicatum* (NAGAO), *Chlamys ashiyaensis* (NAGAO), *Crassatellites yabei* NAGAO, *Venericardia subnipponica* NAGAO (abundant), *Dosinia chikuzenensis* NAGAO, etc.

These fossils, except *Batillaria takeharai*, belong also to the Ashiya faunule. *B. takeharai* has been treated as a characteristic species of the Saseboan stage (MIZUNO, 1964), which is considered to be upper than the Taoyama. The faunal compositions of each fossil bed seem to vary according to localities.

3. Hitomaru formation

This formation is developed in Hisatomi, the areas around Hitomaru station, the Igami area, and the area around Tateishi of the Yuya-Hioki bay, but not exposed in the Kiwado and Kottoi bays. This formation, 500 m+ thick, is chiefly composed of fine-grained sandstone, alternation of shale to fine-grained sandstone and tuff, fine-

grained sandstone with shale intercalations in ascending order. There is a probable diastem under the alternation of shale to fine-grained sandstone and tuff (near the bottom of the formation). Pebble to granule conglomerate and tuff layers are inserted in the middle and upper of the formation. Coaly shale layers are also often intercalated. The lithofacies shows lateral change. Wave ripple-marks are well preserved in the middle and upper.

The shale to fine-grained sandstone layers of fossil bed H yield a crowd of *Corbicula matusitai* SUZUKI accompanied by a few "*Viviparus*" sp. and paralic? molluscs. These molluscs are the elements of the Sasebo non-marine molluscan faunule by SUZUKI (1941). The following fossil plants were collected from the fine-grained sandstone layers with shale intercalations in the middle of the formation at Daibô and Yamane. These plants were named the Daibô florule* by IMAMURA and WADA (1956), and IMAMURA and OKAMOTO (1959).

Populus cf. *balsamoides* GOEPPERT, *Carpinus paleojaponica* (ENDÔ), *C. grandis* UNGER, *Ulmus longifolia* UNGER, *Zerkova Ungeri* (ETTINGSHAUSEN), *Ficus tiliaefolia* HEER, *Liquidambar formosana* HANCE, *L. trilobum* GOTHAN and SAPORTA, *Platanus aceroides* HEER, *Acer pictum* THUNBERG, *Koelreuteria eointegrifolia* ENDÔ, etc.

Recently, TAKAHASHI, K. (1963b) presented the palynological research of the lower of this formation.

4. Tsuno-shima member

This member, the upper and lower limits of which are probably faulted off, crops out within the fault zone of NW trend on the central south coast of Tsuno-shima. This member, 22 m+ thick, is chiefly composed of pebble conglomerate and coarse-grained sandstone inserted with tuffaceous sandstone. The lithofacies is well similar to those of the Kiwado member and the Taoyama formation. The tuffaceous sandstone yields fossil marine molluscs such as *Batillaria takeharai* MIZUNO (MS), *Cerithium* sp., *Crassostrea gravitesta* (YOKOYAMA) and *Cyclina japonica* KAMADA. A few smaller foraminifera, as *Elphidium* cf. *etigoense* HUSEZIMA and MARUHASI and *Strebulus* cf. *becarii* (LINNAEUS), were obtained from the same rock (OKAMOTO, 1961). This member is treated here as a part of the Hitomaru formation, as will be noted later in the chapter VI.

5. Volcanism during the accumulation of the Hioki group

Tuff to tuffaceous rocks are often intercalated in the Hioki group, especially in the Sakaigawa and Taoyama formations. MUKAE and OKAMOTO examined 12 specimens from various horizons of this group by determinating the refractive indicies of artificially prepared rock-glasses (MUKAE, 1957). Through their examination, it was ascertained that the tuff during the accumulation of the Sakaigawa and Taoyama formations except the uppermost horizon of the latter is probably originated from

* TAKAHASHI, E. (1959b) called it the Hishikai fossil flora.

the volcanism of rhyolite to dacite, and that the tuff for the deposition of the uppermost Taoyama and Hitomaru formations comes likely from the activity of rhyodacite to andesite (?).

C. Yuya-wan group (Okamoto and Imamura, 1964)

The Yuya-wan group rests on the Hioki group with a disconformity, as will be described and discussed in the ensuing paragraph, and is overlain unconformably by the Mukatsuku gravel bed. It is developed in a wide extent of ENE-WSW trend from Kayakari to Tsuno-shima. This group, 450–700 m in total thickness, consists also of the sediments of a megacyclothem, like as the Hioki group does. It is divided into three formations of the Igami, Kadoyama and Kawashiri, which show more or less different lithofacies with one another. The stratigraphic relationship among them is shown in Fig. 2. However, the detailed research of the Yuya-wan group is very hard, because it is scattered around Yuya-wan and is extensively covered by the Olivine-trachybasalt. In general the lithofacies of the group are similar to those of the Sasebo group in Northwest Kyushu.

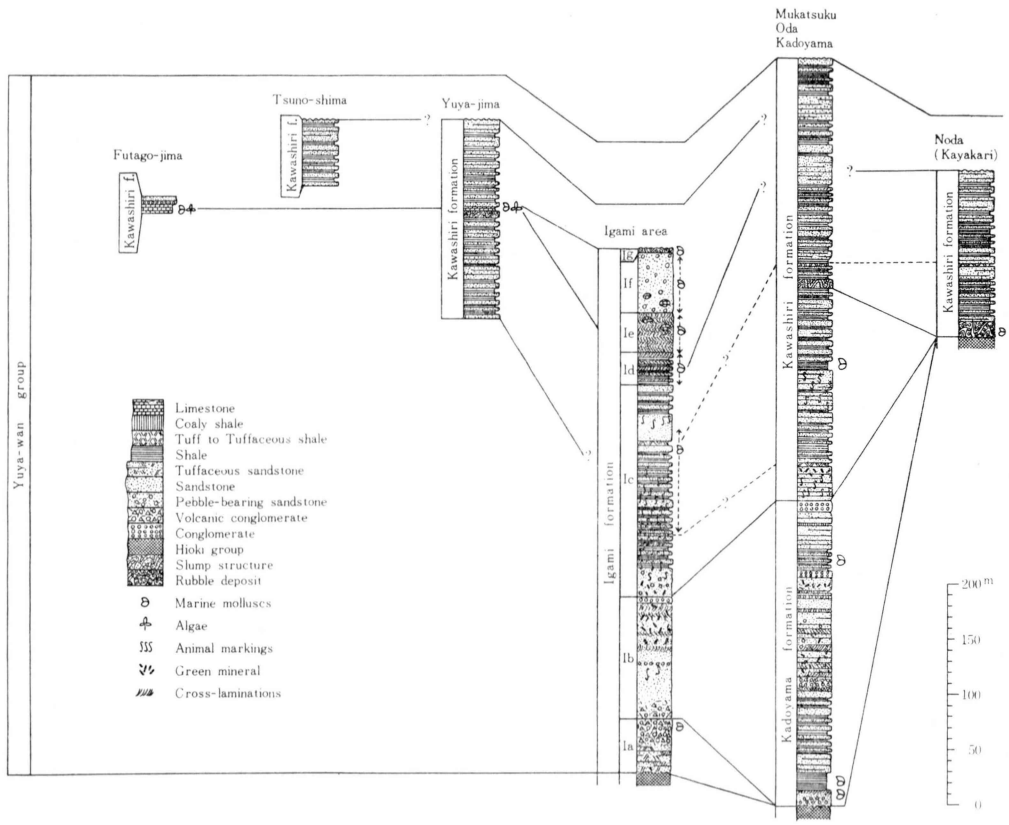

Fig. 2 Columnar sections of the Yuya-wan group.

1. Stratigraphic relationship between the Hioki and Yuya-wan Groups

The very outcrop demonstrating the relationship between the Hioki and Yuya-wan groups is not found unfortunately. In the Igami area the Ia bed of the Igami formation, the basal part of the Yuya-wan group, indicates an asymmetrical synclinal structure with the axis plunging slightly to the west. This structure accords well with that of the uppermost Hitomaru formation of the Hioki group.

However, the Ia bed seems to cover somewhat different horizons of the uppermost Hitomaru formation. Moreover, the sandstone and shale facies at the top of the Hitomaru formation is abruptly succeeded by the basal facies of the Igami formation made up of purplish to blackish red tuffaceous sandstone and variegated volcanic conglomerate. The matrix of the purplish to reddish colored rock is considered to be originated from the source-area under the appropriate condition that the purplish to reddish colored soils are formed. In a word, this is probably the "red clay conglomerate" by CLARK (1962). In general the reddish colored rock facies appears to relate fairly to "unconformity" in the Paleogene strata of North Kyushu (MATSUSHITA, 1949). Of course the conglomerate of the Ia bed has some pebbles originated from the Hioki group.

