Formation and Development of Sedimentary Basins during the Paleogene in Amakusa and its Adjacent Areas, Western Kyushu

Miki, Takashi
Faculty of Science, Kyushu University

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Formation and Development of Sedimentary Basins during the Paleogene in Amakusa and its Adjacent Areas, Western Kyushu

Takashi MIKI

Abstract

The stratigraphic boundary between the Cretaceous and Tertiary formations in Amakusa and its adjacent areas is restudied through both field and laboratory works. The paleontological and lithostratigraphical studies have revealed that the unconformity separating the two systems represents a time-interval of variable extent from place to place. The studies of geological structures and petrography of sandstone indicate that a remarkable crustal movement accompanied with clear changes in source rocks and environments occurred in the age represented by the unconformity and that the Paleogene sediments were accumulated in the tectonic depressions formed by the movement. Another movement took place in mid-Tertiary in these areas.

Based on the available data, the Paleogene paleogeography and the paleoenvironment of the studied areas and the tectonic development of the sedimentary basins are discussed in comparison with other related areas.

Contents

I. Introduction

The coal-bearing Paleogene formations accompanied with the Upper Cretaceous strata are widely distributed in Kyushu. They have been investigated for a long time from the standpoint of stratigraphy, paleontology and economic geology. In spite of a large number of previous papers, the problem of the relation between the Paleogene and the Cretaceous formations has not been solved, leaving questions how to understand properly the role of underlying Cretaceous rocks for the formation of the Paleogene sedimentary basins and how these basins were subsequently

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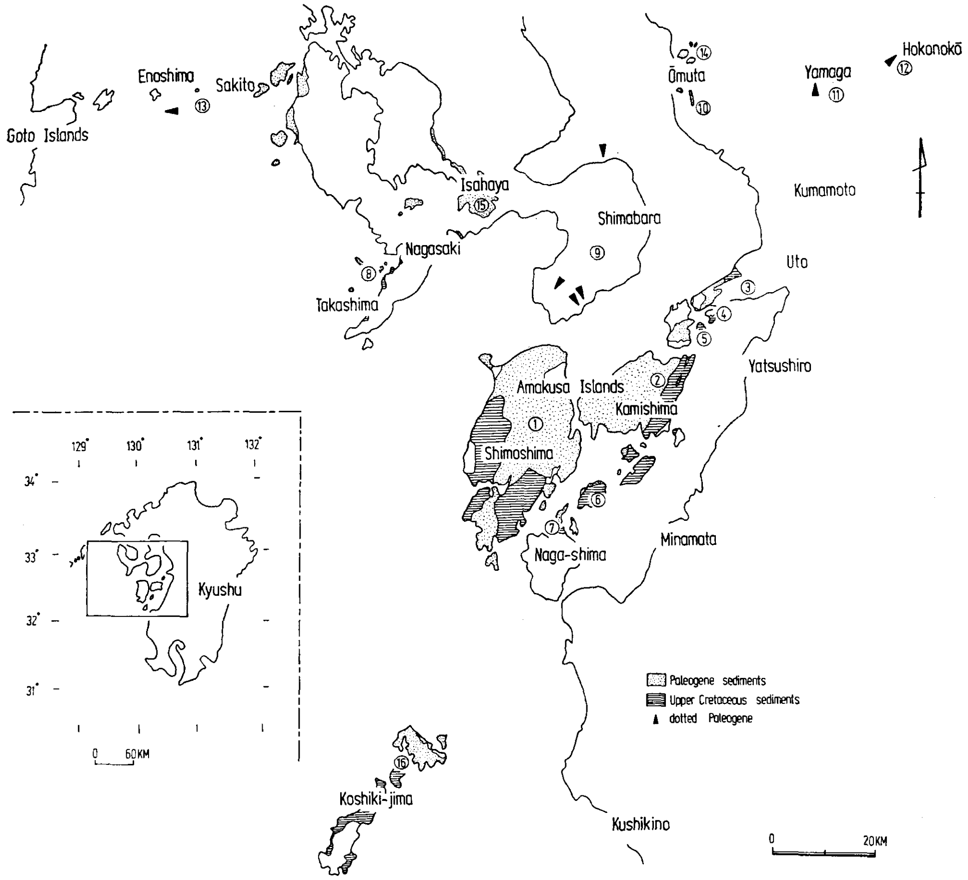

Fig. 1. A map showing the distribution of the Upper Cretaceous and Paleogene in the studied area. Numbers correspond to the heading numbers of Chapter II.

modified and displaced.

To find answers to these questions, the writer has been engaged in a research of the Cretaceous and the Tertiary in Amakusa where the two systems are widely distributed in contact with each other. The results are given in the present paper, together with remarks on the relevant formations in the adjacent areas. In this paper, the term "Amakusa" includes the area from Uto to Shimoshima through Tobase-jima, Iwa-jima, Kamishima, Shishi-jima, and Naga-shima.

The discussions are focussed on two subjects; one is the relationship between the Cretaceous and Tertiary formations and the other is the development process of the sedimentary basins during the Paleogene.

II. Stratigraphy of the Upper Cretaceous and Paleogene Formations

As the basic data for the later discussions, the stratigraphic succession and litho-facies of the Upper Cretaceous and the Tertiary formations, as well as the characters of the unconformity are described in this chapter.

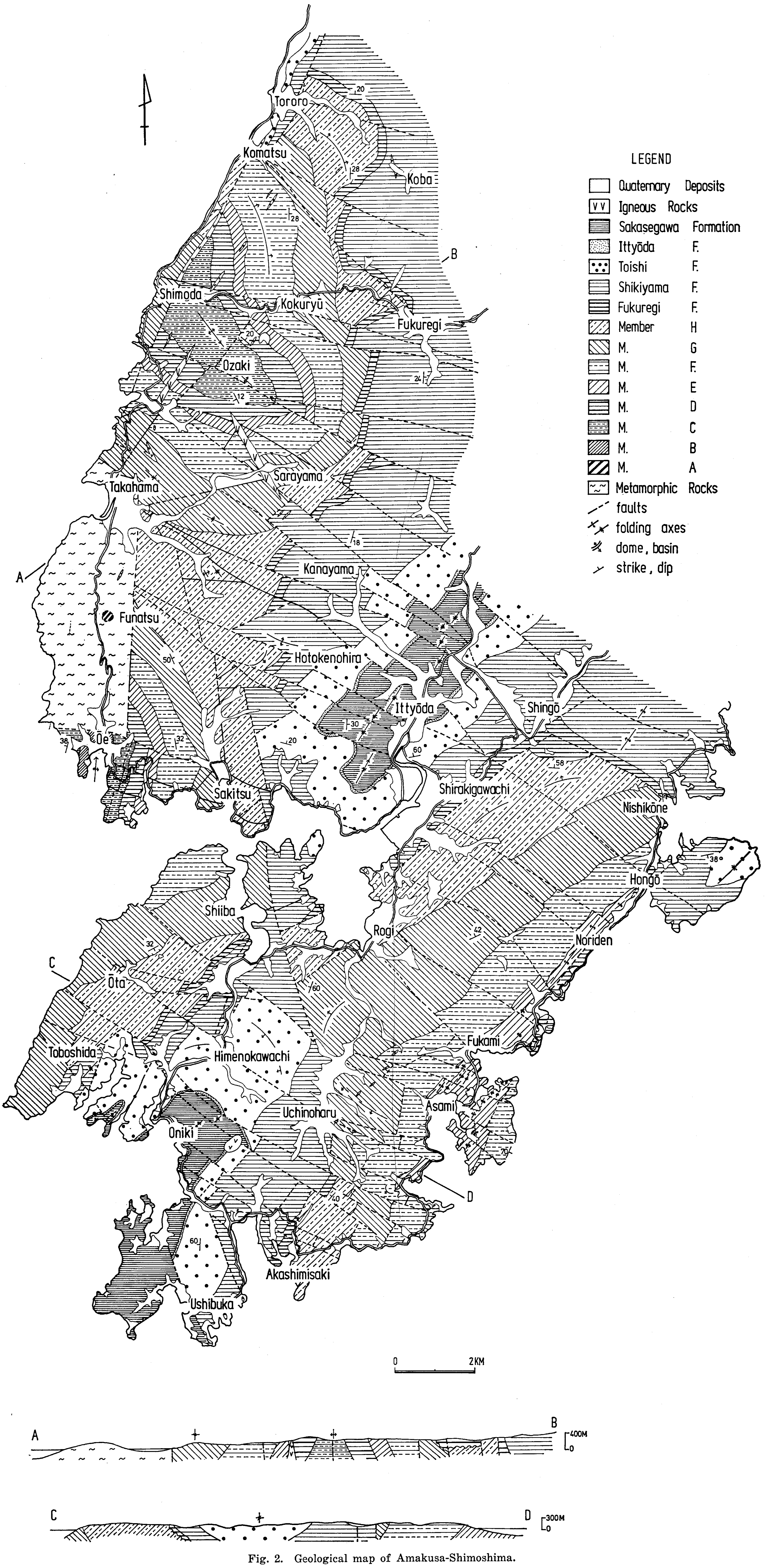

Fig. 2. Geological map of Amakusa-Shimoshima.

Since the geology of the main part of Amakusa-Shimoshima has already been reported (MIKI, 1972a, 1972b; MIKI and UEMATSU, 1973), a concise explanation is given.

1. Amakusa-Shimoshima

1) *Upper Cretaceous formations.* The Upper Cretaceous strata crop out in three separated parts in Amakusa-Shimoshima; i.e. the Sakitsu-Tororo area in the west, the Kameura area in the southwest and the Fukami-Hongō area in the east. They are in contact with the schist group by a fault and with the Paleogene formations by an unconformity of regional significance as discussed later in detail. These strata are named the Upper Himenoura Subgroup by TASHIRO and NODA (1973). In the present study, eight members from A to H in ascending order are recognized, although the whole sequence is observable only in the southern half of the western part.

