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The Muro Group in the Kii Peninsula, Southwest Japan

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Abstract

The Muro group in the Kii Peninsula, Southwest Japan, is the uppermost strata of the basement rocks in the Shimanto terrain. It is stratigraphically divided into three subgroups and several formations. It consists mainly of Paleogene and partly of lower Miocene and upper Cretaceous (?).

The area, which consists of the Muro group, is structurally divided by faults into two subbelts and four districts. Their structural differences are generally described and discussed.

From the viewpoint of the lithological features and geological situation of the Shimanto terrain, the Muro group is correlated with the Hyûga group in South Kyushu and the Setogawa group in Central Japan.

Two angular unconformities within Tertiary system are described and the so-called Takachiho disturbance and the pre-Takachiho disturbance are discussed.

I. Introduction

It is known that in the southern part of the Kii Peninsula, the so-called undivided strata are distributed very widely. The Muro group, their upper part, is dealt with in this paper. Few investigations have been made on these undivided strata, especially, on the Muro group. This group has been treated as Paleogene strata, but no detailed study has been undertaken in the past. It is true that the complicated geological structure, the scanty paleontological data and the monotonous strata have prevented earnest study on that group. Such a vacuum of

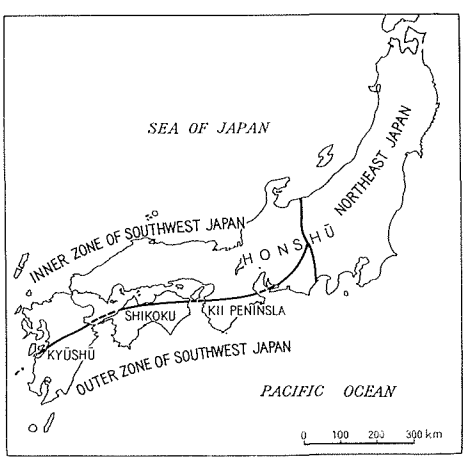

Fig. 1. Index Map

geological investigations on these wide area has made it impossible to clarify the tectonic development of this belt. Similar strata are also found in the Shimanto terrain of the Outer Zone of Southwest Japan occupying a vast area from Southern Kyushu through Southern Shikoku to the Tokai district in Central Japan. The latest appreciable studies on the Muro group equivalents in Shikoku and Kyushu have been made by KATTO (1961), HASHIMOTO (1962) and SHUTO (1963). From these studies, it has become possible to draw some inference on the geological situation of the Muro group in the Shimanto terrain of the Kii Peninsula. On the other hand, in order to establish the stratigraphy and to find the clue to the tectonic history of the Shimanto terrain, the author and the other members of Kyoto University are conducting investigations on the so-called Mikura and Setogawa group of the Tokai district and the Muro group of the Kii Peninsula. According to their preliminary reports, the Muro group is very similar in lithological and structural characters to the Setogawa group, and an unconformity has been confirmed between the upper and the middle parts of the Muro group as in the Tokai district. On the basis of these results, the author has conducted a survey on the greater part of the entire area of the Muro group. In this paper, he will summarize the stratigraphy and the geological structures of this group. Detailed considerations will be given after further studies.

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II. General Geology

According to MATSUSHITA (1953), characteristic zonal arrangements of the Outer Zone of Southwest Japan are also seen in the Kii peninsula, namely, from north to south, (1) the Nagatoro metamorphic zone consisting of the Sanbagawa system, (2) the Chichibu Paleozoic zone (Chichibu terrain), and (3) the Shimanto terrain.

The Shimanto terrain of the Kii peninsula is divided into two regions, the Hitaka belt and the Muro belt. The former is occupied by undivided Mesozoic sediments called the Hitakagawa group and the latter consists of the Paleogene Muro group. Although some uncertainty still remains concerning the boundary of these belts, the author has followed MATSUSHITA's definition of the Muro group. Therefore, the Muro group in this paper comprises some part of the Mesozoic formations by SUZUKI & ITO (1946), the Muro Series by SUZUKI (1938, 1939), the Higashimuro group by MURAYAMA (1954) and the Kinan group by TANAI & MIZUNO (1954) and MIZUNO (1957). The boundary between the Hitaka and the Muro belts is shown by the faults which are recognized to the north of Hongû and to the north of