The relationship between the Hioki and Yuya-wan groups is hardly discussed from the paleontological evidence, though there is a remarkable distinction in the faunal compositions. But some hiatus is recognized when both groups are assigned to their proper positions in the successive Tertiary geologic column of Northwest Kyushu (Table 2).

Thus the stratigraphic relationship between the Hioki and Yuya-wan groups is thought to be a disconformity.

2. Igami formation

This formation, which lies disconformably upon the Hitomaru formation and the uppermost of which sinks under the Yuya-wan, is exposed in the Igami area. It is very variable, 80–425 m+, in thickness, and is lithologically subdivided into seven beds, i.e., the Ia-Ig beds in upward succession.

Ia bed: 15–50 m thick. Purplish to blackish red tuffaceous sandstone and variegated volcanic conglomerate. Most pebbles of conglomerate are derived from the basement rocks, and some from the Hioki group. Blackish red tuffaceous sandstone yields fossil molluscs as *Dosinia* sp. etc. Conglomerate yields also such molluscs as *Chlamys* cf. *arakawai* (NOMURA), *C.* cf. *miyatokoensis* (NOMURA and HATAI), *Kotorapecten* cf. *egregius* (ITOIGAWA), *Lima goliath* SOWERBY, *L.* cf. *konnoi* OTUKA, etc.*

Ib bed: 8–80 m thick. Fine- to coarse-grained sandstone including a kind of green mineral, with pebble conglomerate at the top of the bed. Fossil molluscs scarcely occur, but the animal marking belonging to Helmintoid group (TAKAHASHI, E., 1959a) is preserved.

* The molluscs from the Yuya-wan group were discriminated by MASUDA, K.

Ic bed: 10–185 m thick. Blue green coarse- to fine-grained sandstone, and alternation of sandstone and shale. This bed intercalates two layers of white tuff. Sandstone contains often a large number of mudstone breccia in irregular shape. Green mineral is also contained in the lower of the bed. This bed yields such molluscs as *Dentalium* sp., *Chlamys* cf. *arakawai* (NOMURA), *Lucinoma acutilineatum* (CONRAD), etc., and an echinoid *Linthia nipponica* YOSHIWARA. A crowd of the characteristic animal marking occurs in the lower and middle of the bed.

Id bed: 0–25 m thick. Alternation of coarse-grained sandstone to granule conglomerate and shale. Herringbone structure is well preserved. A large number of fragments of *Chlamys* sp. and *Balanus* sp. occur in this bed.

Ie bed: 0–30 m thick. Blue green massive coarse-grained sandstone containing rounded pebbles of algal limestone. Tabular cross-lamination is well observable in the upper. The algae in the pebbles are similar to those in the so-called *Lithothamnium* limestone at Shiraishi and Honyuya (ISHIJIMA, 1962).

If bed: 40–50 m thick. Light blue green massive pebble-bearing granule conglomerate to coarse-grained sandstone. The pebbles of limestone are also found. Molluscs such as *Chlamys* cf. *arakawai* (NOMURA) and *Ostrea* sp., and bryozoans are obtained.

Ig bed: 4m+ thick. Rubble deposit of pebble to boulder conglomerate. This bed covers the If bed with an uneven surface (load casts). The deposit yields such fragmentary molluscs as *Polinices* cf. *meisensis* MAKIYAMA, *Cypraea*? sp., and *Chicoreus* sp., and corals.

3. *Kadoyama formation*

This formation laps (LAHEE, 1959) unconformably on the Hitomaru formation. The relationship between the Kadoyama and the overlying Kawashiri formation is conformable at the west of Kadoyama, and becomes gradually indistinguishable eastwards. It is developed in Kakebuchi and Kadoyama. This formation, about 300 m thick, is chiefly composed of coarse-grained sandstone inserted with cobble to pebble conglomerate layers, black shale, fine-grained sandstone with shale intercalations, pebble to granule conglomerate, coarse- to fine-grained sandstone with a tuff intercalation, pebble conglomerate, alternation of shale and fine-grained sandstone, coarse- to fine-grained sandstone with a coaly shale intercalation, and pebble conglomerate in ascending order. Sandstone above and below the tuff includes also a kind of green mineral. The tabular and lenticular cross-laminations and load casts are often observed.

The occurrence of fossil molluscs is sporadic. Abundant fragments of *Ostrea* sp. and a brachiopod *Telebratalia* sp. were obtained from the basal coarse-grained sandstone. The shale above the basal sandstone yields such molluscs as *Siphonalia osawanoensis* TSUDA, *Dentalium weinkaufii* (DUNKER), *Nuculana* cf. *pennula* (YOKOYAMA), *Yoldia laudabilis* YOKOYAMA, *Y.* cf. *tokunagai* YOKOYAMA, *Propeamussium tateiwai* KANEHARA, *Lucinoma* cf. *acutilineatum* (CONRAD), *Cuspidaria osawanoensis* TSUDA, etc.

4. Kawashiri formation

This formation lies upon the Kadoyama formation with the relationship mentioned before, and is unconformably overlain by the Mukatsuku gravel bed. It is developed in wide extent from Kayakari, through Noda, the foot of Amagoi-dake, Mukatsuku and Yuya-jima, to Motoyama of Tsuno-shima and Futago-jima (islands). This formation, about 400 m thick, is chiefly composed of coarse- to fine-grained sandstone, black shale, and sandstone-predominant "Flysch type" alternation. Conglomerate scarcely occurs, and at least a tuff layer is inserted. The so-called *Lithothamnium* limestone (algal limestone), 1.3–2 m thick, is intercalated at Shiraishi (OGURA, 1918, 1919; YABE, 1920) of Tawarashima and Honyuya. The blocks of sandy algal limestone were collected on the central south coast of Tsuno-shima, and they are considered to be derived from the sea bottom south of the island. The same limestone, 7.5 m+ thick, is also found at Futago-jima southwest off the coast of Tsukuno. From these finds, it is undoubtedly inferred that the sandy algal limestone is exposed in fairly wide extent on the sea bottom south off Tsuno-shima. The sedimentary structures* such as graded bedding, load casts, slump structures, pull-aparts, buckling with thrust, etc. are well preserved.

The fossil molluscs are scant in this formation as well as in the Kadoyama formation. *Dentalium weinkaufii* (DUNKER), *Solemya tokunagai* YOKOYAMA, *Nuculana* cf. *pennula* (YOKOYAMA), *Saccella* sp., *Akebiconcha* sp., *Anisodonta* sp., *Lucinoma acutilineatum* (CONRAD), *Paphia* sp., *Macoma* sp., *Tellina* cf. *notoensis* MASUDA, *Cuspidaria* sp., etc. were obtained from the shale layer on the coast south-southeast of Kawashiri. *Batillaria tateiwai* MAKIYAMA, *Cancellaria* sp., *Anadara* sp., *Limopsis* sp., *Placopecten* sp., *Paphia* cf. *hirabayashii* OTUKA, etc. were collected from the pebble-bearing shale at the pass between Noda and Tsuô. *Nassarius* sp., *Dentalium* sp., *Saccella* sp., *Chlamys* sp., etc. were gathered from the cobble-bearing shale at Kayakari. *Ostrea* sp. and *Tellina* sp. occurred rarely in the sandstone at the place east of Oda suffered from the landslide. The so-called *Lithothamnium* limestone consists chiefly of such algae as *Dermatolithon* cf. *saipanense* JOHNSON, *Lithophyllum Imamurai* ISHIJIMA, *L. yuyashimaensis* ISHIJIMA and *Mesophyllum yuyashimaensis* ISHIJIMA (ISHIJIMA, 1954, 1962). In addition to the algae, the limestone yields molluscs, as *Crassostrea* cf. *sakitoensis* (NAGAO) and *Cyclina*? sp., an echinoid *Echinolampas yoshiwarai* (LORIOL)** and a bryozoan Cf. *Cellepora formosensis* NEWTON and HOLLAND.*** The sandy algal limestone derived from the sea bottom south off Tsuno-shima yields algae, smaller foraminifera, as *Discorbis*? sp. and *Robulus lucidus* (CUSHMAN), fragments of molluscs, etc. (OKAMOTO, 1960). The animal marking identical with that from the Ic bed of the Igami formation is also found at Tenaga-jima (island) of Yuya-wan and on the north coast of Kadoyama.