Member A, which is exposed in a limited narrow area adjacent to the metamorphic basement rocks, is tentatively regarded as the lowest member of the Upper Himenoura Subgroup, although without any fossil evidence. It is about 20 m in thickness and composed mainly of medium-grained, unfossiliferous brownish gray sandstone which is badly weathered.

Member B of about 50 m in thickness is exposed on both sides of Ōe Bay, consisting of conglomerate, sandstone and interbedded fossiliferous layers of black shale, in which *Glycymeris amakusensis* NAGAO and other bivalves are contained. The strata are remarkably disturbed.

Member C exposed in the western part is characterized by the prominence of black or grayish black shale, siltstone and their alternations. It is nearly 135 m in thickness. Molluscan fossils found in this formation are *Glycymeris* sp. and others.

Member D, distributed in the western part, is about 100 m and comprises dark brownish, medium to coarse-grained sandstone, conglomerate and subordinately intercalated black or grayish black shale. It is about 100 m. The litho-facies of the member in the north is similar to that of Member C, being coarser than that in the south with frequent conglomerate.

Member E, exposed in the western and eastern parts, consists almost entirely of black or grayish black shale and sandy shale with a subordinate amount of sandstone and conglomerate. The thickness of the member varies from 100 to 200 m and generally tend to thicken to the east. From this member such kinds of fossils as *Astarte* sp. and *Cymatoceras* sp. are found.

Member F is more than 500 m thick and shows more coarse-grained litho-facies than Member E. The lithological change from E to F is, however, transitional. The formation is composed chiefly of coarse and hard sandstone with interbedded shale. Sandstone is bluish gray or bluish green, commonly cross-bedded and intraformationally folded and slided. It frequently includes patches of black shale, indicating contemporaneous erosion. Slumping structures and scours are also common. Fossils are found from the lower part of the member; they are *Apiotrigonia postonodosa* NAKANO, *Ostrea* sp., *Leionucula* sp., *Acila* cf. *hokkaidoensis* (NAGAO), *Inoceramus* sp. and others.

Member G is about 500–600 m thick in the north and 900 m in the east. It consists of bluish green to bluish gray granule to pebble conglomerate and coarse to medium sandstone of the same color with intercalated shale. A thin lenticular

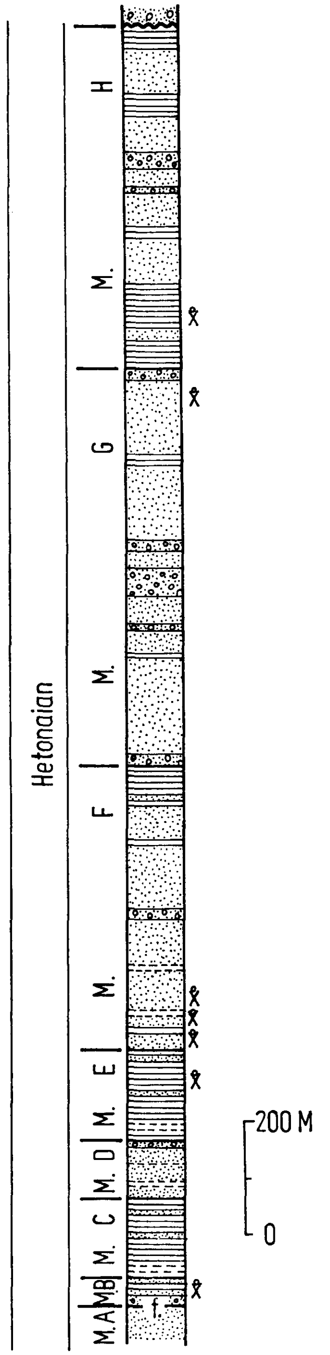

Fig. 3. Columnar section of the Upper Cretaceous in Amakusa-Shimoshima.

layer of tuff occurs in the lower part. Cross-bedding, calcite veins and slumping structures are observed in the member, and the trend of the cross-bedding is dominantly towards the east as in the underlying Member F (see NAGAHAMA, 1968). *Pleurogrammatodon splendus* ICHIKAWA and MAEDA was found in this member (TAKAI and BŌJŌ, 1963).

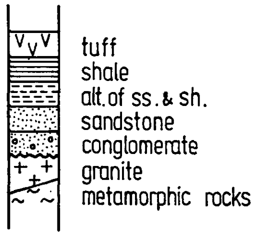

Fig. 4. Legends for columnar sections.

Member H, the uppermost unit of the Cretaceous sequence in Shimoshima, consists of granule to cobble conglomerate, bluish green coarse to medium sandstone and black shale. The amount of shale is larger than in Member G, particularly in the eastern area, where the member consists chiefly of shale. Thin layers of coaly shale are often seen, although they are not traced laterally so far. The writer has found *Hormomya* sp., *Glycymeris* sp. and *Crassostrea*? sp. and TASHIRO (1975) has recently described *Tenea japonica* ICHIKAWA and MAEDA and *Portlandia cuneistriata* ICHIKAWA and MAEDA from the beds which are assignable to the lower part of Member H.

2) *Paleogene formations.* The Lower Tertiary in the central backbone of Shimoshima comprises five formations, which are respectively characterized by distinct litho-facies and fossil contents.

The Fukuregi Formation consists of white coarse-to medium-grained sandstone and conglomerate with a minor amount of shale. It is about 30 m thick in the western part and 100 m thick in the southern and eastern parts. The litho-facies is markedly changed from place to place in the south-southeastern area, although it is nearly homogeneous in the southwest-western part. The variation in thickness and rock-facies indicates that the sediments may have been deposited on an uneven sea floor, and poorly cemented conglomerate with angular-shaped cobbles and boulders in the southern area support the view that nearby areas were the provenances of the sediments. This formation contains in abundance larger foraminifera such as *Nummulites amakusensis-subamakusensis* YABE and HANZAWA, *N. ushibukensis* HANZAWA and URATA, *N. hongoensis* HANZAWA and *Discocyclina* *fukamiensis* HANZAWA which indicate Lower Eocene, probably Ypresian (HANZAWA and URATA, 1964). Besides, many molluscan fossils such as *Colpospira tashiroi* KOTAKA, *Joannisiella problematica* NAGAO occur.

The formation covers the underlying Member H with an inclined unconformity plane as clearly seen at the following five exposures; Hotokenohira, Jūsanno, Ōkōchi, Nakaura and Akashimisaki. Both formation and member are not markedly differ in dipping at exposures, but their unconformable relation is clearly known from areal field observations and on the geological map.

An exposure showing an interesting phenomenon has been recently discovered by MATSUMOTO (personal communication) in the east of Tororo. On that exposure, sandstone, sandy shale with non-marine molluscan fossils and coaly shale are found below the white sandstone of the Fukuregi Formation separated with an irregular plane. The relationship between this newly found unnamed formation and the underlying one is uncertain as the lower limit of the former is not exposed. But this discovery of the pre-Ypresian formation is a significant datum not to be neglected.

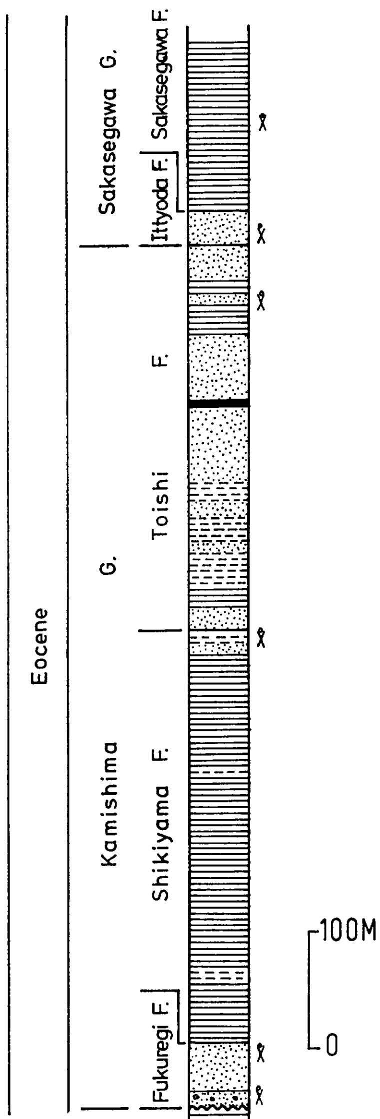

Fig. 5. Columnar section of the Paleogene in Amakusa-Shimoshima.

The Overlying Shikiyama Formation is approximately 500 m in thickness and consists of black shale and siltstone with interbedded fine- to medium-grained quartzose sandstone. The strata show disturbance caused by contemporaneous movement. A fossiliferous layer called the Tōmiyama Fossil Bed (HATAE, 1960b) is recognized at the uppermost horizon throughout the island, and it contains *Venericardia mandaica* (YOKOYAMA), *V. nipponica* YOKOYAMA, *Crassatella nipponica* YOKOYAMA, *C. fusca* (YOKOYAMA), *Flabellum* sp. and many other fossils. They indicate Middle Eocene in age.

The Toishi Formation consists of bluish gray, fine-to medium-grained sandstone with interbeds of black shale, coaly shale and coal. It is a sole workable coal-bearing formation in Amakusa.