Table 1. Tectonic division of the Muro belt in Kii Peninsula

Tectonic Division				Group and Subgroup	Age
Shimanto terrain	Hitaka belt			Hitakagawa group	Jurassic (Triassic ?) ~ Cretaceous
		Fushiogami thrust			
	Muro belt	Muro northern subbelt	N	Otonashigawa district	Tanabe and Kumano groups	middle Miocene
					Otonashigawa-Muro subgroup and the correlatives	Paleogene ?
			Hongū-Koyadani fault		
			S	Uchikoshi district	Tanabe and Kumano groups	middle Miocene
					Ukekawa-Muro subgroup and the correlatives	late Oligocene ~ early Miocene
					Yomurakawa-Muro subgroup and the correlatives	Paleogene ?
		Ôtô-Tonda tectonic line			
		Muro southern subbelt	NW	Ichikano district	Kanayama group	middle Miocene
					Ukekawa-Muro subgroup and the correlatives	late Oligocene ~ early Miocene
					Yomurakawa-Muro subgroup and the correlatives	Paleogene ?
			Shichikawa-Mirozu fault		
			SE	Kozagawa district	Kumano group	middle Miocene
					Ukekawa-Muro subgroup and the correlatives	late Oligocene ~ early Miocene
					Yomurakawa-Muro subgroup and the correlatives	Paleogene ?

~~~~ unconformity

Kizetsukyo. The basement of the Muro belt is formed by the Muro group which has been treated as undivided Paleogene strata. Besides these, Miocene to Pliocene rocks called the Kumano group, the Tanabe group, the Kanayama group and Kumano igneous rocks are distributed, occupying more than a half of this area.
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The Muro group is overlain with unconformity by the Kumano group in the east and by the Tanabe and the Kanayama groups in the west.

Table 2. Stratigraphical division of the Muro group

Tanabe, Kanayama and Kumano groups	
angular unconformity	
Muro group	Ukekawa-Muro subgroup
	angular unconformity
	Yomurakawa-Muro subgroup
	fault
	Otonashigawa-Muro subgroup
thrust	
Hitakagawa group	

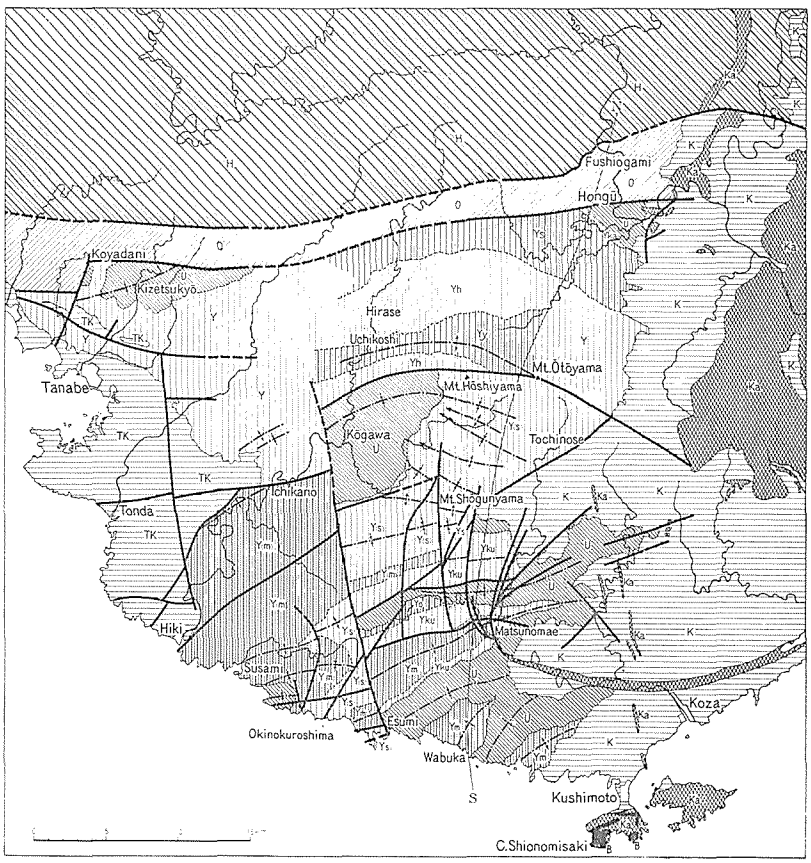
The Muro group consists mainly of marine sandstone and mudstone alternations of flysch type some conglomerates, and intercalates tuffs very rarely. Stratigraphically, the Muro group is divided into three subgroups the Otonasigawa-Muro, the Yomurakawa-Muro and the Ukekawa-Muro subgroups. The first and second subgroups contact with each other by fault, but, as will be stated later, it is presumed that the upper half of the first subgroup is correlated to the lowermost part of the second, while the Yomurakawa-Muro is overlain unconformably by the Ukekawa-Muro subgroup. The lithological characters of these subgroups are as follows.

A) The Otonashigawa-Muro subgroup

This subgroup consists of sandstones and mudstones. The lower part is composed of flysch type alternations of sandstone and mudstone, and is characterized by thick-bedded intercalations of dark grey, massive and hard mudstone. The upper part is flysch type alternations of sandstone and mudstone which is distinguished from the lower by the presence of a single thick bed of coarse-grained sandstone.

B) The Yomurakawa-Muro subgroup

This subgroup is formed of flysch type alternations of sandstone and mudstone, rarely intercalating conglomerates and tuffs. Generally speaking, the lower part is characterized by coarse-grained sandstone, and is flysch type alternations of sandstone and mudstone which include a thick bed of black to dark grey mudstone. The middle part consists of black, massive, hard mudstone beds and of flysch type thin alternations (each cycle 10~20 cm. thick) of sandstone and mudstone. The upper part is composed of alternations of thick sandstone and thin mudstone, and a part of these, especially of the former, is represented by bedded sandstone. It is very characteristic that ripple marks, trace marks and other sedimentary structures are commonly developed, especially, in the upper part of this subgroup.



Basic rocks		B	Gabbro and Diabase
Kumano acidic igneous rocks		Ka	Granophyre, Biotite granite porphyry and Persemic biotite rhyolite
Kumano, Tanabe and Kanayama groups		K TK	K ; Kumano Group, TK ; Tanabe and Kanayama Groups
Muro group	Ukekawa-Muro subgroup	U	Yunomine, Ukekawa, Masago and Hisohara Formations
	Yomurakawa-Muro subgroup	Y	Undivided Formation of the Yomurakawa-Muro Subgroup
		Ys, Yy, Yo, Ym, Y(m)	Ys ; Shizukawa Formation, Yy ; Yasukawa Formation, Ym ; Matsunomae Formation, Yo ; Oikawa Formation, Y(m) ; Muddy Formation of the Yomurakawa-Muro Subgroup
		Yka, Yh, Yku, Y(s)	Yka ; Kawayu Formation, Yh ; Hirase Formation, Yku ; Kurumi Formation, Y(s) ; Sandy Formation of the Yomurakawa-Muro Subgroup
	Otonashigawa-Muro subgroup	O	Otonashigawa Formation and the correlatives
Hitakagawa group		H	Undivided Mesozoic strata

Fig. 2. Geological Map of the Muro Belt

—compiled by the author, based on his own survey and concerning to the marginal area referring to Mizuno (1957-a), Murayama (1957) and the unpublished data by Shinagawa and Hirose—

C) The Ukekawa-Muro subgroup

This subgroup is characterized by a series of marine beds beginning with basal conglomerate. The lower part consists mainly of black, compact, massive and thick mudstone beds. Towards the upper part, the lithofacies becomes more sandy, and flysch type alternations of thick coarse-grained sandstone bed and thin mudstone bed are predominant. The upper part is composed of mudstone beds which have calcareous nodules.

D) Age and geological structure

Owing to the scantiness of paleontological data, the geological age of the Muro group has not yet been clarified. From foraminiferal and molluscan fossils from the Ukekawa-Muro subgroup, MIZUNO (1957) inferred that this faunal assemblage may belong to Eocene. The Yomurakawa-Muro subgroup yields *Paleodictyon majus*, *P. tenus*, *P. rebstum* and *Hydrodictyon tertiarum* (KORIBA and MIKI, 1939), but these fossils give no definite proof about the age. The author and others (1963) reported the occurrence of *Costacallista* cfr. *shikokuensis*, *Portlandia* (*Portlandella*) sp., *Venericardia tokunagai*, etc. from the Ukekawa-Muro subgroup, and considered the geological age of that subgroup to be late Oligocene to early Miocene. Although the geological ages of both the Yomurakawa-Muro and the Otonashigawa-Muro subgroup are unknown, the author infers that the main part belongs to the Paleogene and that the remainder may include the upper Cretaceous strata, from the results of studies on the equivalents of the Shimanto terrain in South Kyushu and South Shikoku (HASHIMOTO, 1961; KATTO, 1960 and 1961).