5. The stratigraphic relationship among the Igami, Kadoyama and Kawashiri formations

Now the writer will here describe and discuss the stratigraphic relationship among

* For the sedimentary structures the terms defined by ARAI (1960) are here used.
** Discriminated by MORISHITA, A.
*** Discriminated by HANZAWA, S.

the Igami, Kadoyama and Kawashiri formations scattered around Yuya-wan, regarding the Igami fromation as the type of the Yuya-wan group (Fig. 2).

The correlative with the Ia bed of the Igami formation is not found in Kakebuchi and Kadoyama, i.e., the base of the Yuya-wan group is missing there.

The Kadoyama formation is correlated with the Ib bed of the Igami, because there are some similarities in the lithofacies, and the conglomerate at the top of the Kadoyama is thought to be equivalent to that at the top of the Ib.

The occurrence of the characteristic animal marking in the lower and middle of the Ic bed of the Igami is traced from Igami, through Take-shima and Tenaga-jima of Yuya-wan, to the north coast of Kadoyama where the lower of the Kawashiri formation is exposed. Accordingly, the lower limit of the Kawashiri is correlated with that of the Ic. It is not ascertained whether which part of the Kawashiri corresponds to the Id bed of the Igami. Among the Ic–Ig beds, the upper of the Ic and the If contain the rounded pebbles made up chiefly of algae, which are thought to be formed simultaneously with the accumulation of these beds. Besides, the water-worn fragmentary molluscs, corals, bryozoans and acorn-shells were obtained from the Ic–Ig. The so-called *Lithothamnium* limestone at Shiraishi and Honyuya yields smaller foraminifera, molluscs, bryozoan, echinoid, and algae of the same kind. The sandy algal limestone at and around Futago-jima yields also similar fossils. Judging from the lithofacies and fossil associations, the Ic–Ig beds, the so-called *Lithothamnium* limestone and the sandy algal limestone are not the deposits at various times, but must be a contemporaneous accumulation to build up an open shoal-reef (HENSON, 1950), showing remarkable lateral change.

Although the beds upper than the Ig bed of the Igami are unknown, the correlatives with these beds are the strata upper than the limestone of the Kawashiri, which are developed in Mukatsuku, Yuya-jima and Tsuno-shima.

6. Volcanism during the accumulation of the Yuya-wan group

The Yuya-wan group intercalates two layers of tuff or tuffaceous rock at least. The writer examined 7 specimens from the layers by means applied to the specimens from the Hioki group as well. It was hereby known that the tuff layers of the Yuya-wan group came probably from the volcanism of dacite to andesite (?).

D. BRONZITE-AUGITE-ANDESITE AND RHYOLITE

1. Bronzite-augite-andesite (ŌJI, 1961a, b)

This andesite occurs, as dikes with 5–12 m width, along or parallel to the faults of NW or NNW trend which cut the Tertiary strata. These andesite dikes are found in Sakaigawa, Kiwado, Kadoyama and the environs of Oda and Dôte, and on the coast of Igami.

The Quartz-dolerite (ŌJI, 1961a, b) intrudes also as dikes into the Yuya-wan group on the coasts of Igami and to the south-southeast of Kawashiri. On the latter coast this dolerite cuts across a dike of the Bronzite-augite-andesite.

2. Rhyolite (Ōji, 1961a, b)

This Rhyolite intrudes, as a dike of NW direction with 10 m width, into the Paleogene Hypersthene-bearing pigeonite-augite-olivine-andesite on the northwest coast of Tsuô.

E. Mukatsuku gravel bed and Olivine-trachybasalt

1. Mukatsuku gravel bed (Okamoto and Imamura, 1964)

The Mukatsuku gravel bed lies unconformably upon the Kawashiri formation and others, and is overlain by the Olivine-trachybasalt with a probable conformity. It is exposed narrowly along the boundary between the Olivine-trachybasalt and the underlying strata in the area west of Amagoi-dake, Mukatsuku, Yuya-jima, and Shimado. Consequently, the gravel bed is not shown on the geological map (Pl. VI). This gravel bed, about 5 m thick, is chiefly composed of gravel containing rounded to subrounded pebbles and cobbles of "rhyolite and quartz-porphyry", and andesites, with subordinate conglomerate, sandstone, shale, basalt and tuff. No fossils are collected. In general the gravel bed inclines slightly to the north-northwest.

2. Olivine-trachybasalt (Kurasawa and Takahashi, K., 1960; Ōji, 1961a, b)

This basalt overlies the Mukatsuku gravel bed with a probable conformity, and is developed in wide extent of this district as a member of the so-called circum Japan Sea alkaline petrological province. This basalt, about 150 m thick, is composed of lavas intercalated with a few layers of conglomerate and tuffaceous rock. At places the dikes and sheets of the basalt are found.

F. Furuichi and Oyama gravel beds (Okamoto, 1961; Okamoto and Imamura, 1964)

The Furuichi graved bed is developed in the area around Furuichi and others. The Oyama gravel bed is exposed in the Oyama area of Tsuno-shima. The former is made up of fluvial deposits and the latter probably of coastal terrace ones.

V. Geologic structure

Generally speaking, the Tertiary formations of this district show the so-called Chikuhô type structure defined by Matsushita (1951), which is conveniently named to the geologic structure characterized by the developement of normal faults of NW or NNW trend in the Chikuhô coal field of North Kyushu. The folds of each Tertiary unit and the faults will be given as under.

A. Folds

1. Paleogene andesites

In the northeastern marginal area of the Yuya-Hioki bay, the Hypersthene-bearing pigeonite-augite-olivine- and Olivine-andesites show a monoclinal structure,

having the strike of WNW direction and dip of 10–20° to the south. Then these andesites have the same tendency with the underlying Kwanmon group in structural behavior.

2. Hioki group

The Hioki group forms an asymmetrical synclinal or semi-basin structure in each of the three different sedimentary basins (Pl. VI). That is to say, the group in the Kiwado bay shows an asymmetrical syncline with the axis of N-S or NNW direction along the Niigahama-Kiwado fault; the group in the Yuya-Hioki bay makes up an asymmetrical syncline (or semi-basin) with the axis of E-W trend plunging slightly to the west along the Juraku-Kaikawa fault; and the group in the Kottoi bay shows also an asymmetrical syncline with the axis of NNW direction along the Waku-Shimoda fault.

3. Yuya-wan group

The Ia–Ib beds, the lower of the Igami formation, in the Igami area show an asymmetrical synclinal or semi-basin structure with the axis plunging slightly to the west, in accordance with that of the Hitomaru formation of the Hioki group. However, the major parts of the Yuya-wan group distributed from Kayakari to Tsunoshima show, as a whole, an undulating monoclinal structure dipping to the north-northwest, repeating minor folds with the axes of NE or ENE trend plunging sometimes to the east or the west.

B. Faults

There are some interesting faults controlling the Tertiary distribution and structure of this district, i.e., the Niigahama-Kiwado and Waku-Shimoda faults of N-S or NNW trend, and the Kaisaku and Jûraku-Kaikawa faults of E-W trend (Pl. VI). In each sedimentary basin the eastern or northeastern margin of the Tertiary strata rests unconformably on the basement rocks, whereas the western or southern end is in contact with the basement by the fault mentioned above, along which the axis of syncline runs. At some places on these fault lines, the Tertiary formations cover the basement rocks with an unconformity. These characteristic faults must belong to the category of the so-called fundamental fault (Matsushita and Takahashi, R., 1964) or the sedimentary fault* by Sakakura (1964, pp. 133–137, Fig. 75).

In the whole of the district the Tertiary strata are often cut by the faults of NNW or NW and E-W or ENE directions. The Mukatsuku gravel bed and the Olivine-trachybasalt are also faulted with the same directions, but the displacement is much

* According to Sakakura (1964), the "sedimentary fault" had originally been produced before the accumulation of the Tertiary strata in the Chikuhô and other coal fields of North Kyushu. After that, the coal-bearing Tertiary formations were deposited unconformably on the fault scarp of the basement rocks, and then were sliding down along the scarp by the loading of themselves in the course of the deposition. Consequently, the Tertiary formations are now contiguous to the basement rocks by the interesting "sedimentary fault".

smaller than that in the Tertiary. In the west of the district the Tertiary strata are cut by the fault of N-S or NNE trend.