The overlying is the Ittyōda Formation of glauconite-bearing medium to coarse sandstone of 20 m thick in maximum. It is characterized by its homogeneous greenish rock-facies and abundance of fossils such as *Venericardia mandaica* (YO-

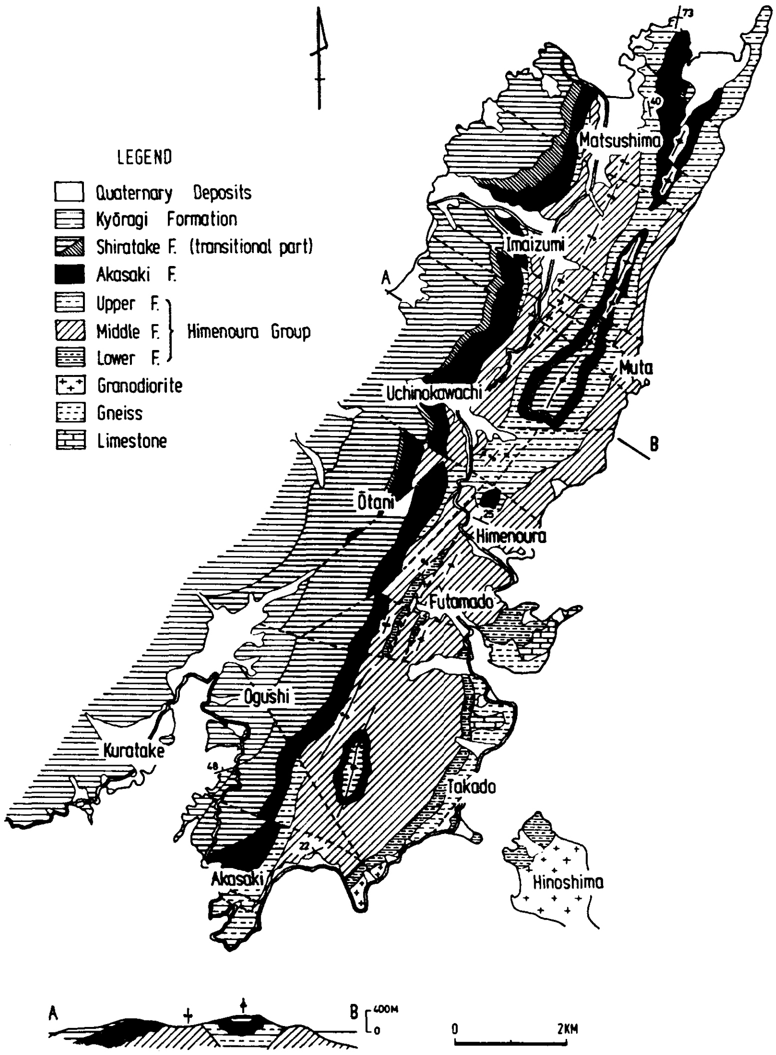

Fig. 6. Geological map of the eastern part of Amakusa-Kamishima.

KOYAMA), *V. nipponica* YOKOYAMA and others. The formation indicates the beginning of the marine invasion generally named the Sakasegawa transgression.

The Sakasegawa Formation consists mainly of black shale, but its upper part contains considerable amounts of sandstone. Foraminiferal fossils are well known to occur (ASANO and MURATA, 1957) but mollusks are rare.

2. Amakusa-Kamishima

1) *Upper Cretaceous formations.* The Upper Cretaceous rocks in Amakusa were reported by NAGAO (1922) who proposed the name "Himenoura Group" to them. His type section was located in the eastern part of Kamishima, and the group was subdivided to three formations from the lithostratigraphic viewpoint, namely the Lower, Middle and Upper. UEDA and FURUKAWA (1960) gave detailed

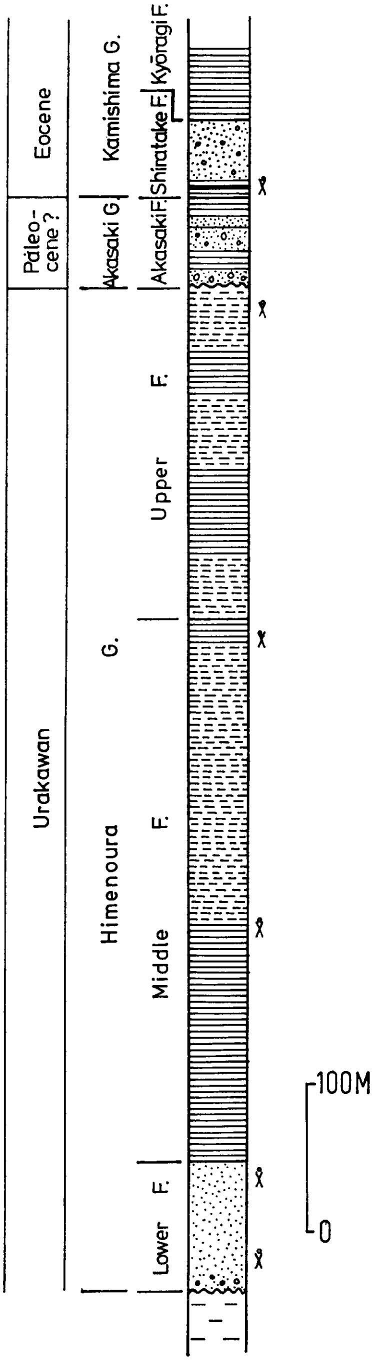

Fig. 7. Columnar section of the Upper Cretaceous and Paleogene in Amakusa-Kamishima.

stratigraphic descriptions for them based on field and paleontological data. In this paper the writer follows their subdivisions of the group after partly corrected by himself. The group corresponds to the Lower Himenoura Subgroup by TASHIRO and NODA (1973).

The Lower Formation rests on the metamorphic basement called the Higo Metamorphic Rocks and the pre-Himenoura Granodiorite with a distinct unconformity. The rocks consist dominantly of granule to pebble conglomerate and black to bluish, coarse-to medium-grained sandstone with subordinate black shale and alternation of them. Cross-bedding is partly observed. The thickness of the formation varies from 100 to 250 m from place to place.

The Middle Formation, about 500 m thick, consists, for the most part, of black shale, sandy shale and a subordinate amount of fine-to medium-grained sandstone and alternation of sandstone and shale of quite variable thickness.

The Upper Formation attains a thickness of 300 m. It consists of greenish blue, sometimes white, medium sandstone, sandy shale and their alternation. Thin coaly shale and tuffaceous shale are also interbedded.

The Himenoura Group in Kamishima contains many molluscan fossils. UEDA and FURUKAWA (1960) divided the group biostratigraphically into four zones based on the plentiful fossil evidence as follows; *Inoceramus amakusensis* zone (*I. amakusensis* NAGAO and MATSUMOTO, *Texanites oliveti* (BLANCKENHORN), *Glycymeris amakusensis* NAGAO, etc.), *I. japonicus* zone (*I. japonicus* NAGAO and MATSUMOTO, *Acila hokkaidoensis* (NAGAO), etc.), *I. orientalis* zone (*I. orientalis nagaoi* MATSUMOTO and UEDA, *Eupachydiscus haradai* (JIMBO), etc.) and *I. balticus* zone (*I. balticus toyajoanus* NAGAO and MATSUMOTO, *Leionucula* sp., etc.), and regarded their age to range from K5α (Coniacian by MATSUMOTO, 1959) to K6α (Upper Campanian by MATSUMOTO, 1959). TASHIRO and NODA (1973) claimed the age to be K5α–K5γ (Lower Campanian by MATSUMOTO, 1959).

2) *Paleogene formations.* The Paleogene is subdivided into six conformable formations, namely Akasaki, Shiratake, Kyōragi, Toishi, Ittyōda, and Sakasegawa in ascending order. Descriptions of the last two are omitted here because of their limited areal distribution and of little importance for the later discussions.

The Akasaki Formation, which rests clino-unconformably on the Cretaceous beds, attains to a maximum thickness of about 80 m in the north although it thins to the south. An unconformity plane between the formation and the Cretaceous beds is observed in Akasaki. It is predominantly composed of purple shale and siltstone with subordinate conglomerate and sandstone. Conglomerate occurs at the basal part, with poorly sorted and angular-shaped cobbles to boulders. Pebbles of the conglomerate are green-schist, mica-schist, sandstone, igneous rocks and others. Schist is presumed to have been transported from the Kiyama or Manotani Metamorphic areas judging from their mineral assemblages (MIKI and MATSUEDA, 1974). No fossils have been found from the formation.

The Shiratake Formation aggregating to 130 m thick in maximum consists of two members, the lower and the upper; the lower member, about 30 m thick in average, is the transitional part from the underlying Akasaki Formation, and is composed of black shale, thin coaly shale and fine to medium sandstone, and the upper member is the Shiratake proper consisting almost of medium to coarse grained sandstone. The lower member becomes thinner to the south. The lower member contains *Colpospira tashiroi* KOTAKA, *Corbula kyushuensis* NAGAO, *Callista ariakensis* NAGAO and other molluscan fossils, and their age is regarded as Lower Eocene.

In marked contrast to the Shiratake Formation, the Kyōragi Formation which occupies the main part of the western half of the island consists generally of black shale with subordinate sandstone. According to SUZUKAWA (1975)'s recent study, foraminiferal fossils including *Plectofrondicularia packardi* CUSHMAN and SCHENCK and *Nodosaria okinoshimaensis* ASANO and MURATA, which characterize the Sakasegawa Formation in Shimoshima, occur in the uppermost part of the Kyōragi Formation in the coastal area of Kamishima. The total thickness of the Kyōragi Formation is at least 1200 m. The strata frequently show the slumping structures. The fossil fauna in this formation consists of *Venericardia nipponica* YOKOYAMA, *V. mandaica* (YOKOYAMA), *Crassatella fusca* (YOKOYAMA), *Glycymeris altoumbonata* NAGAO, *Lima amakusensis* NAGAO and others. They indicate Middle Eocene.

The Toishi Formation equivalent, which is limited in distribution to the southwestern margin of Kamishima, has massive medium-grained sandstone and is 650 m in thickness. In contrast to the case in Shimoshima, the formation contains neither coal-seams nor plants, but some marine molluscan fossils, such as *Venericardia nipponica* YOKOYAMA, *Callista* sp. and *Cardium* sp.