The geological structures of the Muro group are generally complicated, and the strata are partially overturned. Fracturing and shearing are common phenomena in this area. From the viewpoint of geological structure, the Muro belt is divided into the Muro northern and Muro southern subbelts. Generally speaking, the structure of the Muro northern subbelt is characterized by zonal arrangement parallel to the Outer Zone of Southwest Japan, while that of the Muro southern subbelt runs in an oblique line from the latter.

Such structural contrast is remarkable in the degree of deformation. The boundary between these two subbelts is shown to be the fault (the Ôtô-Tonda tectonic line) which runs from Kashihara, Irokawa-mura in the east, through Ôtôyama, to Tonda, Tanabe city in the west. The Muro northern subbelt is characterized by gentle symmetrical folding and monoclinic structure. The trend of the folding axis varies from N 60°E in the west to N 60°W in the east, forming an arch in the central area with the convex side northward. In the Muro southern subbelt, blockwise structure and foldings of N 60°E trend are predominant. Especially, in the southeast area, asymmetrical foldings and isoclinal foldings are characteristic.

Moreover, the Muro northern subbelt is divided by the Hongû-Koyadani fault into the northernmost Otonashigawa and the Uchikoshi district occupying the main part of the subbelt. The Muro southern subbelt is also divided by the Shichikawa-Mirozu fault into the southeast Kozagawa district and the northwest Ichikano district.

The Muro group of the northern subbelt is equivalent to that of the southern subbelt in the main part, but contains still lower horizons than the latter. For instance the Otonashigawa-Muro subgroup and the lower part of the Yomurakawa-Muro subgroup are limited to the northern subbelt.

III. Description of the Muro Group in Each District

A) The Muro northern subbelt

a) Uchikoshi District

The Uchikohsi district borders at the north on the Otonashigawa district by normal fault, which is called the Hongû fault in the east and the Koyadani fault in the west. The former runs with east-west trend in the north of Shingû, while the latter runs from south of Koyadani to north of Kurisugawa. This district borders on the Muro southern subbelt by the Ôtô-Tonda tectonic line. The Muro group is overlain unconformably by the Miocene Kumano group having a strike of N 20°± E, in the east of the Uchikoshi district, namely, in the east of Kitakawa and Hongû. On the other hand, this group is overlain with unconformity by the Tanabe group of N 30° W to N 60° W strike in the west, namely, from Hieda to Minabe-machi. Therefore, the Uchikoshi district as a whole forms a square area. The following descriptions are concerned mainly with the central and the eastern part of the Uchikoshi district. This area is occupied by the Yomurakawa-Muro and the Ukekawa-Muro subgroup. These subgroups are subdivided lithologically into six formations as shown in Table 3.

Table 3. Subdivision of Muro group in Uchikoshi district

Muro group	Ukekawa-Muro subgroup	Ukekawa formation (Muddy, ?)
		Yunomine formation (Conglomeratic muddy, 970 m.)
	~~ unconformity ~~~~	
	Yomurakawa-Muro subgroup	Kawayu formation (Sandy, 300 m. ±)
		Shizukawa formation (Muddy, 1250 m.)
		Hirase formation (Sandy, 1300 m.)
		Yasukawa formation (Muddy, 745 m.)

The basement of the Yomurakawa-Muro subgroup is unknown, because the lowermost Yasukawa formation of the Yomurakawa-Muro subgroup forms the axial

Table 4. Precise nature of the Muro group in Uchikoshi district

Group	Subgroup	Lithological Division: Formation (Thickness, Metre)	Lithological Division: Member (Thickness, Metre)	Character	Geographic Distribution in Uchikoshi District	Remark
Muro group	Ukekawa-Muro subgroup	Ukekawa formation (?)	Ukekawa mudstone beds (?)	Massive, compact and black mudstone	Local, Southwest of Hongû and in northwestern area	Calcareous nodules of hand specimen size; *Pitar, Solemya**
		Yunomine formation (970)	Sandstone beds with gravels (210)	Flysch type alternations of massive, compact, often thick-bedded and black mudstone, sandstone and conglomerate with associated well rounded cobbles of quartz porphyry and pebbles of sandstone, chert and mudstone		
			Muddy flysch type alternations (250)			
			Medium sandstone beds with gravels (150)			
			Fine flysch type alternations (220)			
			Coarse sandston beds (140)			
			Basal conglomerate			
	Yomurakawa-Muro subgroup	Kawayu formation (300±)	Kawayu alternations (300 ±)	Sandy flysch type alternatins of thick-bedded sandstone (about 40cm. thick) and thin-bedded mudstone (5~7 cm. thick)	Very local, Kawayu	
		Shizukawa formation (1250)	Hiba fine alternations (400)	Flysch type fine alternations of black mudstone and fine-grained sandstone (each cycle of 10~20 cm. thick)	Widespread	
			Shizukawa mudstone beds (850)	Flysch type muddy alternations; predominantly compact, hard and black mudstone, intercalated with associated conglomerate		
		Hirase formation (1300)	Sandy flysch type alternations (775)	Predominantly grey to black-coloured massive sandstone (20~100 cm. thick), intercalated with mudstone (3~7 cm. thick)	Widespread	
			Muddy flysch type alternations (325)	Predominantly, massive, compact and black mudstone with intercalated fine sandstone		
			Sandy flysch type alternations (200)	Predominantly well bedded coarse to medium sandstones (15~20 cm. thick) and thin-bedded black mudstone (several mm. to 5cm. thick) and intercalated with upper conglomeratic layers with associated pebbles and cobbles of chert, nodular mudstone and boulders of sandstone		*Paleodictyon majus, P. tenus, P. rebstum* and *Hydrodictyon* (Koriba and Miki, 1939) Sedimentary structure and Trace mark