VI. Faunas and Floras

Fairly abundant fossils from the Hioki and Yuya-wan groups are classified into the following assemblages:

Ashiya (Kiwado-Taoyama) faunule
Sasebo non-marine molluscan (Hitomaru) faunule
Faunule of the Tsuno-shima member (unnamed)
Noda florule
Daibô florule
Yatsuo-Kadonosawa (Yuya-wan) faunule

For the pollen and spore assemblages from the Kiwado member and the Hitomaru formation of the Hioki group, readers are refered to Takahashi, K. (1963a, b). The foraminiferal assemblages are now being studied by the writer.

Ashiya (Kiwado-Taoyama) faunule: The marine molluscs except *Batillaria takeharai* from the Kiwado member and the Taoyama formation of the Hioki group are the elements of the Ashiya faunule (fauna), which is chiefly distributed in Southwest Japan and has been regarded as an index of Oligocene or Early Miocene of Japan. The characteristic species are *Turritella infralirata* Nagao, *Euspira ashiyaensis* (Nagao),* *Phyllonotus ashiyaensis* (Nagao), *Molopophorus denselineatus* (Nagao),* *Acila ashiyaensis* (Nagao),* *Glycymeris cisshuensis* Makiyama,* *Chlamys ashiyaensis* (Nagao), *Crassostrea sakitoensis* (Nagao),* *Crassatellites yabei* Nagao, *Venericardia subnipponica* Nagao,* *Pitar ashiyaensis* (Nagao), *Callista hanzawai* (Nagao),* *Dosinia chikuzenensis* Nagao,* *Angulus maximus* (Nagao),* etc., with the echinoid *Echinodiscus chikuzenensis* Nagao. At first the faunule was described and monographed by Nagao (1928a, b) from the Ashiya group and its equivalents in North and Northwest Kyushu. After that, Hatai (1938), Hirayama (1956), Mizuno (1956, 1964), Oyama et al. (1960), and Shuto (1963a) studied the faunule. According to them, it should be noteworthy that the Ashiya faunule contains the elements related more closely to the Miocene faunules than the Paleogene ones in Japan, though the Ashiya has some similarities to the Oligocene Lincoln and Blakeley faunule in the United States.

Sasebo non-marine molluscan (Hitomaru) faunule: A large number of *Corbicula matusitai*, with a few "*Viviparus*" sp. and paralic? molluscs, were obtained from the lowest of the Hitomaru formation of the Hioki group. These fossils belong to the Sasebo non-marine molluscan faunule (fauna) by Suzuki (1941). In the past *Corbicula matusitai* had been found from the Miocene Ainoura, Sasebo and Nojima groups in Northwest

* These species are often included in the strata overlying or underlying the Ashiya group and its equivalents.

Kyushu and the Koura formation in the San-in district of Chugoku. In Northwest Kyushu the formations with the Sasebo non-marine molluscan faunule overlie those with the Ashiya faunule.

Faunule of the Tsuno-shima member (unnamed): The marine molluscs such as *Batillaria takeharai*, *Cerithium* sp., *Crassostrea gravitesta* and *Cyclina japonica* were gathered from the Tsuno-shima member of the Hioki group. These, together with the Sasebo non-marine molluscan faunule, are found in the Saseboan Ainoura and Sasebo groups of Northwest Kyushu (Mizuno, 1964). *Crassostrea gravitesta* and *Cyclina japonica* are commonly discovered in the so-called Middle Miocene strata of Japan, though *Batillaria takeharai* is newly found from the Taoyama formation of Kottoi.

The Tsuno-shima member is probably regarded as a part of the Kiwado member or the Taoyama formation from the lithology and geologic structure, but the fossil contents of the Tsuno-shima differ remarkably from those of the Kiwado and the Taoyama. Accordingly, the facts mentioned above bring here a contrast between the lithostratigraphy and the biostratigraphy of the Tsuno-shima. In this papes, however, the Tsuno-shima member is treated as a part of the Hitomaru formation until the more distinct and sufficient data will be obtained.

Noda florule: This florule (Imamura, 1958) was collected from the uppermost of the Kiwado member of the Hioki group at Noda. It is important by reason that fossil plants have not yet been reported from the Tertiary strata of Japan correlated with this member. Among the plants discriminated, the species such as *Juglans nigella*, Cf. *J. acuminata*, *Betula Brongniarti*, *Castanea Kubinyi*, *C. Ungeri*, *Fagus Antipofi*, and *Ficus tiliaefolia* are found from the Eocene to Miocene strata in and around Japan, whereas the elements such as *Populus zaddachi*, *Quercus Lyallii*, *Q.* cf. *gloenlandica*, *Broussonetia* cf. *Imaii*, *Cercidiphyllum eojaponicum*, *Platanus aceroides*, *Celastrophyllum* cf. *crenatum*, *Rhamnus* cf. *Rossässleri*, and *Viburnum Nordenskiöldi* occur restrictedly in the Paleogene formations of Japan and its adjacent regions. The proportion of the former species to the latter is nearly equal. Consequently, it was thought by Imamura (1958) that this florule is a Paleogene type and indicates Oligocene in age.

According to Takahashi, E. (1959b), the florule consists mainly of temperate broad-leaved trees with a few evergreen Lauraceae, showing the floristic composition in the middle to lower latitudes of temperate zone.

Daibô florule: This florule (Imamura and Wada, 1956; Imamura and Okamoto, 1959) was gathered from the middle of the Hitomaru formation of the Hioki group at Daibô and Yamane. It consists of temperate elements such as *Ulmus*, *Zelkova*, *Acer*, *Carpinus* and warm elements such as *Liquidambar* and *Cinnamomum*, with some Paleogene species as *Platanus* cf. *aceroides* (Tanai, 1961). As for the geologic age, there are divergent opinions. Takahashi, E. (1959b) considered that the florule in question is more intimate with the Noda florule than the Early or Earliest Miocene Ainoura flora (Tanai and Onoe, 1956; Tanai, 1961), which is the Neogene type with some Paleogene relic species, from the Ainoura group in Northwest Kyushu. By this reason he placed the age of the florule at Oligocene. On the other hand, Tanai

(1961) regarded the Daibô florule as a closely similar one to the Ainoura type flora in respect to floristic composition and components. The writer prefers TANAI's view to TAKAHASHI's, with an opinion that the Hitomaru formation can be correlated with a part of the Ainoura group from the occurrence of *Corbicula matusitai* etc., as well as from the lithofacies and volcanism.

Yatsuo-Kadonosawa (Yuya-wan) faunule: Among the marine molluscs from the Yuya-wan group, the important ones are as follows:

Batillaria tateiwai, *Polinices* cf. *meisensis*, *Siphonalia osawanoensis*, *Nuculana* cf. *pennula*, *Yoldia* cf. *tokunagai*, *Propeamussium tateiwai*, *Chlamys* cf. *arakawai*, *C.* cf. *miyatokoensis*, *Kotorapecten* cf. *egregius*, *Lima* cf. *konnoi*, *Paphia* cf. *hirabayashii*, *Tellina* cf. *notoensis*, *Cuspidaria* cf. *osawanoensis*, etc.

These are the elements or the accompanists of the so-called Yatsuo-Kadonosawa faunule (fauna), being distinctly different from those of the Ashiya faunule. The echinoid *Echinolampas yoshiwarai* is also accompanied by this faunule. *Crassostrea* cf. *sakitoensis* which came from the Kawashiri formation is only a relict of the Ashiya. The Yatsuo-Kadonosawa faunule in association with *Miogypsina* and *Operculina* was extensively flourished in Japan at Middle Miocene.

VII. CORRELATION AND AGE

The correlation among the Tertiary formations in the Saikai sedimentary province including the surveyed district and the adjacent Setouchi and San-in sedimentary provinces is summarized as shown on Table 2. For the correlation, the writer takes into consideration not only the fossil-evidence but also the stratigraphic records including sequence of strata, lithofacies, cycles of sedimentation, stratigraphic breaks and volcanism. The detailed account of the correlation was given by OKAMOTO and IMAMURA (1964).

The Hypersthene-olivine-basalt, the Hypersthene-bearing pigeonite-augite-olivine-andesite and other andesites scarcely have evidence for age-determination except the fact that the basalt rests on the Yahata formation and is covered by the Hioki group. These volcanic rocks seem to be lithologically younger than the Sakugi volcanic rocks (YOSHIDA, 1961) yielding the Senonian Suritaki florule (ENDÔ, 1959; IMAMURA, YOSHIDA and MIURA, 1960) in Hiroshima Prefecture. Accordingly, the age of these basalt and andesites is probably placed at a Paleogene.