3. Uto Peninsula

1) *Upper Cretaceous formations.* A part of the Himenoura Group is exposed in the coastal area of the Uto Peninsula. It consists of alternating beds of thin black shale and fine to medium sandstone with thin conglomerate. Their total thickness is more than 400 m. The Himenoura Group in this area is famous for the occurrence of *Protexanites fukazawai* (YABE and SHIMIZU) and *Gaudryceras denseplicatum* (JIMBO), which indicate K5β stage (Santonian by MATSUMOTO, 1959). The group in this area is correlated to the Middle-Upper Formation of the

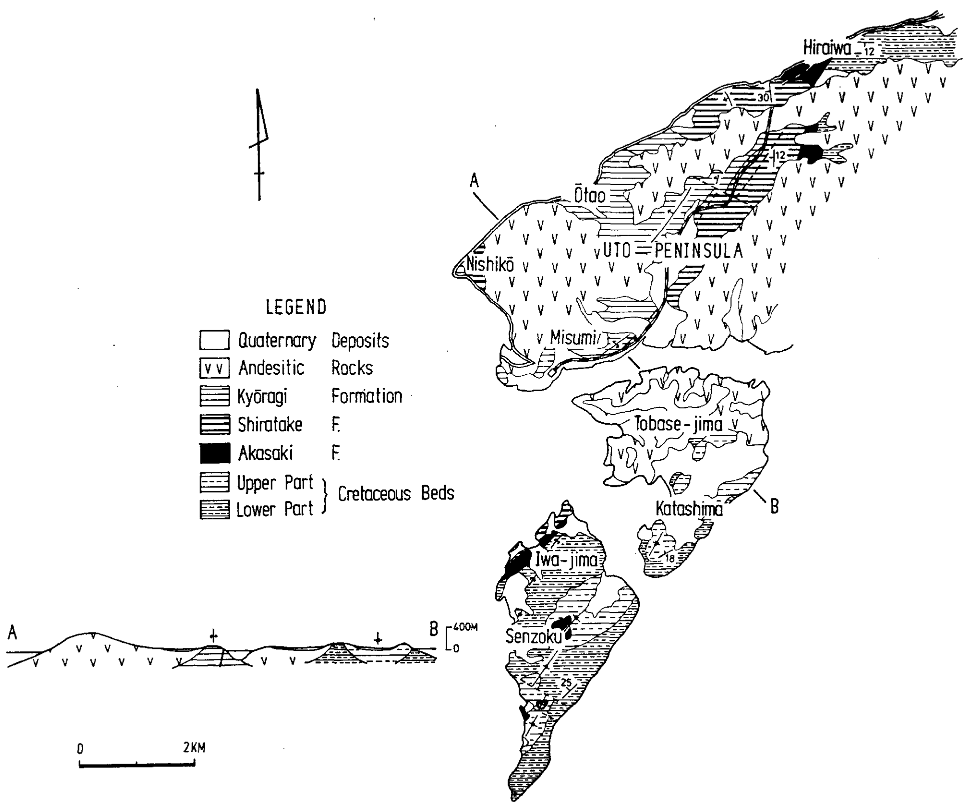

Fig. 8. Geological map of Uto Peninsula and its vicinity.

group in Kamishima.

2) *Paleogene formations.* The Akasaki Formation consists mostly of purple or red-colored shale and siltstone, besides a small amount of conglomerate and sandstone. The formation overlies unconformably the Himenoura Group as seen in Hiraiwa.

The Shiratake, which conformably covers the Akasaki, is characterized by white, medium-to coarse-grained sandstone throughout the formation. It contains the same molluscan species as those in Kamishima.

The Kyōragi Formation of black to grayish black shale with interbeds of fine to medium sandstone is exposed in the western margin of the peninsula, being covered with the andesitic lava, tuff and tuff breccia of younger ages.

4. Tobase-jima

1) *Upper Cretaceous formations.* A part of the Himenoura Group is exposed in the southeastern part of the island being covered with andesitic rocks. It is lithostratigraphically divisible to two parts. The lower part consists mainly of bedded black shale with minor interbeds of medium-to coarse-grained sandstone. The upper part consists of medium-to coarse-grained sandstone with a small amount of black shale, sandy shale, tuffaceous shale, and coaly shale. AMANO (1960)

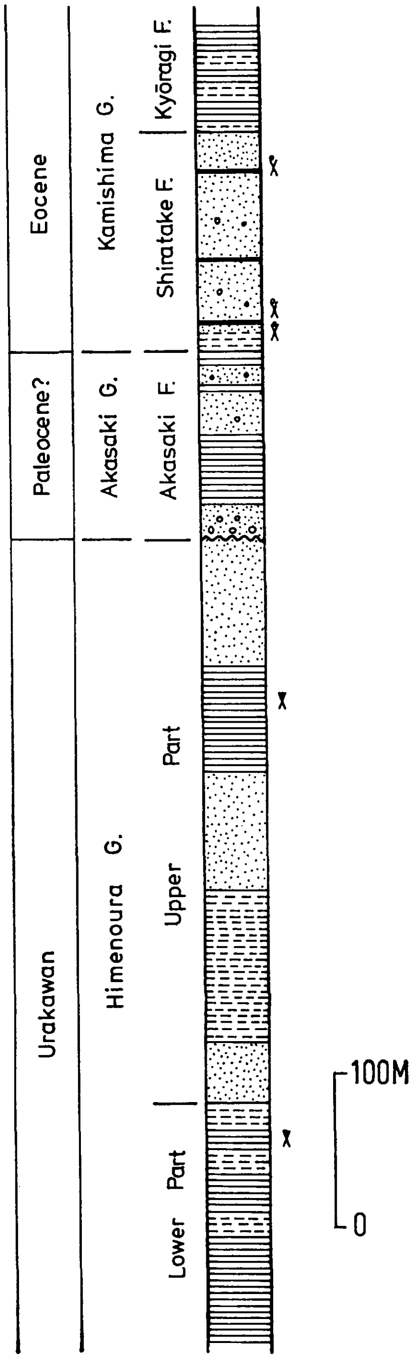

Fig. 9. Columnar section of the Upper Cretaceous and Paleogene in Uto Peninsula and its vicinity.

reported *Inoceramus orientalis nagaoi* MATSUMOTO and UEDA from the writer's upper part indicating K5γ stage, and consequently, this part is probably equivalent of the Upper Formation of the type Himenoura Group.

5. Iwa-jima (Senzokuzōzō-jima)

1) *Upper Cretaceous formations.* A part of the Himenoura Group crops out in the central part of the island along a synclinal axis. It is divisible to two parts. The lower part consists of bedded black shale accompanied with thin sandstone layers and alternation of sandstone and shale, and yields *Inoceramus orientalis nagaoi* MATSUMOTO and UEDA (AMANO, 1960). It is probably the equivalent of the Upper Formation of the type Himenoura Group. The upper part is composed predominantly of medium to coarse sandstone.

2) *Paleogene formations.* They rest on the Himenoura Group in the central part and are also exposed on the western margin of the island. Most of them is occupied by the Akasaki Formation which unconformably overlies the Cretaceous beds, and the Shiratake is present only in a limited area in the west. Litho-facies of these formations is closely similar to that of the same formations in Kamishima.

6. Shishi-jima

1) *Upper Cretaceous formations.* The Cretaceous strata in Shishi-jima are classified into two groups separated by faults from each other; the Himenoura of the upper and the Goshonoura of the lower. The Goshonoura Group is, in summary, composed mainly of sandstone with members of silty fine sandstone or fine-sandy siltstone at two levels. It contains shallow water mollusks with some ammonites indicating mostly Cenomanian and Upper Albian ages. For further informa-

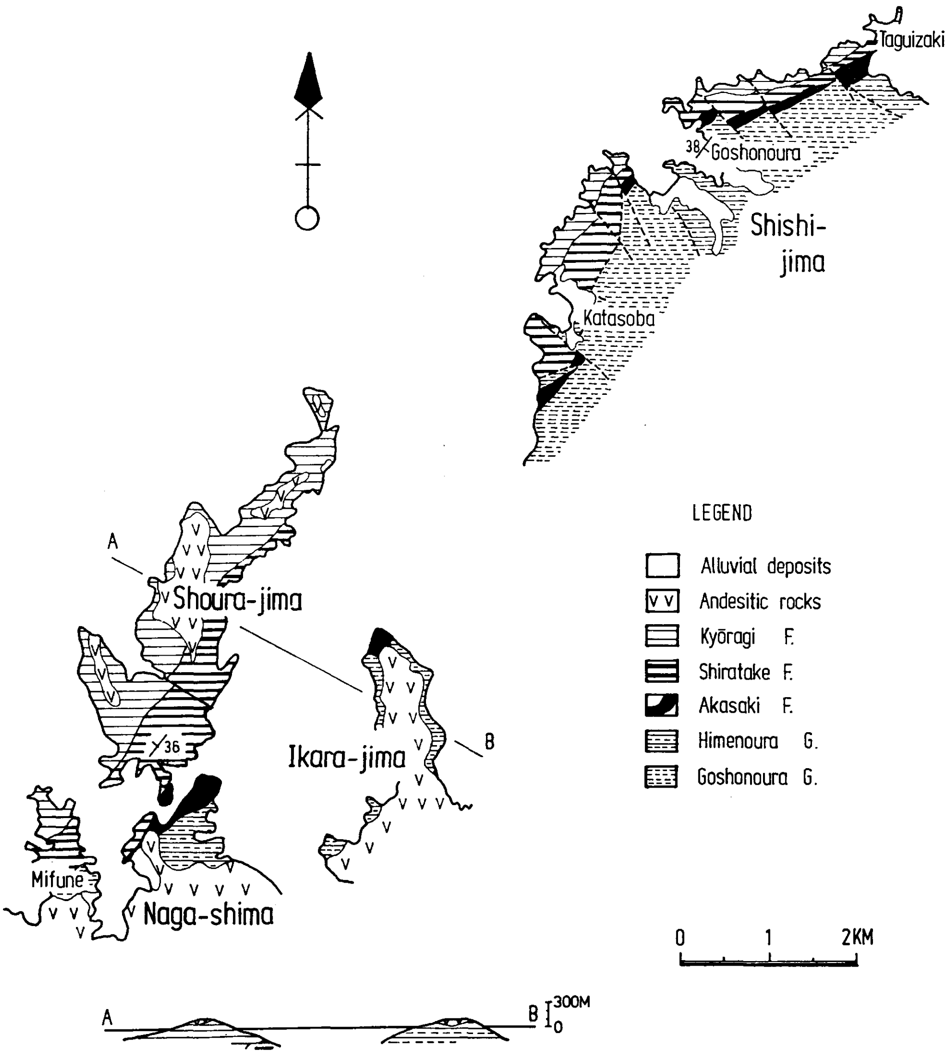

Fig. 10. Geological map of Shishi-jima and Naga-shima.

tion see papers by MATSUMOTO (1960), AMANO (1962) and YAMAMOTO and HAYAMI (1971).