	Ôtonashigawa-Muro subgroup	Yasukawa formation (745+)	Bedded sandstones and mudstones (320)	Alternations of coarse-grained sandstone and black mudstone	Southwestern area, Northwest of Mt. Ôtôyama	Calcareous nodules of boulder size
			Muddy flysch type alternations (265)	Predominantly black massive mudstone with intercalated fine to medium-grained sandstone (5~10 cm. thick)		Fragments fo Foraminiferal fossil
			Siliceous mudstone beds (160+)	Black, massive and siliceous mudstone		

* after personal communication of Mr. Saheki

part of the anticline. The upper part of the Ukekawa-Muro subgroup is overlain with unconformity by the Miocene Kumano group.

It is presumes that the lowermost Yasukawa formation of the Yomurakawa-Muro subgroup is correlated with the upper half of the Otonashigawa-Muro subgroup by lithological features. The Kawayu and the Shizukawa formations of the Yomurakawa-Muro subbelt are overlain with unconformity by the Yunomine formation of the Ukekawa-Muro subgroup.

The Yomurakawa-Muro subgroup is distributed widely almost all over this subbelt, while the Ukekawa-Muro subgroup is limited to the north-eastern and the north-western part of this subbelt. The precise nature of these strata are shown in Table 4.

The geological structure is relatively generous in the Uchikoshi district. The Uchikoshi anticline in the central and the eastern part of this district represents the only folding structure. This anticline runs along the Ôtô-Tonda tectonic line, and has an axis of east-west trend pitching gently westward. In the southern wing of that anticline, the strata strike generally from east to west dipping 50°~80° southward, while, in the northern wing, their general strike varies from N 60°~70° E with a dip of 50°~70° to the north.

Accordingly, the geological structure in this district is generally monoclinic dipping to the north, except in a part of the southern wing of that anticline.

Table 5. The type routes of each formation in the Muro northern subbelt

Formation	Type route
Ukekawa formation	From Ukekawa to Kotsuka, the banks of the Kumano and the Ôtô rivers
Yunomine formation	From 300 m. east of Kawayu to Ukekawa, the banks of the Ôtô river
Kawayu formation	Kawayu and its neighbourhood, the banks of the Ôtô river
Hirase formation	From 1000 m. north of the junction of the Hiki and the Yasukawa rivers to 1500 m. south of the Chikatsuyu, the banks of the Hiki river
Yasukawa formation	The banks of the Yasukawa river, a tributary of the Hiki river
Otonashigawa formation	From Hongū to Fushiogami, the banks of the Kumano river

b) Otonashigawa district

The Otonashigawa district borders on the Hitaka belt at the north by Fushiogami-Ishigami thrust and the Uchikoshi district at the south by Hongû-Koyadani fault.

In the eastern part the Miocene Kumano group overlies the Muro group unconformably. Accordingly, this district forms a narrow belt extending from east to west. The eastern part between the Fushiogami fault and the Hongû fault, is the type area of the Otonashigawa-Muro subgroup. This subgroup is divided lithologically into two formations, the lower the Hongû mudstones and the upper the Otonashigawa alternations, which are conformable with each other. In the middle part of the latter, the Hiraiwa sandstone member is intercalated. The basal and the uppermost parts of this subgroup are cut by faults, namely the basal part of the Hongû mudstones is cut by the Hongû fault and the uppermost part of the Otonashigawa alternations by the Fushiogami fault. Thickness of the Otonashigawa-Muro subgroup attains to about 1500 m.

The geological structure is represented by a monocline, with a strike of N 60° E dipping 20°～30° N. Therefore, the Hongû mudstones occupy the southeastern part of this district, while the Otonashigawa mudstones occupy the northwestern part.

Along the Fushiogami fault which runs from Kirihata, the upper stream of the Kumano River, through Sanri (Hagi) to Fushiogami, the Hitakagawa group overthrusts toward the Muro group at a low angle (16°～20° N). In the neighbourhood of this remarkable fault, the Muro group (the Otonashigawa alternations) of the foot wall is strongly crushed over an area of about 1 km. wide. The strike directions of both the Hitakagawa and the Muro groups are somewhat parallel with the fault.

B) Muro Southern Subbelt

a) Kozagawa district

This district is separated from the Ichikano district by fault running with trends of N 60° E to N 45° E from Shichikawa through the south of Ôtôyama to Okinokuroshima. In the eastern part, the middle Miocene Kumano group overlies the Muro group with unconformity.

Table 6. Subdivision of Muro group in Kozagawa district

Ukekawa Muro subgroup	Hisohara formation (Muddy, 200 m.+)	
	Masago formation (Sandy, 945 m.)	
unconformity		
Yomurakawa-Muro subgroup	Oikawa formation (Muddy, 1000 m.+)	
	Kurumi formation (Sandy, 1145 m.)	
	Matsunomae formation (Muddy, 910m.)	

The Muro group of this district is classified under the Yomurakawa-Muro subgroup and the Ukekawa-Muro subgroup. Furthermore, the former is subdivided lithologically into three formations, the Matsunomae, the Kurumi and the Oikawa

Table 7. Precise nature of the Muro group in Kozagawa district

Group	Subgroup	Formation (Thickmess, m.)	Member (Thickness, m.)	Character	Remark	Type route
Muro Group	Ukekawa-Muro subgroup	Hisohara formation (200+)		Predominantly black mudstone, partly interbedded with coarse to medium-grained sandstone	Calcareous nodules of hand specimen size	Hisohara and its neighbourhood,
		Masago formation (945)	Sandstone beds (120)	Thick-bedded, hard, coarse-grained and light grey sandstone with localy associated pebbly conglomerate	*Venericardia* (*Cyclocardia*) *tokunagai* *Costacallista* cfr. *shikokuensis* *Portlandia* (*Portlandella*) sp.	From Masago to Sada, the banks of the Koza river.
			Muddy flysch type alternations (340)	Predominantly thin-bedded, hard, compact and black mudstone, intercalated a small amount of siltstone and medium-grained arkose sandstone		
			Sandstone beds (150)	Interbedded, hard and coarse to medium sandstone with localy associated pebbles of chert, quartz porphyry, sandstone and mudstone		