As for the age of the Hioki group, the Sakaigawa and Taoyama formations might be assigned to Oligocene from the viewpoint of the Ashiya faunule and the Noda florule, though TAKAHASHI, K. (1962, 1963a) considered that the pollen and spore florule of the Kiwado member belongs to his Miocene Sasebo pollen florule (1961). On the other hand, the Hitomaru formation is placed at Early Miocene from the occurrence of *Corbicula matusitai* and the Daibô florule.

On the basis of the planktonic foraminifera, however, ASANO (1962a, b) stated

that the accumulation of the Kishima group in Northwest Kyushu started at the time represented by the *Catapsydrax dissimilis-C. stainforthi* zones of Trinidad. Moreover, Shuto (1963a, b) inferred that the ages of the Kishima formation and the Kishima group without the Kishima formation are probably assigned respectively to Rupelian-Chattian and Aquitanian from the Tertiary lithologic sequence and the time-range of planktonic foraminifera in Japan. If so, it may be more appropriate to place the ages of the Jûraku member and the Hioki group excluding the Jûraku at Late Oligocene and Early Miocene (Aquitanian) respectively.

The Yuya-wan group can be placed at the horizon of the so-called Yatsuo-Kadonosawa faunule associated with *Miogypsina* and *Operculina*. Saito (1963) regards the *Miogypsina* and *Operculina*-bearing horizon as the Burdigalian *Globorotalia fohsi barisaensis* zone. Therefore, the Yuya-wan group is assigned to Middle Miocene (Burdigalian) in age.

The Bronzite-augite-andesite and the Quartz-dolerite seem to be the equivalents of the Kôyama basalts, namely, the bronzite-augite-andesite and quartz-dolerite (Ōji, 1961a, b) at and near Kôyama-misaki (cape) in the northeast of Yamaguchi Prefecture. Moreover, the so-called Kôyama basalts are thought to correspond to the Late Miocene Hizen dolerites in Northwest Kyushu (Matsumoto, Y., 1961, 1963). Accordingly, the age of the andesite and dolerite is probably assigned to Late Miocene. The age of the Rhyolite intruding into the Paleogene andesite at the northwest of Tsuô is placed at Late Miocene or Early Pliocene after Ōji (1961a, b).

The Mukatsuku gravel bed and the Olivine-trachybasalt are respectively correlated with the Hachinokubo and Sarushi gravel beds and the Matsuura basalts in Northwest Kyushu, both of which are assigned to a Pliocene by Yamasaki (1959a), Matsumoto, Y. (1961), Tachibana (1963) and others. Thus the age of the Mukatsuku gravel bed and the Olivine-trachybasalt is considered to be a Pliocene, though there are other opinions on this subject by Takahashi, E. (1953) and Iwahashi (1961a).

VIII. Remarks on the Tertiary geologic history and paleogeography of West Chugoku

The Tertiary geology of the Yuya-wan district is not similar to that of the Setouchi and San-in sedimentary provinces, but to that of the Saikai sedimentary province. In other words, the Tertiary geologic history of West Chugoku had been developed in close connection with that of North and Northwest Kyushu, as will be remarked in the ensuing pages.

Eocene Nôgatan (Okinoshiman) age: The oldest Tertiary strata in West Chugoku is the Upper Eocene Ube group (Matsumoto, Takaichi and Seto, 1961) in Ube and its adjacent areas, which is correlated with the formations of North and Northwest Kyushu at Nôgatan age. The Tertiary strata in the environs of Yamaguchi northeast of Ube are also regarded as the correlatives with the Ube group from the lithofacies

TABLE 2 CORRELATION AMONG THE TERTIARY FORMATIONS OF THE SAIKAI, IN WHICH THE YUYA-WAN DISTRICT IS INCLUDED, SETOUCHI AND SAN-IN SEDIMENTARY PROVINCES.

Age	Stage: MATSUSHITA (1949)	Stage: MIZUNO (1962, '64)	South Korea	Saikai Sedimentary Province: Tsushima	Saikai: Sasebo Coal Field	Saikai: Chikuhô Coal Field	Saikai: Yuya-wan District	Setouchi Sedimentary Province: Miyoshi・Shôbara	San-in Sedimentary Province: Shimane Prefecture
Pleistocene									Tsunozu f. ∂ ⊕ ✕
Pliocene					Matsuura basalts		Olivine-trachybasalt		
					?		?		
					Hachinokubo gravel b.		Mukatsuku gravel b.		
					Hirado f. ⊕				Izumo g.: Matsue f. ∂ ∘∘
Miocene including Aquitanian (Early) — Late					Nojima g.: Minami-tabira f.; Fuka-zuki f. ⊕d 6; Ôya f. 6; Sanukitic rocks; Hizen dolerites		Bronzite-augite-andesite etc.		Izumo g.: Fuzina f. ∂ ∘∘ ✕
	Chikushi — Upper	Saseboan	Ennichi (Yŏngil) g. ∂k ⊕d?		Sasebo g.: Kase f. ∂k ∘∘		Yuya-wan g. ∂k ∘∘ ⊕	Bihoku g. ∂k ∘∘	Iwami g.: Ômori f. ∂
			Poumgongni g.		Fukui f. ∂k 6 ⊕n		↓ ?	Shiomachi f. ⊕d	Iwami g.: Kuri f. ∂ ∘∘
			Chôki (Changgi) g. ∂ ⊕		Sechibaru f. ∂ 6				Iwami g.: Kawai f. ∂k (6) ∘∘
			↓ ?		Up. Yunoki f. 6 ⊕n ✕				Iwami g.: Hata sg. ⊕d ✕
					Low. Yunoki f. ∂ ⊕n				↓ ?
					Nakazato f. ∂ 6 ✕				
					Ainoura g.: Einoshima f. ⊕i		?		
					Masaru f. ∂				
					Tanakata f. 6 ⊕i				
					Usunoura f. ∂				
					Sida f. ⊕i				
				?	Kishima g.: Daitô f. ∂a ∘∘	Ashiya g.: Wakita f. ∂a ∘∘		Hioki g.: Hitomaru f. 6 ⊕i	
					Haiki f. ∂a ∘∘	Sakamizu f. ∂a ∘∘		Taoyama f. ∂a ∘∘	
				Taishu g. ∂ ⊕	Mikawachi f. ∂a ∘∘	Yamaga f. ∂a ∘∘		Sakaigawa f.: Kiwado m. ∂a ∘∘ ⊕	
					Magarikawa f. ∂a ∘∘			Sakaigawa f.: Jûraku m.	
		Mazean			Kishima f. ∂m ∘∘	Ôtsuji g.: Onga f. ∂m		?	
	Ôtsuji	Funazuan			Paleogene strata	Ideyama f. ∂		Hypersthene-bearing pigeonite-augite-olivine-andesite etc.	
	Nôgata	Okinoshiman				Paleogene strata			
Eo.-Oligocene	Ariake	Takashiman		?				Hypersthene-olivine-basalte	
	Amakusa								

∘∘ Smaller foraminifera
∂ Marine molluscs
∂k Yatsuo-Kadonosawa faunule
∂a Ashiya faunule
∂m Kishima (Maze) faunule
6 Fresh-and brackish-water molluscs
✕ Vertebrates and others
⊕ Plants
⊕d Daijima florule
⊕n Aniai florule
⊕i Ainoura florule

g. : group sg. : subgroup
f. : formation m. : member
b. : bed

The tabel is compiled on the basis of the following papers:

Sasebo and Chikuhô coal fields……ASANO (1962a, b), IWAHASHI (1961a, b, c), MATSUI (1961), MATSUMOTO, Y. (1961, 1963), MATSUSHITA (1949), MATSUSHITA et al. (1956), MIZUNO (1964), MURATA (1961), ŌJI (1961a, b), SHUTO (1963a, b), TACHIBANA (1963), TAKAHASHI, K. (1962), TAKAHASHI, R., UEDA and IWAHASHI (1957), TANAI (1961), and YAMASAKI (1959b).

Tsushima……KANNO (1955) and TAKAHASHI, K. (1958).

Setouchi and San-in districts……IMAMURA (1953, 1957, 1964), MUKAE (1958), OKAMOTO (1959), and TAI (1959, 1963).

South Korea……TAKAHASHI, E. (1959c), TATEIWA (1924), and TSURUTA (formerly KANEHARA) (1936).