The Himenoura Group exposed partly in the narrow area of the northwestern part of the island seems to be in fault contact with the Paleogene in many places, but an unconformity is preserved at a few points. It consists predominantly of intraformationally disturbed black or gray shale, with intercalated thin layers of fine to medium sandstone. Some Santonian to Lower Campanian mollusks such as *Inoceramus amakusensis* NAGAO and MATSUMOTO, *I. japonicus* NAGAO and MATSUMOTO, *I. orientalis nagaoi* MATSUMOTO and UEDA, *I. balticus toyajoanus* NAGAO and MATSUMOTO and *Gaudryceras denseplicatum* (JIMBO) are found (YAMAMOTO and HAYAMI, 1971).

2) *Paleogene formations.* The sequences corresponding to the Akasaki, Shiratake and Kyōragi Formations in Kamishima are exposed, but detailed descrip-

tions are omitted on account of their narrow and scattered distribution. The Akasaki Formation consists of purple shale and granule to cobble, poorly sorted conglomerate with interbeds of coarse sandstone. The purple color of the rock sometimes changes to bluish green and white. The Shiratake is predominated with medium to coarse sandstone with a minor amount of conglomerate and shale. The Kyōragi consist chiefly of black shale.

7. Naga-shima

1) *Upper Cretaceous formations.* In Naga-shima, Shoura-jima and Ikara-jima the Cretaceous and the Paleogene deposits crop out below the covering of andesitic rocks. The outcrop of the Cretaceous is limited to the northern part of Naga-shima and the marginal area of Ikara-jima. The lower part is medium to coarse sandstone and granule conglomerate, whereas the upper part is chiefly black or gray shale associated with alternating sandstone and shale. TAKAI and MATSUMOTO (1961) reported an occurrence of *Inoceramus* cf. *uwajimensis* YEHARA and *I. elegans pseudosulcatus* NAGAO and MATSUMOTO, but TASHIRO and NODA (1973) have recently expressed some doubts about the identification of the former species.

2) *Paleogene formations.* The Paleogene rests on the Cretaceous with a distinct unconformity as exposed at the northern edge of Ikara-jima. TAKAI and MATSUMOTO (1961) regarded the three formations of Paleogene in three islands as being equivalent to the Akasaki, Shiratake and Kyōragi Formations in the type area.

The Akasaki Formation is composed mainly of pebble to cobble conglomerate with coarse sandstone. The conglomerate consists of a large amount of pebbles and cobbles, with little matrices, and is poorly sorted without stratification. Thin layers of purple shale are found.

The Shiratake Formation consists chiefly of predominant granule to pebble conglomerate with coarse-grained sandstone, but in the upper part, it consists of black or grayish black, sheared shale with minor amounts of sandstone containing such fossils as *Colpospira tashiroi* KOTAKA (TAKAI and MATSUMOTO, 1961), *Nummulites* sp., *Pseudoliva japonica* (NAGAO) (HATAE, 1960b). The writer also obtained some fragmentary fossils from this part.

The Kyōragi Formation is composed of cobble-bearing granule to pebble conglomerate, coarse sandstone followed by predominant shale frequently alternating with fine-grained sandstone.

8. Takashima

1) *Upper Cretaceous formations.* The Cretaceous in the Takashima area is called the Mitsuse Formation. The term "Mitsuse Formation" was first introduced by HINOKUMA (1962) for the thick deposits of conglomerate, sandstone and shale, which show frequently purple color. *Inoceramus* cf. *amakusensis* NAGAO and MATSUMOTO was found in the black shale at one underground locality. The name was derived from Mitsuse Gallery of Takashima Coal Mine where *Inoceramus* was discovered. The sediments are observable not only in the galleries and shafts of the Takashima and Hashima Collieries but also on the land surface in the western margin of the Nomo Peninsula. The formation is lithostratigraphically divided into two members. The Lower Member, more than 400 m thick, is composed of sandstone, black shale, conglomerate and purple shale, with locally intercalated beds

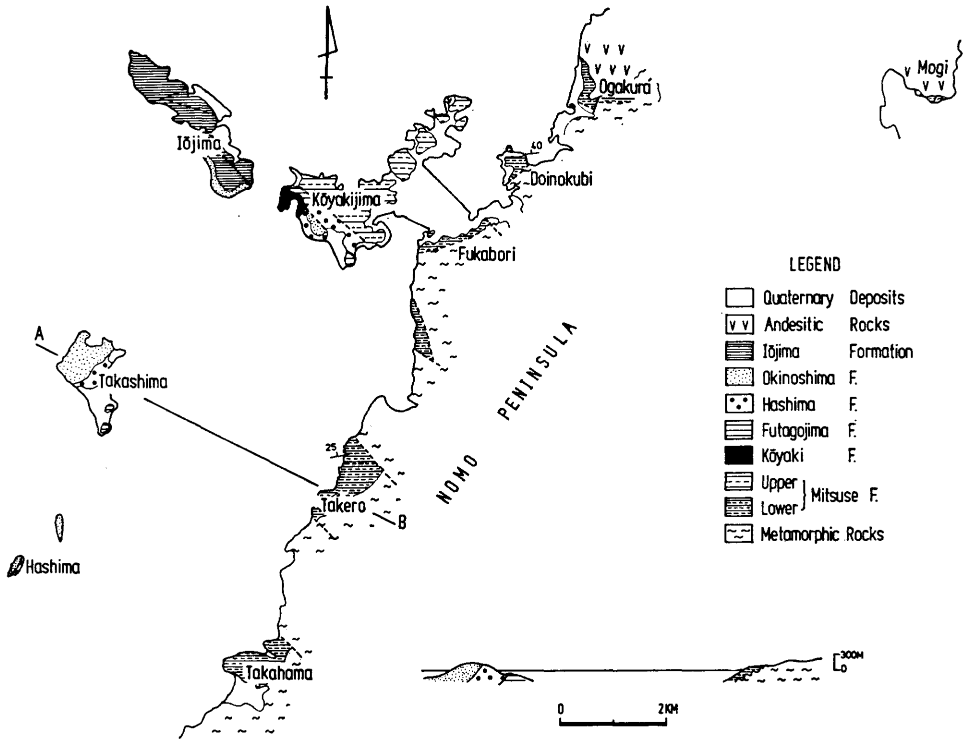

Fig. 11. Geological map of the Takashima area.

of thin coaly shale. Hard sandstone and conglomerate exposed on the shaft and land surface are bluish green in color and often cut by calcite veinlets. The Upper Member of about 270 m thick is coarser in facies than the Lower Member and is predominantly composed of conglomerate accompanied with subordinate shale. Purple shale also reduces its amount. The member yields *Inoceramus* cf. *amakusensis* as already mentioned.

Bluish green sandstone at Mogi on the eastern side of the Nomo Peninsula may be correlated with the Mitsuse Formation from a viewpoint of lotho-facies, but its exact age is open to question.

2) *Paleogene formations.* Paleogene in the Takashima area is divided into the following three groups or five formations in ascending order in accordance with MATSUSHITA (1949) ; Kōyaki Formation (Akasaki Group), Futagojima and Hashima Formations (Takashima Group), Okinoshima and Iōjima Formations (Iōjima Group). They are sporadically exposed in the islands of Okinoshima, Kōyakijima, Iōjima, Takashima, Hashima and Kaminoshima. The formations from Kōyaki to Hashima are conformably superposed with each other. The Kōyaki Formation, which should be restricted to the upper part of the so-called Kōyaki in the former usage, is 300 m thick on the average and thickens to the south. It is predominantly fine- to coarse-grained sandstone, shale and conglomerate, dominantly with purple color. The so-called "Kōyaki Fossiliferous Bed" containing *Colpospira okadai* (NAGAO) and others is recognized in the middle part of the formation. The Futagojima Formation, which begins with the so-called "Lower *Orthaulax japonicus* Zone" containing *Pseudoliva japonica* (NAGAO), *Polinices eocenica* NAGAO, *Pitar hinokumai*

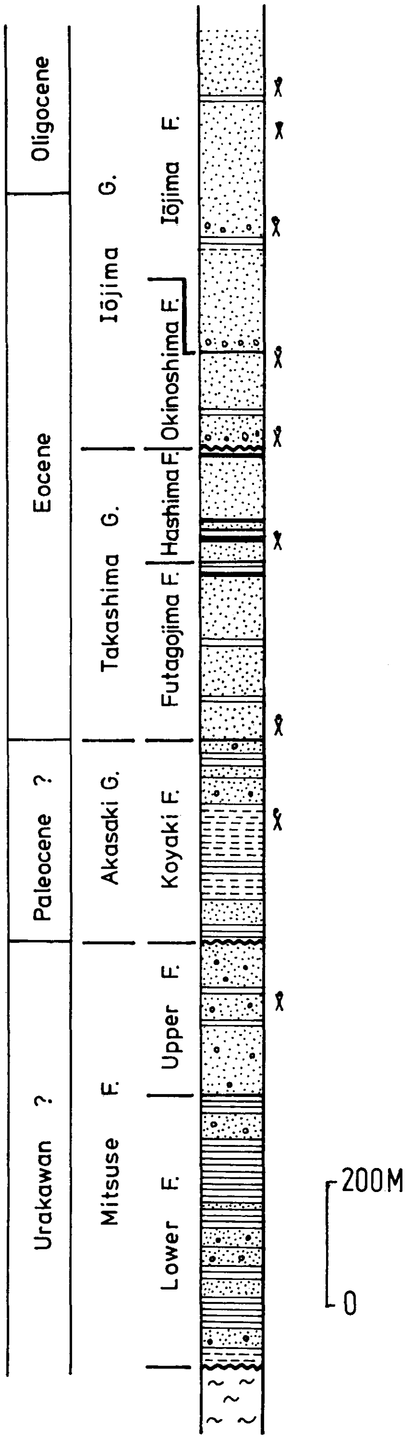

Fig. 12. Columnar section of the Cretaceous and Paleogene in the Takashima area.