			Fine alternations (280)	Well thin-bedded (5～7 cm. thick) alternations of black mudstone, siltstone and ash-coloured fine sandstone		
			Sandstone beds (100)	Hard, coarse-grained grey-white sandstone		
			Basal conglomerate (50)	Conglomerate with rounded to well rounded pebbles of chert, sandstone, mudstone and rarely quartz porphyry and a smaller quantity of cobbles and boulders and matrices of coarse sandstone	Ripple mark	
	Yomurakawa-Muro supgroup	Oikawa formation (1000+)		Alternations of black mudstone, siltstone and fine-grained dark grey sandstone, localy intercalated with two thin-layered conglomerates; one contains smaller and angular pebbles and matrices of medium-grained white sandstone, the other contains a small quantity of pebbles of chert and sandstone and matrices of black mudstone.		From Ōtani to Hirano, the banks of the Samato river.
		Kurumi formation (1145)	Muddy flysch type alternations (130)	Predominantly, thick-bedded, hard, compact and black mudstone with a small amount of medium to coarse-grained white and ash-coloured sandstone	Sedimentary structure Trace mark Problematic casts	From Shimomasago to Masago, the banks of the Koza river.
			Sandy flysch type alternations (150)	Thick-bedded, coarse-grained and light grey sandstone with intercalated thin-layered black mudstone and localy a minor amount of fine conglomerate, with associated pebbles and granules of chert, quartz porphyry, mudstone and sandstone		
			Muddy flysch type alternations (125)	Predominantly thick-bedded black mudstone with intercalated a small amount of thin-layered, arkose and white sandstone		
			Sandy flysch type alternations (180)	Predominantly thick-layered light grey sandstone (20～40 cm. thick), intercalated with a small amount of thin-layered black mudstone		
			Muddy flysch type alternations (50)	Interbedded black mudstone with associated siltstone, intercalated with thin-layered dark grey sandstone		
			Sandy flysch type alternations (100)	Predominantly well bedded cosrse-grained white sandstone, intercalated with thin-layered black mudstone		
			Sandstone beds (40)	Massive, medium-grained, arkose and grey-white sandstone		
			Sandy flysch type alternations (110)	Predominantly, well bedded, coarse and white sandstone with intercalated thin-layered black mudstone		
			Sandstone beds (25)	Massive, Medium-grained and white-grey sandstone		
			Sandy flysch type alternations (235)	Predominantly thick-bedded coarse-grained sandstone with intercalated a small amount of thin-layered black mudstone		
		Matsunomae formation (910)	Fine alternations (610)	Thin-bedded alternations of hard, black and localy green-black mudstone, medium-grained grey-white-coloured arkose sandstone and a small quantity of siltstone		Matsunomae and its neighbourhood, the banks of the Koza river.
			Sandy flysch type alternations (40)	Interbedded medium-grained light grey sandstone with intercalated thin-layered black mudstone		
			Muddy flysch type alternations (260)	Predominantly, massive and black mudstone with associated siltstone, intercalated with medium-grained light grey sandstone		
			Sandstone beds (?)	Coarse-grained light grey sandstone		

formations in ascending order, and the latter is subdivided into two, the Masago and the Hisohara* fornations. As the lowest Matsunomae formation forms the axial part of the anticline, the basal part is unknown. Moreover, the Ukekawa-Muro subgroup is overlain unconformably by the Kumano group. Therefore the upper limit of the Muro group cannot be confirmed there. The Masago formation overlies unconformably the different horizons of the Yomurakawa-Muro subgroup, such as, the Oikawa, the Kurumi and the Matsunomae formations.

The structure of the Muro group in this district is characterized by a repetition of anticlines and synclines which generelly have N 60° E axes. It is to be noted that the Yomurakawa-Muro subgroup forms the axial parts of anticlines, while the Ukekawa-Muro subgoup forms those of synclines. These two subgroups are therefore distributed throughout this district. Detail descriptions are tabulated in Table 7.

b) Ichikano district

Between this district and the Kozagawa district in the southeast, the fault runs with N 60° E to N 45° E trend from the south of the Ôtôyama to the Okinokuroshima, and the Ôtô-Tonda tectonic line forms a boundary between this district and the Uchikoshi district in the north.

In the western part of this district the middle Miocene Kanayama and Kumano groups cover unconformably the Muro group. The Muro group is divided into two subgroups, the Yomurakawa-Muro subgroup and the Ukekawa-Muro. Both the lower and the upper limits of this group are hardly recognized because of the presence of faults and unconformity. In this district, the Ukekawa-Muro subgroup is distributed in a small area only around Ichikano in the north and Susami in the south. A detailed description of the geology will be given in another paper.

C) Correlation

As the Muro group is barren in fossil and the geological structure is complicated by fault system, it is very difficult to correlate the strata in the Muro northern and Muro southern subbelts with each other. Accordingly, the author has attempted a tentative correlation based on the characteristic vertical variations of their lithofacies.

In the northern subbelt, the lithofacies of the Muro group changes, in ascending order, from muddy (the Otonashigawa formation and the Yasukawa formation), sandy (the Hirase formation), muddy again (the Shizukawa formation), sandy again (the Kawayu formation). —unconformity—, conglomeratic muddy (the Yunomine formation) to muddy facies (the Ukekawa formation).

In the southern subbelt, the vertical variations of lithofacies are traced from muddy (the Matsunomae formation), sandy (the Kurumi formation), muddy again

* The detailed lithologic characters and the type-localities are shown in Table 7.

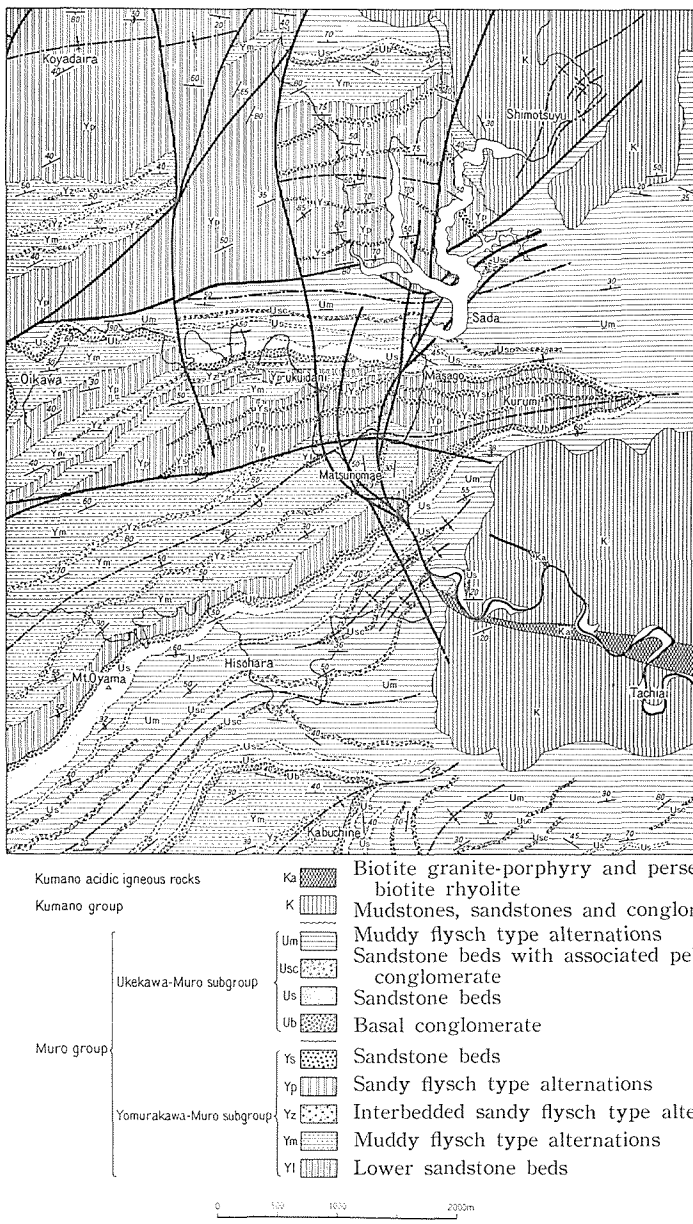


Fig. 3. Geological Map of the Kozagawa District (compiled partly using the unpublished data that are given by the common study of MAKIYAMA, MORISHIMA, ISHIDA and the author)