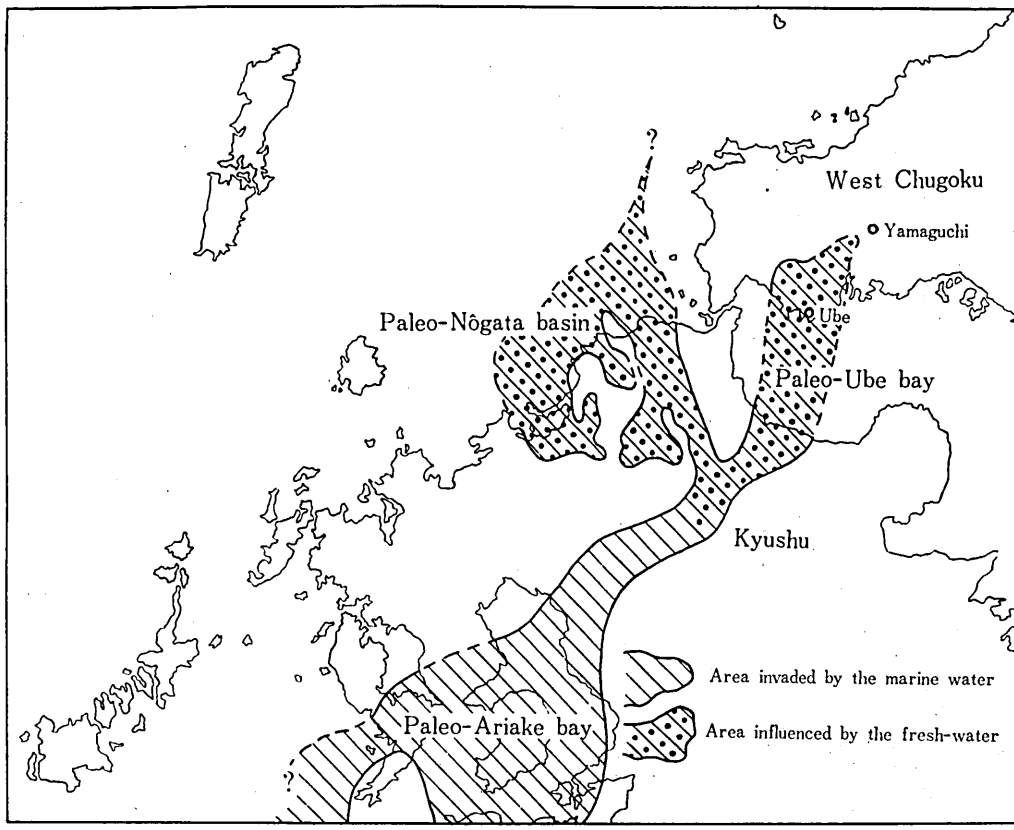

FIG. 3a Paleogeographic map at Nôgatan (Okinoshiman) age.

The paleogeographic maps of Kyushu in Figs. 3a-d are compiled from those by MATSUSHITA (1949), MATSUSHITA et al. (1956), MIZUNO (1964), and SHUTO (1963a).

(MATSUSHITA, TAKAHASHI, E. and TSUYUKI, 1959). Accordingly, the paleogeographic map at this age will be given as shown in Fig. 3a.

In the Yuya-wan district there are the Paleogene basalt and andesites. The volcanic activities during Paleogene in North and Northwest Kyushu were inferred by OHARA (1962) from the heavy mineral associations of the Tertiary strata. At the present time, however, the relationship among the volcanic activities in these districts is not clear and accurate, because the volcanic activities similar to those in this district can not be found in North and Northwest Kyushu. Moreover, the basalt and andesites of this district seem to differ petrographically from the so-called Paleogene (or the Late Cretaceous) andesites in Hamada and Masuda east-northeast of the district (MURAKAMI, 1959; FUJITA, 1964). The stratigraphic relationship between the Ube group and the basalt and andesites in question is not determined too.

Oligocene Ôtsujian to earliest Early Chikushian (Funazuan to Mazean) age: After the eruption of the basalt and andesites, the paralic Jûraku member of the Hioki group

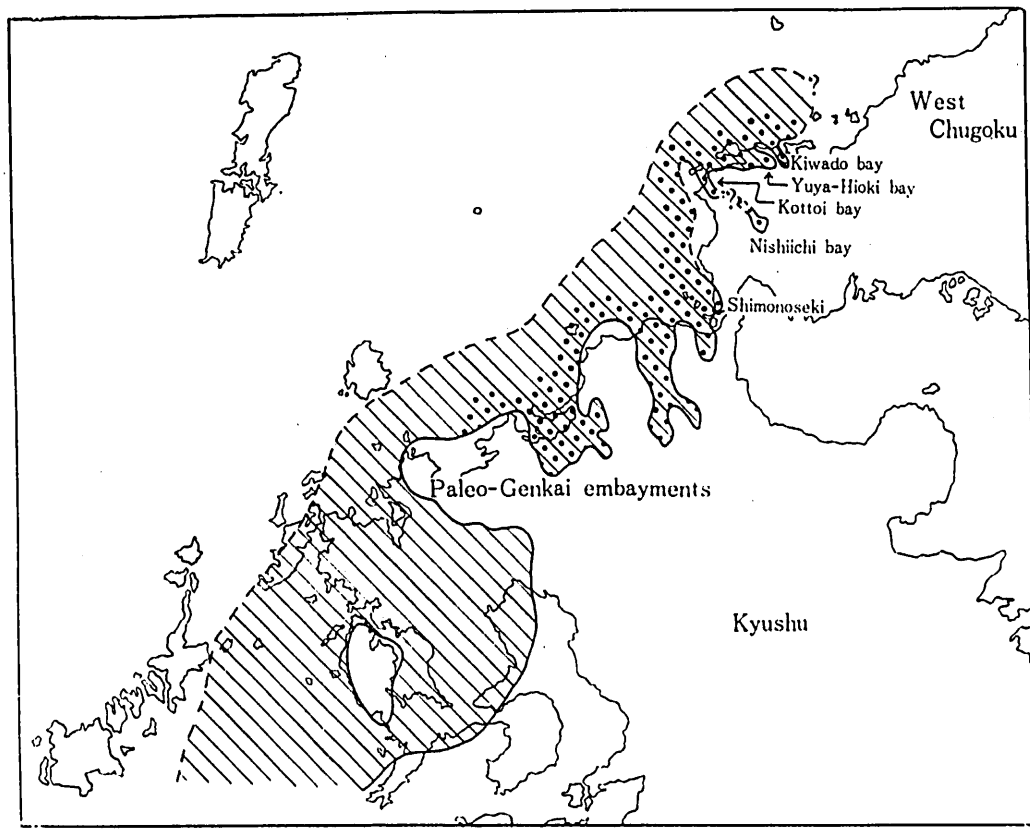

Fig. 3b Paleogeographic map at Ôtsujian to earliest Early Chikushian (Funazuan to Mazean) age.

and its equivalents (the so-called Ôtsuji group) at Ôtsujian to the earliest Early Chikushian (Funazuan to Mazean) age were accumulated in the environs of Yuya-wan, the Nishiichi area (Takahashi, K., 1961) and Shimonoseki (Uyeda, 1957). The paleogeographic map during the age is given as shown in Fig. 3b.

In the Saikai sedimentary province the accumulation of the Paleogene formations started generally earlier in the southwestern areas than in the northeastern areas. The deposition of the strata in the Yuya-wan district, which is situated in the most northeast, commenced at this age, being further later than in Kyushu. From this fact, it is concluded that the transgression progressed from the southwest to the northeast.