MIZUNO and others, consists chiefly of alternating sandstone and shale with interbeds of conglomerate and coal. The Hashima of about 200 m in thickness is a workable coal-bearing formation and composed of thick fine to medium sandstone, thin shale and coal. The Okinoshima Formation which overlies unconformably the Hashima Formation (IESAKA *et al.*, 1971) is about 300 m thick, and composed of medium sandstone with subordinate shale and coal. The Iōjima Formation which begins with the so-called "Dezaki Conglomerate Bed" consists mainly of sandstone with intercalated conglomerate and shale.

9. Shimabara Peninsula

The Paleogene strata of black shale and sandy shale with a minor amount of sandstone crop out in the Mukaigoya and Yamaguchi areas of the southern part of the Shimabara Peninsula underneath the Pleistocene Kuchinotsu Group. An outcrop of similar black shale is known also in the Kōjiro area at the northern border of the peninsula under the volcanic lavas (ŌTA, 1973) and in the Ōe area in the southern part (ŌTA, personal communication). On the evidence of foraminifera these strata are correlated to the Sakasegawa Formation of Amakusa (FUKUTA, 1962).

10. Tamana

The Paleogene strata outcropping in a narrow area at Ryūganji, Tamana City, are purple shale with blue mottlings. They are similar in lithology to the Ginsui Formation of the Ōmuta area.

11. Yamaga

In the northeastern area of Yamaga City there is a narrow outcrop of hard conglomerate which was once reported as agglomerate (AKAGI, 1933). The conglomerate consists of poorly sorted, nonstratified pebbles, cobbles and boulders of amphibolite and green schist which are of the same kinds as those now exposed in the neighboring areas. It has a minor amount of matrix. Boulders sometimes reach one meter in diameter. The conglomerate is regarded tentatively as the basal member of the Paleogene, but it could possibly be Cretaceous.

12. Hokonokō

In the Hokonokō area the Paleogene called the Hokonokō Formation (YAMAOKA, 1956) is scattered, which is composed of white, medium to coarse sandstone with a minor amount of conglomerate and shale. FURUKAWA and URATA (1960) further divided the formation to two members: Hokonokō in the lower and Kannon-dake in the upper. The Kannon-dake Member consisting of conglomerate and sandstone with thin coal contains molluscan fossils such as *Venericardia* aff. *mandaica* (YOKOYAMA), *Cardium* sp., *Faunus nipponicus* NAGAO and others (FURUKAWA and URATA, 1960). The Hokonokō Formation is composed mainly of conglomerate with subordinate purple shale and contains no fosills. The Kannon-dake is correlated to the Shiratake in Kamishima judging from their fossil assemblages.

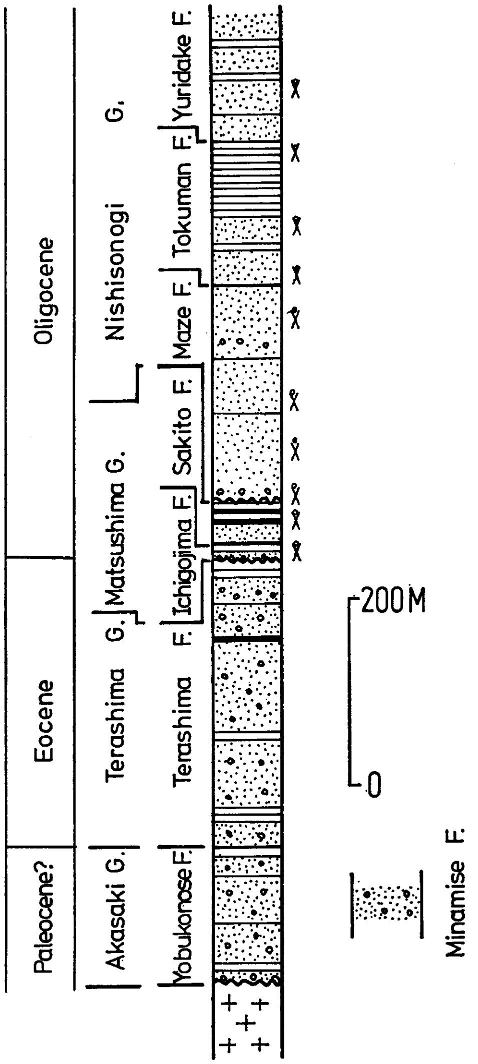

Fig. 13. Columnar section of the Tertiary in the Seto-Minamise area.

13. Seto-Minamise

In the northwestern margin of the Nishisonoki Peninsula and its neighboring islets the Paleogene sediments are exposed. According to MIZUNO (1962) they are divided into six formations in descending order as follows.

Nishisonoki Formation: Mudstone and shale with accompanied sandstone, 500 m+.

Maze Formation: Mudstone, sandstone and conglomerate covering unconformably the underlying beds. Thickness varies from 140 to 300 m.

Sakito Formation: Sandstone and mudstone, with intercalated coal-seam, 0–120 m.

Ichigojima Formation: Basal conglomerate followed by sandstone and mudstone, 0–130 m.

Terashima Formation: Mudstone, sandstone, conglomerate and coal, without fossils, 400 m.

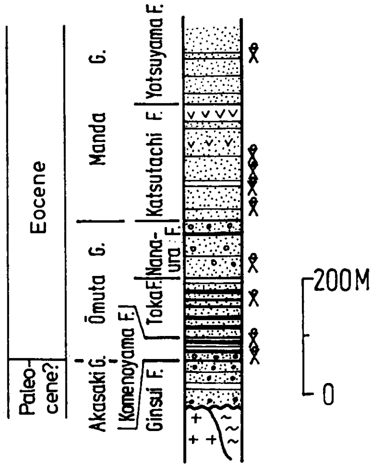

Fig. 14. Columnar section of the Paleogene in the Ōmuta area.

Yobukonose Formation: Sandstone, conglomerate and purple shale, without fossils, 120 m+.

There are small shoals named Minamise, Ōgamenose, etc., which are scattered in the sea area adjacent to Eno-shima, about 25 km west of the Nishisonoki Peninsula. They consist of poorly sorted granule to cobble conglomerate and cross-laminated coarse to very coarse sandstone. These strata were called the Minamise Formation by TACHIBANA (1961). Pebbles and cobbles are mostly those of granites and partly those of hornfels. These rocks, which are clearly discriminated from thermally metamorphosed rocks in Eno-shima, are megascopically presumed to be of Paleogene, and tentatively correlated with the Yobukonose-Terashima Formation from a lithological point of view.

In addition to the above described Paleogene formations there are many Paleogene formations in fairly wide areas in Western Kyushu, namely in Ōmuta, Isahaya and Koshiki-jima. Stratigraphical outlines of these formations are given here without detailed explanations chiefly based on the previous works.

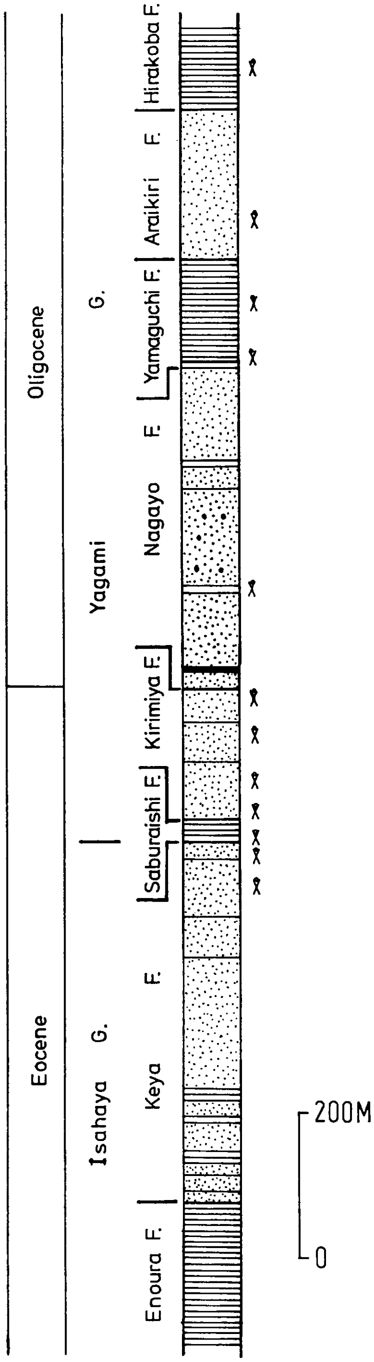

Fig. 15. Columnar section of the Paleogene in the Isahaya area.

14. Ōmuta

The Paleogene rests unconformably on the crystalline schists and granites with the purple beds at the base. Its stratigraphic succession is concisely shown in Fig. 14 in accordance with the result of MATSUSHITA *et al.* (1965).

15. Isahaya

The Paleogene strata in Isahaya City and its south and also the Nagayo area have been investigated by KAMADA (1956, 1957), YAMASAKI (1965), KAMISHIMA and SUGAI (1959) and MIZUNO (1962). Lithostratigraphic succession is summarized in Fig. 15.

16. Koshiki-jima

The writer has not surveyed the island. According to TASHIRO and NODA (1973), the Cretaceous strata in the island are composed mainly of sandstone and shale containing *Apiotrigonia crassoradiata* NAKANO, *Inoceramus balticus toyajoanus* NAGAO and MATSUMOTO and other fossils and are bio- and litho-stratigraphically correlated approximately with the Upper Himenoura Subgroup in Shimoshima. They are unconformably overlain by purple shale presumed to be of the Akasaki Formation.