(the Oikawa formation), —unconformity—, conglomeratic muddy (the Masago formation) to muddy facies (the Hisohara formation). (Table 8)

Table 8. The vertical variations of lithofacies

Muro northern subbelt		Muro southern subbelt	
Facies	Thickness (m.)	Facies	Thickness (m.)
muddy	?	muddy	200+
conglomeratic muddy	970	conglomeratic muddy	945
		muddy	1000+
sandy (II)	300+	sandy	1145
muddy (II)	1250	muddy	910
sandy (I)	1300		
muddy (I)	745+		

On the whole, it is characteristic that the megascopic vertical variations of lithofacies of the Muro group change in each about 1000 m. units. Moreover, the Ukekawa-Muro subgroup above the unconformity is similar in mimute details in both belts. Especially, the Masago formation and the Yunomine formation, of conglomeratic muddy facies, are coincident with each other even in fine stratigraphical successions. (Fig. 4)

As to the Yomurakawa-Muro subgroup, it is possible to correlate the lower part of the Kurumi and the Matsunomae formations of the southern subbelt with the Kawayu and the Shizukawa formations of the northern subbelt respectively. The former two have very characteristic lithofacies, which varies from lower black mudstones to upper alternations of coarse sandstone and mudstone. The Kawayu formation is correlated with Kurmi formation, by the flysh type alternation of sandstones (20～40 cm. in thickness) and mudstones (5～7 cm. in thickness).

The presence of boulder-like calcareous nodules in Yasukawa formation leads to the assumption that the Yasukawa formation of the lowest part of the Muro group in the Uchikoshi district may be correlated with the Otonashigawa formation, because such calcareous nodules are quite absent in other horizons of the Yomurakawa -Muro subgroup.

From the lithological characters stated above, a correlation can be made between the Muro group of both subbelts, which is shown in Table 9.

The total thickuess of the Muro group is calculated as 7600 m. + in this table. However, when the values of the other undivided formations and of the upper part of the Ukekawa-Muro subgroup are added to that thickness, the figure as estimated attains to 8900 m.～10600 m..

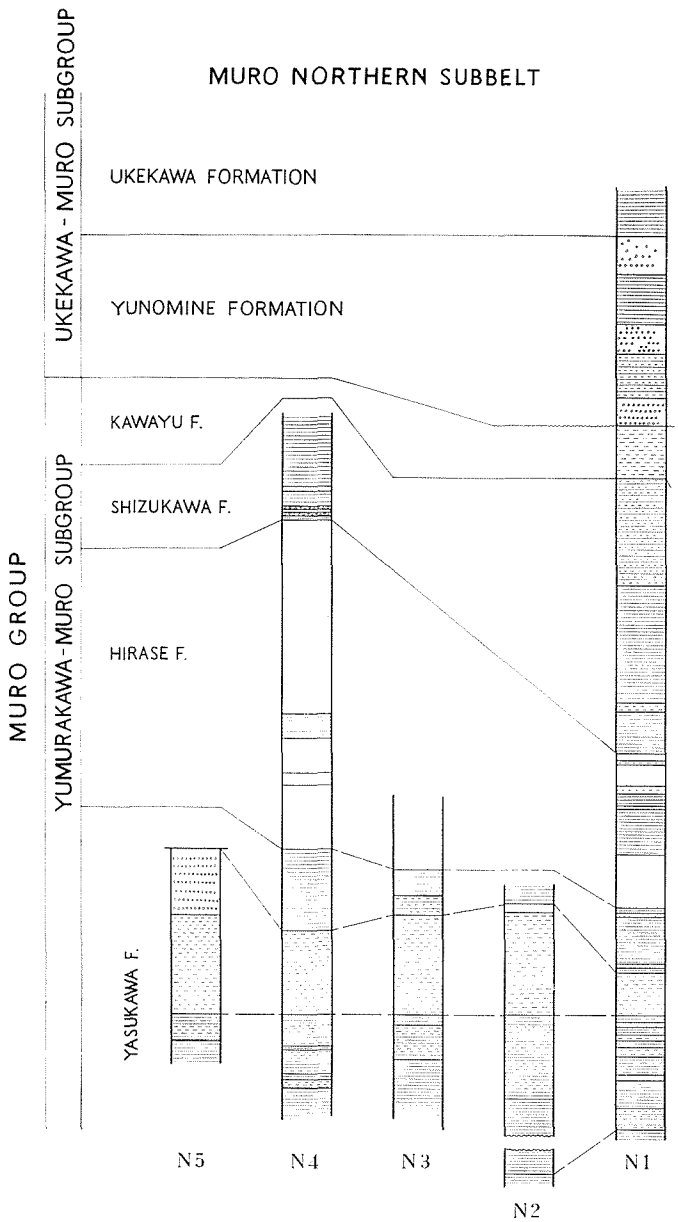
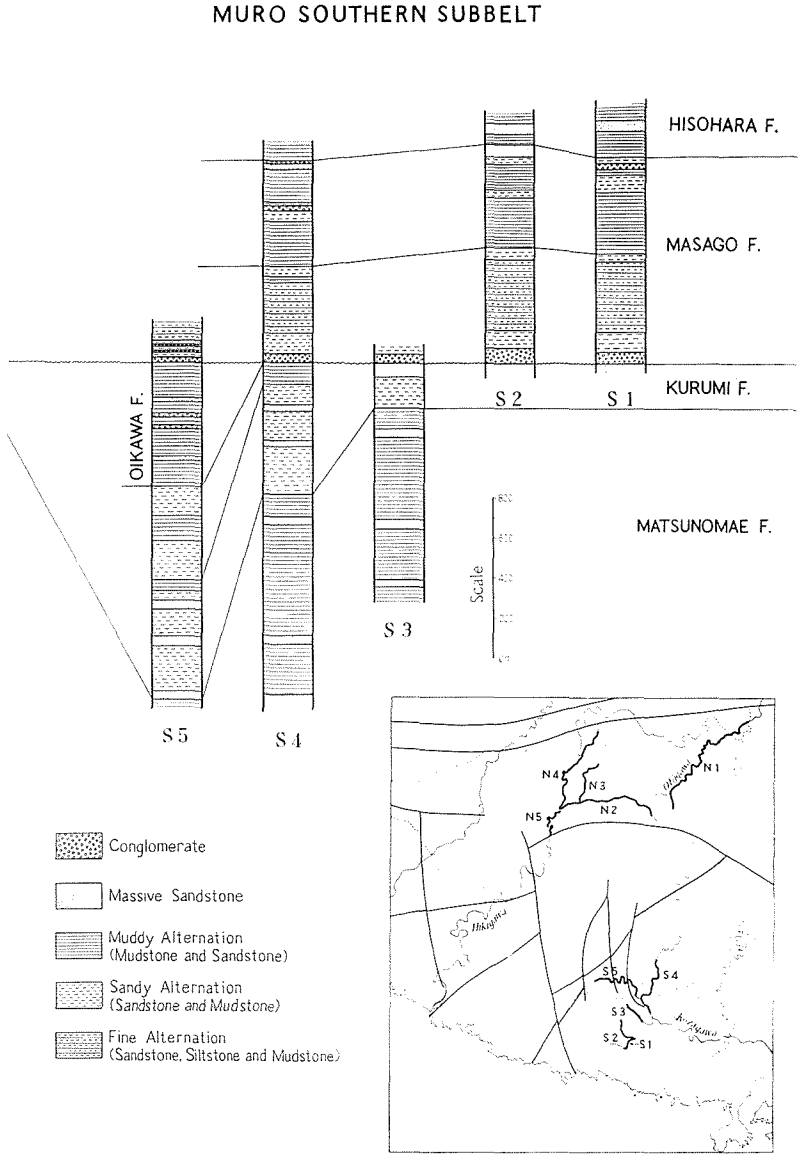


Fig. 4. Columnar Sections



of Muro Group

Table 9. Lithological Correlation of the Muro Southern and Muro Northern Subbelts.

		Muro Northern Subbelt		Muro Southern Subbelt	
		Facies	Formation and Group (Thickness, Metre)	Facies	Formation and Group (Thickness, Metre)
Muro Group	Ukekawa-Muro Subgroup		Kumano, Tanabe and Kanayama groups		Kumano, Tanabe and Kanayama groups
		muddy	Ukekawa formation (?)	muddy	Hisohara formation (200+)
		conglo-meratic, muddy	Yunomine formation (970)	conglo-metatic, muddy	Masago formation (945)
	Yomurakawa-Muro Subgroup				
				muddy	Oikawa formation (1000+)
		sandy	Kawayu formation (300±)	sandy	Kurumi formation (1145)
		muddy	Shizukawa formation (1250)	muddy	Matsunomae formation (910)
		sandy	Hirase formation (1300)		
		muddy	Yasukawa formation (745)		
	Otonashigawa-Muro Subgroup	muddy	Otonashigawa formation (1500+)		

conformity　unconformity　fault

III. Geological Structure

A) Geological structure of the Muro Northern subbelt

The geological structure of the Otonashigawa-Muro subgroup in the north of Hongû is represented by a monoclinal structure. As the strata are crushed heavily and deformed partly, the sandstone beds of the alternations show lenticular occurrence and the muddy formation shows the small-scale folding structure. Crushing, small-scale folding and cleavage are especially conspicuous in the neighbourhood of the Fushiogami thrust, the result apparently of pressure from a northern direction.

The Uchikoshi district under description forms a part of a symmetrical fold with a westerly pitch which is called the Uchikoshi anticline which extends into the adjoining Muro southern subbelt. The dips in the northern limb, although often high, are normal 50° to 70° and rarely exceed 70°; in the southern limb they are generally normal 50° to 70°, but partly, in the west, they are higher and often vertical or overturned, the result apparently of pressure from a northerly direction. Accordingly the Uchikoshi anticline is symmetrical in the eastern to the central area, but asymmetrical in the western area. The succession is best exposed in the northern limb, from the east of Uchikoshi northwards, that is, in a generally ascending sequence, from the lowermost Yasukawa to the Ukekawa formation.

Crushing, small-scale folding and cleavage are conspicuous in the argillaceous strata throughout the area. As a whole, the strata are bent towards north. It has been confirmed that this shows the relative depression of the eastern and the western to the central area.

B) Geological structure of Muro Southern subbelt

The Muro southern subbelt generally forms part of some large asymmetrical or symmetrical folds. The strata have strikes N 60° E generally, but NS to N 45° W partly, namely, in the north-west. The strata are folded in large scale to be exposed over and over again.

The Kozagawa district forms part of six large-scale folds which extend all over area. Their axes show strikes N 60° E pitching down gently in a north-easterly direction. They are seen to range in order towards the south as follows; the Hiraigawa anticline (isoclinal), the Sada syncline (isoclinal), the Matsunomae anticline (isoclinal), the Satokawa syncline (isoclinal), the Wabuka anticline (symmetrical) and the Azashi syncline (symmetrical).

The distances of their axial planes measure 3 km. to 3.5 km.. The dips in both limbs of the isoclinal folds are normal or overturned 60° to 80° towards a northerly direction. The strata are exposed showing a bellows structure, probably the result of their axes pitching towards a north-easterly direction.

The Ichikano district forms part of some symmetrical and monoclinal folds.