In North Kyushu the sedimentary basins for the (coal-bearing) Tertiary strata had been providing there until a latest Cretaceous or an early Paleogene (Matsushita, 1949; Urata, 1962; Sakakura, 1964) by the movement of undulating and faulting of NW-SE or NNW-SSE direction named the Korean trend by Tateiwa (1952). The so-callled fundamental faults are originated from this movement. The similar phenomena can also be found in West Chugoku. Accordingly, the Kiwado, Yuya-Hioki,

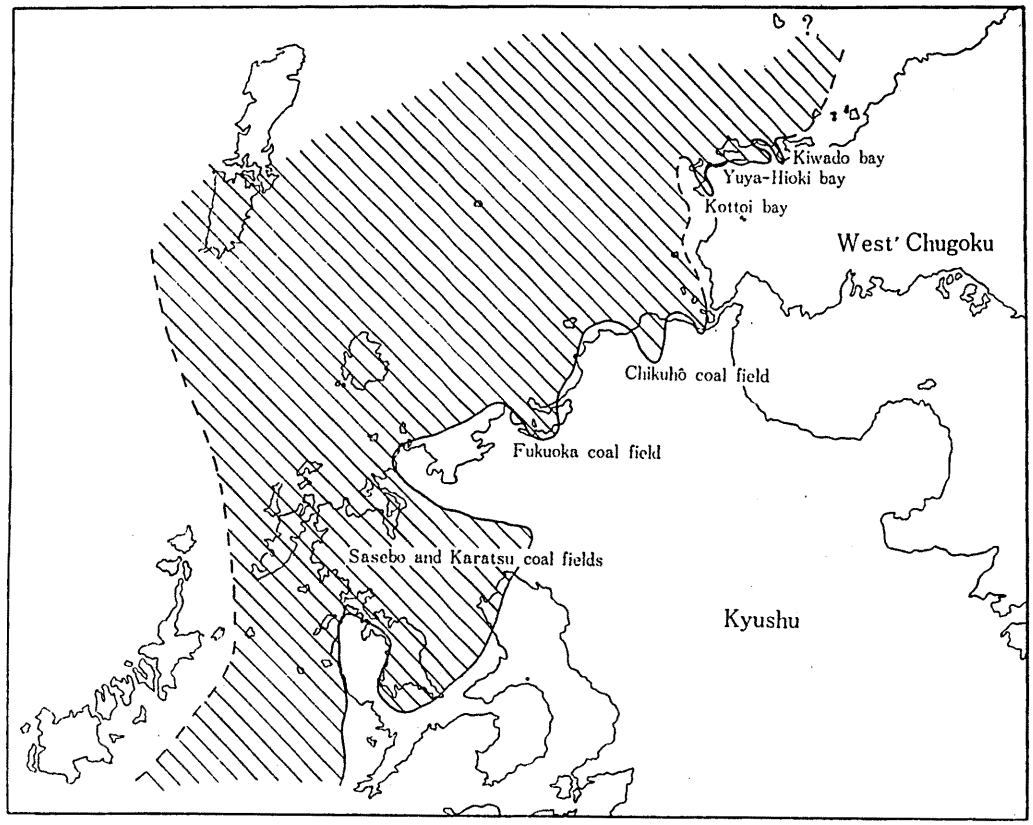

FIG. 3c Paleogeographic map at Early Chikushian (Nishisonogian) age.

Kottoi and Nishiichi sedimentary basins are thought to have been prepared for the Hioki group. The west margins of the Tertiary strata in the Kiwado, Kottoi and Nishiichi bays are respectively distinguished from the basement by the Niigahama-Kiwado, Waku-Shimoda and Ishimachi fundamental faults of NNW-SSE direction or the Korean trend, and the south margin of those in the Yuya-Hioki bay is also restricted by the Jûraku-Kaikawa fundamental fault of E-W direction nearly parallel to the Setouchi trend by HUZITA (1962). While in the Chikuhô and Kokura coal fields and Shimonoseki the east margin of the Tertiary strata in each sedimentary basin is bordered by the fundamental fault of NNW-SSE direction. The fault similar to the Jûraku-Kaikawa one is found on the south limit of the Fukuoka coal field. For the more detailed discussion of the fundamental structure of the Tertiary in North Kyushu and West Chugoku, readers should be referred to T. MATSUMOTO's excellent paper (1951).

In North Kyushu the Nôgatan (Okinoshiman) stage is overlain unconformably by the Ôtsujian (Funazuan) stage (MATSUSHITA et al., 1956), though in Northwest Kyushu the stratigraphic relationship between them seems to be conformable in some

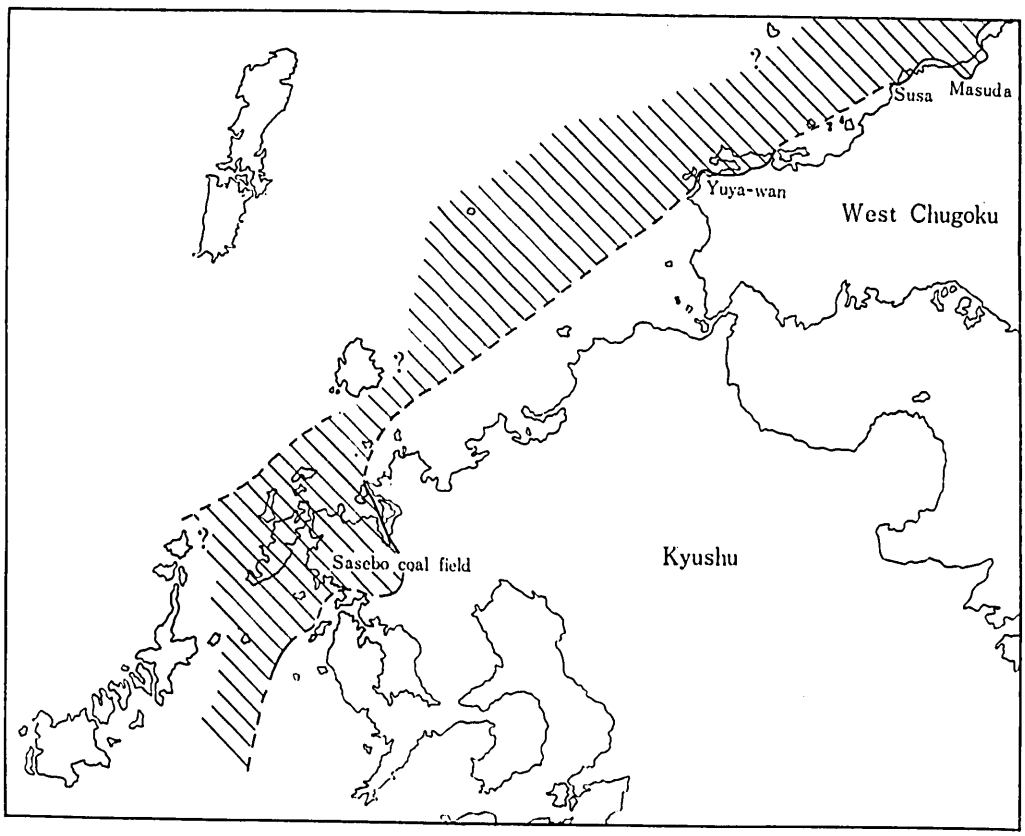

Fig. 3d Paleogeographic map at Late Chikusian (late Seseboan) age.

places, but not in other places. In West Chugoku, however, the Ôtsujian or/to the lowest Lower Chikushian Jûraku member and its equivalent are developed separately from the Nôgatan Ube group, covering directly the basement rocks (Figs. 3a-b). From these facts, it can be concluded that the uplift of the basement took place in the central and northern Kyushu and the south side of West Chugoku at the time between Nôgatan and Ôtsujian ages, causing a remarkable change of paleogeography. This is comprehended as the embryonic phase of the Takachiho disturbance (Shuto, 1963a), which corresponds approximately to the late Paleogene to early Neogene movement of the Takachiho phase (Kuroda and Matsumoto, T., 1942) in the Outer zone of Southwest Japan.

Miocene Early Chikushian (Nishisonogian) age: The paleogeographic map for the Kiwado member and the Taoyama formation of the Hioki group and the Ashiya (Kishima) group at Early Chikushian (Nishisonogian) age is given as shown in Fig. 3c.

In general this stage is gradual and successive from the underlying lowest Lower Chikushian stage, though the former overlies unconformably the latter in some places of Kyushu. The so-called Ashiya marine invasion penetrated into the land, and the

Ashiya (Kishima) group was accumulated respectively in the Sasebo-Karatsu and Chikuhô coal fields of Kyushu, the Yuya-wan district and others. Each embayment is considered to be joined with an open sea situated in the recent Sea of Japan (SHUTO, 1958), and there is a tendency that the embayments become generally smaller in scale from the southwest to the northeast. The embayments formed through Ôtsujian to Early Chikushian age are called the Paleo-Genkai embayments by MATSUSHITA (1949). In the Yuya-wan district the Early Chikushian Kiwado member and Taoyama formation appear in the Kiwado, Yuya-Hioki and Kottoi bays, but the earliest Late Chikushian (earliest Saseboan) Hitomaru formation of the Hioki group is missing in the Kiwado and Kottoi bays. Taking the scale of the basins and the movement of basement with sedimentation under consideration, the Kiwado and Kottoi bays are probably inferred not to be capable of the accumulation of the Hitomaru formation. The maximum invasion would be indicated by the shale facies of the Taoyama formation, and the retreat of this sea began with the deposition of the paralic Hitomaru formation. A probable diastem slightly above the bottom of the Hitomaru formation exhibits perhaps the first phase of the Takachiho disturbance (SHUTO, 1963a).