III. Relationship between the Upper Cretaceous and Paleogene Formations

A. Historical review

Geology of the Amakusa Islands, which consists of two major islands, Kamishima in the east and Shimoshima in the west, with many small islets, has been studied from various points of view since KANEHARA (1904), followed by YEHARA (1922, 1923), NAGAO (1922, 1923, 1926, 1930), YABE (1927), NOTOMI (1929), YABE and HANZAWA (1925), MATSUMOTO (1938), TAKAYAMA (1944), MATSUSHITA (1949), TAKAHASHI (1959), MATSUSHITA *et al.* (1959), HATAE (1959, 1960a, 1960b), UEDA and FURUKAWA (1960), UEDA (1962), AMANO (1960a, 1960b, 1962), TAKAI and BŌJŌ (1963), YAMAMOTO and HAYAMI (1971) and TASHIRO and NODA (1973). But particularly in Shimoshima, a consistent recognition of the Cretaceous-Tertiary relation has been considered difficult because of the general paucity of marine fossils and similarity of litho-facies of the two systems, and many opinions have hitherto been proposed concerning this problem.

Among many previous reports cited above, a special attention was paid to the boundary and its relating problem in the following six papers; NOTOMI (1929), NAGAO (1926), MATSUSHITA (1949), MATSUSHITA *et. al* (1959), HATAE (1959), and TAKAI and BŌJŌ (1963). As consistency and inconsistency of these opinions have been discussed previously by the writer (MIKI, 1972a), a further explanation is omitted in the present paper. In summary, the opinions can be grouped into three according to where the Cretaceous-Tertiary boundary should be placed. In the first opinion, which was proposed by NOTOMI (1929), the boundary is placed within the "Cretaceous formation" of other researchers. In the second, which was shown by NAGAO (1926), MATSUSHITA (1949) and HATAE (1959), the boundary is placed beneath the Fukami Formation, although the usage of the formation-name was different among the workers. The third represented by TAKAI and BŌJŌ (1963), who claims the boundary at the base of the Fukuregi Formation. MATSUSHITA *et al.* (1959) recognized two unconformities, one is beneath the Fukuregi Formation and the other is beneath the redefined Fukami Formation, but they gave no conclusion to the problem.

On the nature of the boundary, two opinions can be discriminated; one is that it is a parallel unconformity apparently showing no structural movement in that age (NOTOMI, 1929; NAGAO, 1926; KOBAYASHI, 1941; MATSUSHITA, 1949), and the other is a clino-unconformity resulted from a remarkable movement (HATAE, 1959; MATSUSHITA *et al.*, 1959; TAKAI and BŌJŌ, 1963).

On the Cretaceous-Tertiary boundary in other islands of Amakusa, the opinions are not so diverse. The prevailing opinion is that the Akasaki Formation with characteristic purple red rock-facies is the lowest member of the Tertiary and that it rests on the Cretaceous beds with a slight clino-unconformity.

HINOKUMA (1962) reported an occurrence of *Inoceramus* from the Kōyaki Formation in Takashima which had been regarded as the lowest member of the Paleogene. This discovery of the Cretaceous fossil threw a new light on a Cretaceous-Tertiary relation in Takashima, and MIZUNO (1963), YAMAMOTO *et al.* (1967) and IESAKA *et al.* (1971) have attempted to clear the problem. Despite their efforts, the Cretaceous-Tertiary relation has remained obscure up to the present, and a temporary boundary is set up from a standpoint of chemical composition of underground water based on the data of the mining company.

As mentioned above, there is much diversity of opinions as to the Cretaceous-Tertiary relationship in Western Kyushu. The discussions have been essentially focussed on the recognition of the boundary in each area and on making clear its geological characteristics.

B. Cretaceous-Paleogene unconformity

1. Field observations of Cretaceous-Tertiary contacts

Unconformity planes are observed beneath the Fukuregi Formation in Shimo-

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Explanation of Plate 27

Fig. 1. An unconformity between the Paleogene Akasaki Formation and the Cretaceous Himenoura Group exposed at Akasaki in Kamishima. A dotted-line shows the unconformity plane.

Fig. 2. An unconformity between the Paleogene Fukuregi Formation and the Cretaceous Member H observed at Akashimisaki in Shimoshima. A dotted-line and a real-line show the unconformity plane and a fault plane respectively.

Fig. 3. An unconformity exposed at Hiraiwa in Uto Peninsula. The unconformity plane shown by the dotted-line separates the Akasaki Formation from the Himenoura Group.

Fig. 4. Conglomerate of the Minamise Formation in Minamise.

Fig. 5. An unconformity between the Fukuregi Formation and the Member H exposed at Hotokenohira in Shimoshima. The unconformity plane is shown by the dotted-line.

Fig. 6. An overturned structure of the Mitsuse Formation observed at Ogakura, near Nagasaki.


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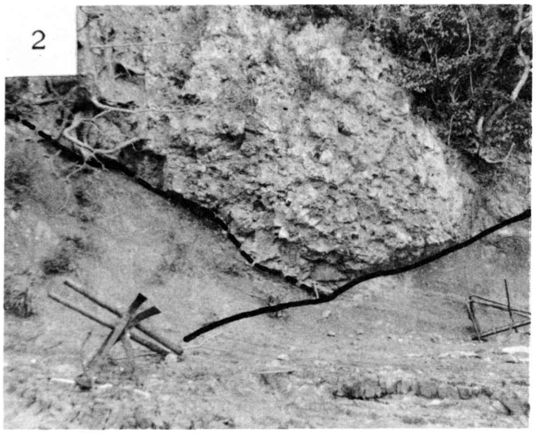
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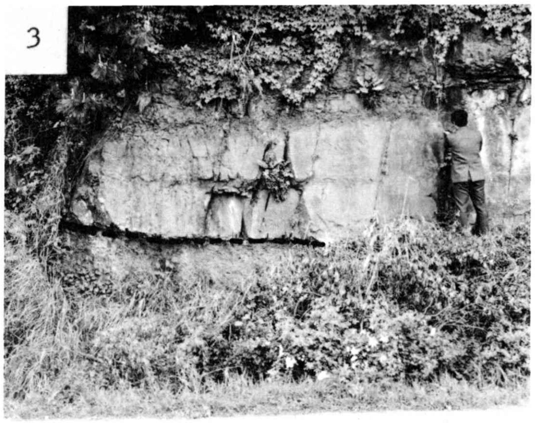
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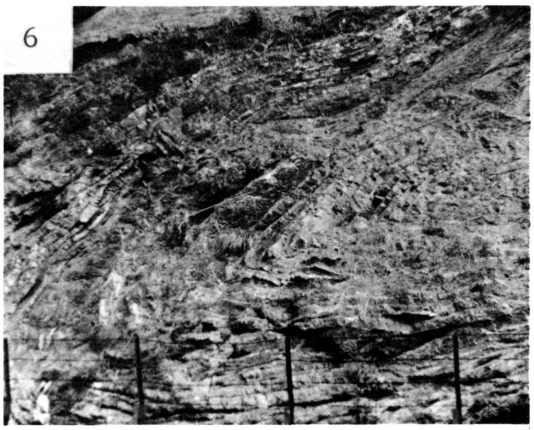
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shima and beneath the Akasaki Formation in other islands of Amakusa as described in detail in the previous chapter. Taking account of the foregoing lithological and fossil evidence, the unconformity undoubtedly marks the Cretaceous-Paleogene boundary in Amakusa. In Takashima an unconformity plane is not exposed and the boundary is provisionally set up about 200 m below the Tertiary fossiliferous bed at the plane where the ground water composition changes.

2. Time-interval represented by the unconformity

The magnitude of time-interval represented by the unconformity mentioned above is discussed from the paleontological evidence.

a. *Amakusa-Shimoshima*

Important fossils which have been reported from the Cretaceous formations are as follows. *Pleurogrammatodon splendus* ICHIKAWA and MAEDA (Member G), *Apiotrigonia postonodosa* NAKANO, *Glycymeris japonicus* TASHIRO, *Acila* cf. *hokkaidoensis* (NAGAO), *Limopsis kogata* (ICHIKAWA and MAEDA) (Member F), *Nanonavis sachalinensis* (SCHMIDT) (Member C), *Glycymeris amakusensis* NAGAO, *Inoceramus sachalinensis* SOKOLOW (Member B).

TAKAI and BŌJŌ (1963) claimed that the upper part of the sequence reaches the Upper Hetonaian (Maastrichtian by MATSUMOTO, 1959) based on the occurrence of *Pleurogrammatodon splendus* ICHIKAWA and MAEDA. In their recent work on Cretaceous fauna in Amakusa, TASHIRO and NODA (1973) collected *Inoceramus sachalinensis* SOKOLOW from the lower part of Shimoshima (Member B in the present paper), and *Limopsis kogata* (ICHIKAWA and MAEDA) from the upper part (Member F in this paper). The former species is known from the Upper Cretaceous formations in Hokkaido, along with the Lower Hetonaian *Inoceramus schmidti* MICHAEL, and the latter from the Upper Hetonaian Izumi Group in Shikoku and the Upper Hetonaian Nemuro Group in Hokkaido. Thus, they have concluded that the age of these formations ranges from the Lower Hetonaian to the Upper Hetonaian, and their opinion is adopted in this paper.

The fossil fauna of the Fukuregi Formation comprises *Nummulites amakusensis-subamakusensis* YABE and HANZAWA, *N. ushibukensis* HANZAWA and URATA, *N. hongoensis* HANZAWA, and *Discocyclina fukamiensis* HANZAWA, and is refered probably to be Ypresian (HANZAWA and URATA, 1964). Consequently, the unconformity beneath the formation shows that the Paleocene (at least its lower part) may be lacking in the Shimoshima area.

b. *Amakusa-Kamishima*

The Cretaceous Himenoura Group in Kamishima was thought by UEDA and FURUKAWA (1960) and UEDA (1962) to be of the Coniacian to Lower Campanian ages with a possibility of extending to Middle Campanian age on the basis of *Inoceramus*. Recent work of TASHIRO and NODA (1973) shows that *I. balticus toyajoanus* NAGAO and MATSUMOTO which has been taken as a representative species of the K5γ plus K6α stages occurs together with *I. japonicus* NAGAO and MATSUMOTO, the leading fossil of K5β stage, and it is, therefore, impossible to discuss the fine age based on the former species. The Middle Formation is, thus, undoubtedly assigned to K5β and the uppermost part of the Upper Formation from which *I. orientalis* SOKOLOW is obtained to K5γ stage. In any case, there is little probability of finding the Hetonaian (K6) in the available material.