These symmetrical folds extend in the north-east and the south area of this district. The northeast area forms part of seven large-scale symmerical and anticlinal or synclinal folds. The trends of each fold very gradually from N 60° W to N 70° E towards the south. The distance between two axial planes measures 1.5 km. to 3 km., being larger in the west than in the east. The axis of their northernmost syncline runs continuing into the west part occupied by the Ukekawa-Muro subgroup. The axis of this syncline varies in its trend from EW in the east to N 60° W in the west. The axes of the other six folds may not run continuing into in the west part, the result probably of folding in the phase shown by the unconformity as stated in the following chapter.

The other large-scale fold is seen in the western area, but the details are unknown. Crushing, small-scale folding and cleavage are conspicuous throughout the area.

In the Muro southern subbelt, the faults, so far as they are revealed, fall into two sets, on running about 10° to 30° north of east and the other having a much more northerly trend, between north-north-west and north-north-east. In the first category are the normal and the reverse strike faults, the presence of which has been ascertained by field observations and constructions of the geological structure. Their fault planes almost dip at a higher or more moderate angle towards a north-westerly direction, but especially in Samoto of the Kozagawa district there is a thrust dipping at a lower angle. The second set of faults evidently belong to the family of dislocations present in the central and the western area of the Muro southern subbelt, where they break the strike faults. They therefore either accompanied the thrusting or appeared later. Several such faults are found in the Kozagawa district, where they form the western part of the ring fracture shown by the so-called ring dyke of the Kumano acidic igneous rocks. They continue in the Miocene Kumano group, having larger displacement towards a northerly direction. In the central area of the Muro southern subbelt are steeply dipping transverse faults of both reverse and normal categories. Each of the transverse faults generally have a north-southerly trend in the central and a north-north-westerly trend in the west part. Another somewhat oblique fault, the Shichikawa-Mirozu fault, is mapped from Shichikawa, east of Ôtôyama, in a south-westerly direction towards Okino-

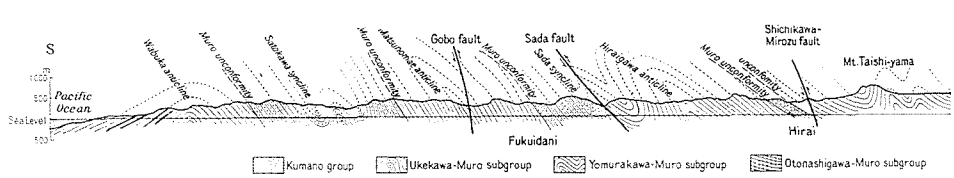


Fig. 5. Geological Section along

kuroshima, east of Mirozu, and this forms a boundary between the Ichikano and the Kozagawa districts in the Muro southern subbelt. Its displacement is not clear, but probably larger towards a north-westerly direction.

C) The structural dirferences between the Muro southern and the Muro northern subbelts

1) In the Muro southern subbelt, the strata are folded throughout the area and a repitition of the folding is seen; in the northern subbelt under description there is only one large-scale fold and the strata mainly show monoclinal structure.

2) The structure of the Muro northern subbelt is characterized by zonal arrangement parallel to the general trend of the Outer Zone of Southwest Japan, while that of the Muro southern subbelt runs oblique to the latter.

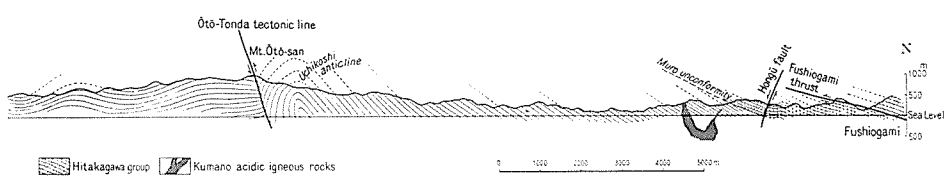
3) Transverse faults are seen in the Muro southern subbelt and these divide the subbelt into several blockwise areas, but they are not seen in the northern subbelt.

The geological section through both subbelts is shown in Fig. 5. The tectonic history will be described in the next paper, but it may be summarized as follows: The structural differences in folding between both subbelts may have been produce before the deposition of the Ukekawa-Muro subgroup and after that of the Yomura-kawa-Muro, but at that phase the trends of the folds are considered to have been parallel to the zonal arrangement of the Outer Zone of Southwest Japan. The distinct differences between them had been produced later, that is, at the so-called Takachiho phase (KURODA & MATSUMOTO, 1942). The main transverse faults in the Muro southern subbelt may have been active at that phase, but was completed later after the middle Miocene Kumano group had been deposited.

IV. Meaning of Muro unconformity and the remaining problem

A) Age of Muro unconformity

An angular unconformity within the Muro group that is, between the Yomura-kawa-Muro and the Ukekawa- Muro subgroups is named the Muro unconformity.



the Line N-S in Fig. 2.

The Ukekawa-Muro subgroup situated above the Muro unconformity yields *Costacallista* cfr. *shikokuensis*, *Portlandia* (*Portlandella*) sp. and *Venericardia tokunagai*, which are considered to belong to late Oligocene to early Miocene in age. (HARATA et al., 1963). Owing to the scantiness of paleontological data, the geological age of the Yomurakawa-Muro and the Otonashigawa-Muro subgroup has not been clarifiied. The author infers, however, that the greater part of these belongs to Paleogene and the remainder may include the upper Cretaceous strata. The Ukekawa-Muro subgroup may be correlated with the Sakatani subgroup of the Nichinan group in South Kyushu (HASHIMOTO, 1962; Shuto, 1963), the Tatsugaseko and the Misaki formation in South Shikoku (KATTO, 1963) and the Ôigawa group in the Tôkai district of Central Japan (MAKIYAMA, 1939; SAWAI, 1963; TOKUOKA, 1964; MATSUMOTO*).

Accordingly, the Muro unconformity represents a part of disturbance which took place during late Paleogene to early Neogene age.

B) Comparison of tectonic division in the Shimanto terrain

I. HASHIMOTO (1962), has subdivided the Shimanto terrain in South Kyushu by six main tectonic lines into six tectonic subbelts, namely, from north to south, the Saeki, the Kamae, the Nobeoka, the Takakumayama, the Nichinan and the Kumage subbelts and these subbelts were combined into two belts, Northern and Southern, by the Nobeoka-Shibisan tectonic line forming a boundary between the Kamae and the Nobeoka subgroups. Furthermore, Hashimoto attempted a correlation of tectonic divisions in the Shimanto terrain throughout the Outer Zone of Southwest Japan. In the Kii peninsula, he correlated the Hitaka and the Muro belts respectively, with his Northern and Southern belts and lithologically the Muro group with the lower subgroup of the Hyûga group. The author has formed the following view:

The Muro belt is arranged outermost in the zonal arrangement of the Outer Zone of Southwest Japan and is situated to the south of the Hitaka belt consisting of Triassic or Jurassic to early Cretaceous system (HIRAYAMA & TANAKA, 1956; SHIIDA, 1962). Consequently, the Muro belt may be correlated in structural situation with the Southern belt in South Kyushu, the belt consisting of the Shijûderayama formation in the east of South Shikoku and the Nakamura, the Arioka, the Shimizu and the Misaki formations in the west of South Shikoku (KATTO et al., 1961) and with the belt which is composed of the so-called Mikura and Setogawa group in Central Japan where the Setogawa belt is situated southeast bordering on the Mikura belt by the Sasayama-Inamata tectonic line (Akaishi Mountainland Geological Research Group, 1961).

Vertical changes of lithofacies, similar to those mentioned in Chapter II, are

* See the Matsumoto's paper in this Number.

seen in the equivalents in the other areas of the Shimanto terrain. For instance, in the Hyûga group, the following succession can be recognized namely, muddy (the Kadoishi member), sandy (the Kushizu member), muddy (the Totoro member), sandy (the Igata member) and muddy facies (the Misu member) (HASHIMOTO & MIYASHITA, 1959; HASHIMOTO, 1961—a, b; NOZAWA & KINO, 1956); in the Tokai district from the Ichinose formation (sandy) towards the Tentokuji formation (muddy) of the Setogawa group (TOKUOKA, 1964).

Consequently, the Otonashigawa-Muro and the Yomurakawa-Muro subgroups may be correlated with the Hyûga and the Setogawa groups from their lithofacies and vertical changes.

Moreover, HASHIMOTO (1962) presumed that the greater part of the Muro group may be correlated lithologically with only the lower subgroup of the Hyûga group, with the exception of some rocks near Hongû, which are included by the author in the Ukekawa-Muro subgroup. The author presumes, however, that the Yomurakawa-Muro and the Otonashigawa-Muro subgroup are the equivalents of the upper and lower subgroups of the Hyûga group, from a comparison of their lithofacies.

C) The so-called Takachiho phase in the Kii Peninsula

An angular unconformity between the Muro and the Kumano groups has been noted in the eastern area of the Muro belt by TANAI and MIZUNO (1954), MIZUNO (1957) and MURAYAMA (1954), and a similar angular unconformity between the Tanabe and the Kanayama groups and the Muro group in the western area. This represents the main disturbance that occurred during late Oligocene to early Miocene time, and is called Takachiho orogeny (KURODA & MATSUMOTO, 1942).

In this phase, a system of broad, strong folds of N 60° E trend and east west faults and thrusts took place in the Muro belt, especially, in the southern subbelt. The late Oligocene of early Miocene structures are quite discordant with the structures of the later disturbance and perhaps concordant with those preceding the Takachiho disturbance.

D) Muro disturbance

The Muro unconformity is obviously angular and can be recognized well in the Kozagawa district, where the Ukekawa-Muro overlies the lower horizons southeastward. Near the southern coast, the Matsunomae formation, the lowest of the Yomurakawa is directly overlain by the basal conglomerate of the Ukekawa-Muro, and the stratigraphical gap amounts to over 1500 m. there. The folding structure of the Ukekawa-Muro is rather concordant with that of the Yomurakawa-Muro subgroup, with the exception of the northwestern part of the Ichikano district.

The disturbance expressed by this unconformity may not be of strong folding but rather of uplifting type. The Muro unconformity is correlated with the Isso unconformity in South Kyushu (HASHIMOTO, 1956) and the unconformity presumed at the basal part of the Ooigawa group in Tōkai district (MAKIYAMA, 1950; TOKUOKA, 1964).

V. Summary

1) The Muro group in the south of the Kii Peninsula is the uppermost strata of the basement rocks in the Shimanto terrain. It consists mainly of Paleogene and partly of lower Miocene and upper Cretaceous.
2) From the viewpoint of geological structure, the Muro belt is divided by the Ôtô-Tonda tectonic line into the Muro northern and the Muro southern subbelts. Furthermore, the northern subbelt is subdivided by the Hongû-Kôyadani fault into the Otonashigawa and the Uchikoshi districts, and the southern subbelt is subdivided by the Shichikawa-Mirozu fault into the Kozagawa and the Ichikano districts.
3) Stratigraphically, the Muro group is divided into three subgroups, the Otonashigawa-Muro and the Yomurakawa-Muro and the Ukekawa-Muro. The first and the second subgroups contact with each other by fault, but it is considered that the upper half of the first subgroup is correlated to the lowermost part of the second, while the Yomurakawa-Muro is overlain unconformably by the Ukekawa-Muro subgroup.
4) From the viewpoint of lithology and geological situation in the Shimanto terrain it is presumed that the Muro group is correlated with the Hyûga group of the Nobeoka subbelt in South Kyushu and with the Setogawa group in the Setogawa belt of the Tôkai district.
5) There are vertical macro-changes of lithofacies in the Yomurakawa-Muro and the Otonashigawa-Muro subgroups namely muddy, sandy, muddy, sandy and muddy facies in ascending order.
6) Remarkable structural differences within Tertiary system are seen between the middle Miocene Kumano, Tanabe and Kanayama groups and the late Oligocene to early Miocene Ukekawa-Muro subgroup. Consequently, in the Kii Peninsula, the so-called Takachiho disturbance is dated as early Miocene or latest Oliogcene.
7) An angular unconformity recognized within the Muro group, i. e., between the Yomurakawa-Muro and the Ukekawa-Muro subgroups, is named the Muro unconformity and represents a disturbance during late Paleogene time. This disturbance is ascribed to the pre-Takachiho orogeny.

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Fig. 1. Muddy thin-layered alternation in Yomurakawa-Muro Subgroup.

Fig. 2. Small-scale fold in Yomurakawa-Muro Subgroup.