Recently SHOJI (1960) gave the discussion on the volcanic detritus incorporated cyclothematic arrangement in the coal-bearing strata in Japan. In the surveyed district each of the Jûraku and Kiwado members is composed of a cyclothem, having remarkable tuff or tuffaceous rocks at the top. The tuff or tuffaceous rocks have thin coaly shale intercalations at their basal part. Throughout the Hioki group, the tuffaceous rocks seem to relate to cyclothematic deposition.

Miocene latest Late Chikushian (late Saseboan) age: The Yuya-wan group was made up by the new invasion, which is called the Mizuho submergence by YABE and AOKI (1923), at the latest Late Chikushian (late Saseboan) age. The paleogeographic map at this age is given as shown in Fig. 3d.

The Yuya-wan group rests disconformably on the underlying Hioki group, and the Kase formation of the Sasebo group in Northwest Kyushu, which is the correlative with the Yuya-wan, lies also unconformably upon the Fukui formation of the same group, though the equivalent of the Yuya-wan is not found in the Chikuhô and its adjacent coal fields. In the Susa and Masuda areas east-northeast of this district, on the other hand, the Susa formation (MURAKAMI, 1963) and Masuda group (FUJITA, 1964), both being the equivalents of the Yuya-wan, rests unconformably on the Cretaceous or Paleogene (?) volcanic rocks and others. Differently expressed, in West Chugoku and Northwest Kyushu (the Saikai sedimentary province), there is a series of the Tertiary strata under the Yuya-wan group and the Kase formation, while in the Susa and Masuda areas (the Setouchi sedimentary province) the Susa formation and the Masuda group cover directly the basement rocks. This is the most distinct difference between the Saikai and Setouchi sedimentary provinces. In addition to the fact mentioned above, the followings are pointed out by the CENOZOIC RESEARCH GROUP of SOUTHWEST JAPAN (1960) as the differences between the Saikai,

and the Setouchi and San-in sedimentary provinces: 1. the presence of the Tertiary thick fresh- and brackish-water sediments, 2. the Tertiary accompanied with the plutonic activity, and 3. the wide distribution of the late Neogene plateau type basalt in the Saikai sedimentary province. From these characters, it is thought by the GROUP that the Saikai province has a close relationship to the Asiatic continent. Further, at Early to Middle Miocene some volcanism from acid to intermediate took place in the Saikai, whereas the intensive volcanic activities from basic to acid did in the wide extent of the San-in.

The disconformity between the Hioki and Yuya-wan groups is regarded as the second phase of the Takachiho disturbance (SHUTO, 1963a). In the Yuya-wan district the embryonic and second phases of the Takachiho disturbance seem to be expressed as stratigraphic breaks more conspicuously than in Northwest Kyushu.

The Yuya-wan group began to be deposited in the Yuya-Hioki bay as far as the writer observes, and the Kiwado and Kottoi bays, which conceived the Hioki group, had been probably diminished and disappeared until this time. Judging from the lateral change of lithofacies and thickness, the sedimentary structures and the occurrence of fossils (RICH, 1950, 1951; ARAI, 1960; MITSUNASHI and KAKIMI, 1964), it is inferred that the basement rocks were inclined to the northwest in the later course of accumulation of the Yuya-wan group, and that the rapid uplift of the hinterland was associated with the outbuilding of the thick deposits extending in ENE-WSW trend. This fact coincides well with a tendency of the northwestward migration of the sinking center of sedimentary basin in Northwest Kyushu (MATSUSHITA, 1949; URATA, 1962), and it is also inferred that the Upper Chikushian stage was accumulated not in North Kyushu, but off that district.

It is concluded that the West Chugoku was being uplifted during and after the latest Late Chikushian age from the inclining of the basement rocks to the northwest and no finding the late Neogene strata there. The Aki area of uplift called by HUZITA (1962) in West Chugoku seems to imply the fact mentioned above. Throughout Miocene to a Pliocene, the faulting of NW-SE or NNW-SSE direction called the Korean trend and that of E-W or ENE-WSW direction parallel to the Setouchi trend were being probably active. Besides these, the faulting of NNE-SSW or N-S direction, which is parallel to the trend of the Ryukyu arc (NAUMANN, 1885; TATEIWA, 1952), had also been active until the late Neogene.

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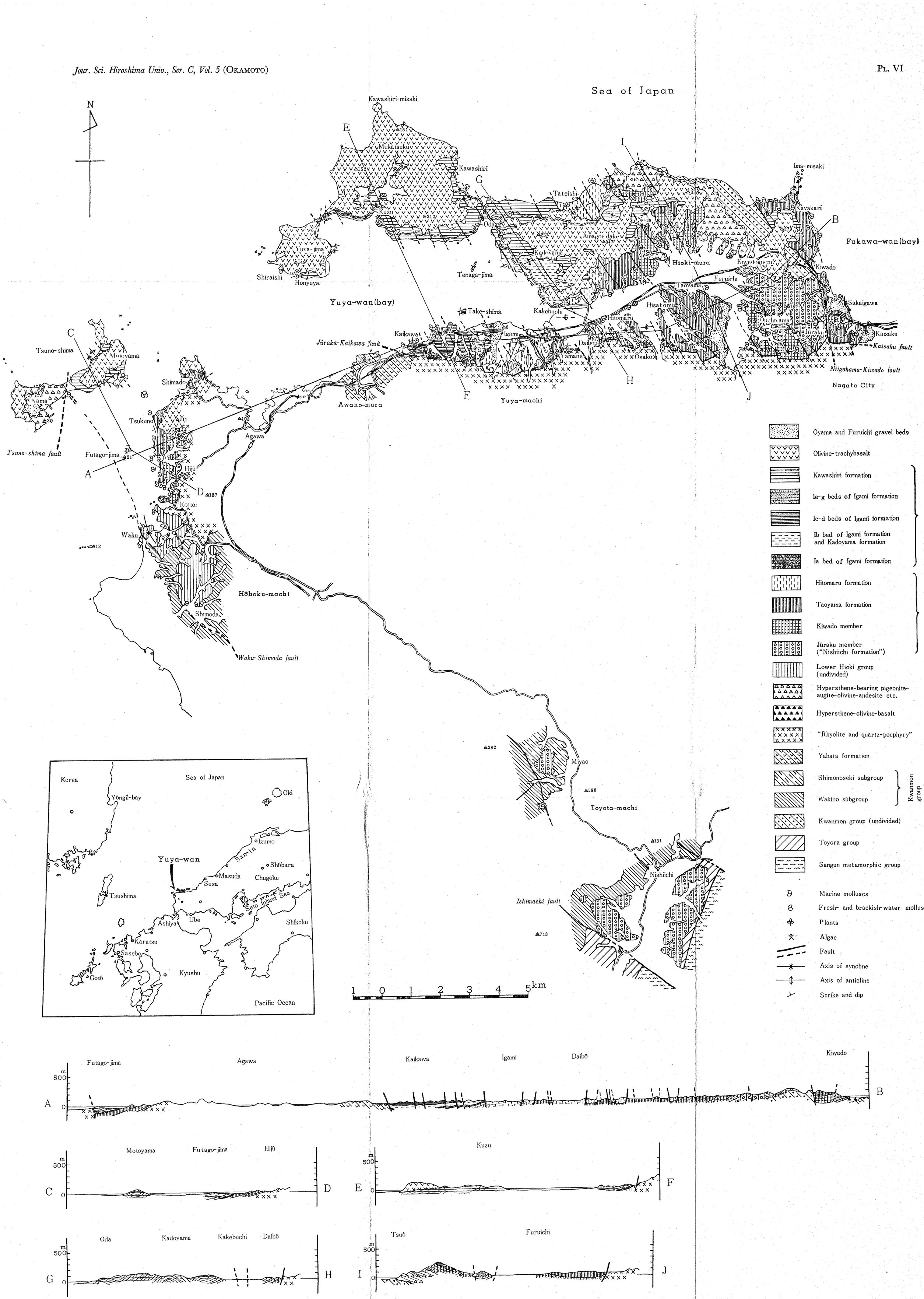

PL. VI GEOLOGICAL MAP OF THE YUYA-WAN DISTRICT AND THE NISHIICHI AREA, WEST CHUGOKU, SOWTHWEST JAPAN.

The map of the area south of Kottoi and the Nishiichi area is compiled on the basis of the following data:

The area south of Kottoi……SHIGEOKA (1952) (MS).

The Nishiichi area……KAWAI (MS), MATSUMOTO, T. and ONO (1947), ONO (1952) (MS), and TORIYAMA (1937).