The molluscan fauna of the Shiratake Formation, on the other hand, resembles that of the Fukuregi Formation in Shimoshima and can be regarded as Ypresian. The age of the unfossiliferous Akasaki Formation which underlies the Shiratake is, in consequence, strongly expected to range down to Paleocene. The unconformity beneath the Akasaki Formation might represent the time-gap of Hetonaian plus Paleocene (at least Lower Paleocene).

c. Uto and its vicinity

The Cretaceous strata in the Uto Peninsula which contain *I. japonicus* NAGAO and MATSUMOTO, *I. orientalis nagaoi* MATSUMOTO and UEDA, *Protexanites fukazawai* (YABE and SHIMIZU) and others (UEDA and FURUKAWA, 1960; TASHIRO and NODA, 1973), are probably referable to K5β to K5γ stages. Assuming that the Akasaki Formation is of the same age as the same formation in Kamishima, it is concluded that the uppermost part of the Upper Urakawan and Hetonaian and the Paleocene (at least its lower part) are lacking here.

In Iwa-jima the exposed part of the Cretaceous contains *I. orientalis nagaoi* MATSUMOTO and UEDA is K5γ, and the time-interval shown by the unconformity is not so different from that in Uto.

d. Shishi-jima

The Cretaceous formation which contains *I. amakusensis* NAGAO and MATSUMOTO, *I. japonicus* NAGAO and MATSUMOTO, *I. orientalis nagaoi* MATSUMOTO and UEDA and *I. balticus toyajoanus* NAGAO and MATSUMOTO are mainly K5β, although the whole sequence of the Himenoura Group in this island may range from K5α to K5γ as YAMAMOTO and HAYAMI (1971) concluded. The Akasaki rests on them.

e. Naga-shima

I. elegans pseudosulcatus NAGAO and MATSUMOTO and *I. balticus toyajoanus* NAGAO and MATSUMOTO are found in the upper part of the Cretaceous formation (TAKAI and MATSUMOTO, 1961). Their age is K5γ. The overlying bed is the Akasaki. The sediments equivalent to the Hetonaian (K6) and Paleocene (at least its lower part) are, therefore, lacking here.

f. Takashima

The Lower Tertiary fossil-bearing horizon is the so-called "Kōyaki Fossiliferous Bed" which contains *Colpospira okadai* (NAGAO) and others. The Urakawan (K5β) has been assigned by HINOKUMA (1962) on the basis of *I.* cf. *amakusensis* NAGAO and MATSUMOTO, but this fossil has not yet been paleontologically described and needs restudy (MATSUMOTO, personal communication). Therefore, the precise discussion on the geological age of the Mitsuse Formation cannot be given at present.

To sum up, the time-interval represented by the unconformity is presumed to be considerably long, the longest of which is shown by absence of at least the Hetonaian and the Paleocene (at least its lower part), although the magnitude of the interval changes from place to place to some extent.

Based on the paleontological data mentioned above, the correlation of the Upper Cretaceous and Paleogene formations in the studied areas is summarized in Table 1. As apparent from the table, the so-called Fukami Formation in Shimoshima which was defined by NAGAO (1926) as the equivalent of the Akasaki Formation in Kamishima, the lowest unit of Paleogene in Amakusa, includes the Creta-

Table 1. Stratigraphic correlation of the Cretaceous and Paleogene formations in Western Kyushu

Period	Epoch / Stage	Substage	Sakito	Takashima	Isahaya	Shimoshima	Kamishima	Shishi-jima	Uto	Ōmuta
Paleogene	Oligocene		Nishisonoki – Ichigojima	Iōjima	Hirakoba – Kirimiya					
Paleogene	Oligocene			Iōjima	Kirimiya	Sakasegawa	Sakasegawa			Yotsuyama
Paleogene	Eocene			Okinoshima	Saburaishi	Ittyōda	Ittyōda			Katsutachi
Paleogene	Eocene			Hashima	Keya	Toishi	Toishi			Nanaura
Paleogene	Eocene		Terashima	Futagojima	Enoura	Shikiyama	Kyōragi	Kyōragi	Kyōragi	Tōka
Paleogene	Eocene		Yobukonose	Kōyaki		Fukuregi	Shiratake	Shiratake	Shiratake	Komenoyama
Paleogene	Paleocene		Yobukonose	Kōyaki			Akasaki	Akasaki	Akasaki	Ginsui
Upper Cretaceous	Hetonaian	K6β				H				
Upper Cretaceous	Hetonaian	K6β				G				
Upper Cretaceous	Hetonaian	K6β				F				
Upper Cretaceous	Hetonaian	K6α		↑ ?		E				
Upper Cretaceous	Hetonaian	K6α		?		D				
Upper Cretaceous	Hetonaian	K6α		?		C				
Upper Cretaceous	Hetonaian	K6α		?		B				
Upper Cretaceous	Hetonaian	K6α		?		A				
Upper Cretaceous	Urakawan	K5γ		?			Himenoura G. Upper	Himenoura Group	Himenoura Group	
Upper Cretaceous	Urakawan	K5β		Mitsuse			Himenoura G. Middle	Himenoura Group		
Upper Cretaceous	Urakawan	K5α					Himenoura G. Lower			

ceous Member H of the present paper. The Akashimisaki Formation (HATAE, 1959) which was the equivalent of the Fukami Formation should be, consequently, divided into two parts, the lower non-fossiliferous and the upper fossil-bearing parts. The former is of Cretaceous and the latter of Paleogene in age.

The foregoing facts and discussions have made clear the Cretaceous-Tertiary boundary in various areas. The Cretaceous strata of Kamishima in the east are older than those of Shimoshima in the west.

C. Significance of the unconformity

In this chapter the differences of geological structure and sedimentary petrography above and below the unconformity are described.

1. Structural differences between the Cretaceous and Tertiary formations

a. Amakusa-Shimoshima

Since geological structures of the island have already been described in detail (MIKI, 1972a, 1972b, 1973; MIKI and UEMATSU, 1973; MIKI and TAKAHASHI, 1974), only their concise summary is given here.

The Cretaceous and Paleogene strata are modified by a large number of faults and foldings. On the basis of degree of disturbance of strata, as well as the stratigraphic analysis, two stages of tectonic movements can be recognized; one is that at the end of Cretaceous to beginning of Tertiary and the other is that of mid-Tertiary. In consequence of the former movement, the Cretaceous strata were considerably folded and faulted. Examples are some structures such as Tororo Semi-dome, Ozaki Anticline, Ōe Anticline, Asami Dome, Takahama Fault and a fault running through the Yōkaku Inlet as already reported (MIKI, 1972a; MIKI and UEMATSU, 1973). The latter movement, on the other hand, is represented by the so-called "Amakusa Type structure" (MATSUSHITA, 1951) by which the Paleogene strata were deformed. It is easily presumed that the Cretaceous structures were further complicated by this movement. Shikiyama Anticline, Ittyōda Syncline, Hondo Syncline, Jikiba Dome and many faults of NW-SE and NNE-SSW directions are fine examples of the latter movement. In the eastern part of the island, structures have not yet been studied in detail, and the differences in structure above and below the unconformity is not confirmed so obviously as in other areas. For example, the Paleogene strata running in NWW-SEE trend in the east and NEE-SWW in the west are controlled by a movement to which the Miyanogawachi Anticlinal structure might be attributed, although the Cretaceous beds run in consistent direction of NNE-SSW. The Miyanogawachi Anticline was probably caused by the same movement which formed the Ittyōda Syncline mentioned above.

b. Amakusa-Kamishima

An angularly unconformable relationship between the Cretaceous and Paleogene formations can be recognized not only on exposure but also on the geological map.

The general attitudes of the Cretaceous and Paleogene beds are of N20° E strike, NW30° ±5° dip. Only difference between them is that the inclination of the latter is slightly smaller than that of the former. All the axes of folding in which the Cretaceous and Paleogene beds take part run in a direction of NNE-

SSW. Fine examples are the one which runs from the east of Matsushima to Ryūga-dake through the Paleogene area, and another which runs in parallel to the west of the former. There are two groups in the fault system in this island, one is that of NNE-SSW direction and the other is that of NW-SE direction, which intersects the former.

It is considerably difficult to distinguish the structures formed at the end of Cretaceous or the beginning of Tertiary from those formed after Paleogene and also to know the detailed characteristics of the structural movement occurred in this Cretaceous-Tertiary time-interval. However, taking account of the field evidence that the Upper Formation of the Cretaceous is intersected by the Akasaki Formation, a structural movement of this time-interval cannot be denied although it was not so strong as that in Shimoshima.

c. Uto and its vicinity

In the Uto Peninsula the trend of Paleogene strata changes gradually from NNE-SSW in the south to NW-SE in the northern coastal area. They incline towards NW or SW. Therefore, a semi-basin structure plunging to SWW is inferable. The Cretaceous beds are obliquely in contact with the Paleogene. Structural differences are, in consequence, perceptible between the two groups.

A fault of N-S trend is presumed to exist between the andesitic rocks near Misumi-dake and the Shiratake Formation in the west, which in turn is covered with the Kyōragi Formation.

In Iwa-jima, Shishi-jima and Naga-shima, the Paleogene strata obliquely cut the Cretaceous ones, but the details are uncertain because of too narrow exposure of the beds.

d. Takashima

The Upper Cretaceous and the Paleogene strata in Takashima are not suitable for the investigations of geological structures because they are narrowly distributed and their contact or plane of unconformity is nowhere observable. But structural difference can be presumed between the Cretaceous strata which forms an overturned structure in Ogakura, south of Nagasaki, and the Paleogene beds which do not show such remarkable structures, and, in consequence, a remarkable movement may be infered at the end of Cretaceous or beginning of Tertiary.

2. Petrography of sandstone

A purpose of this article is to examine how the compositions of sediments

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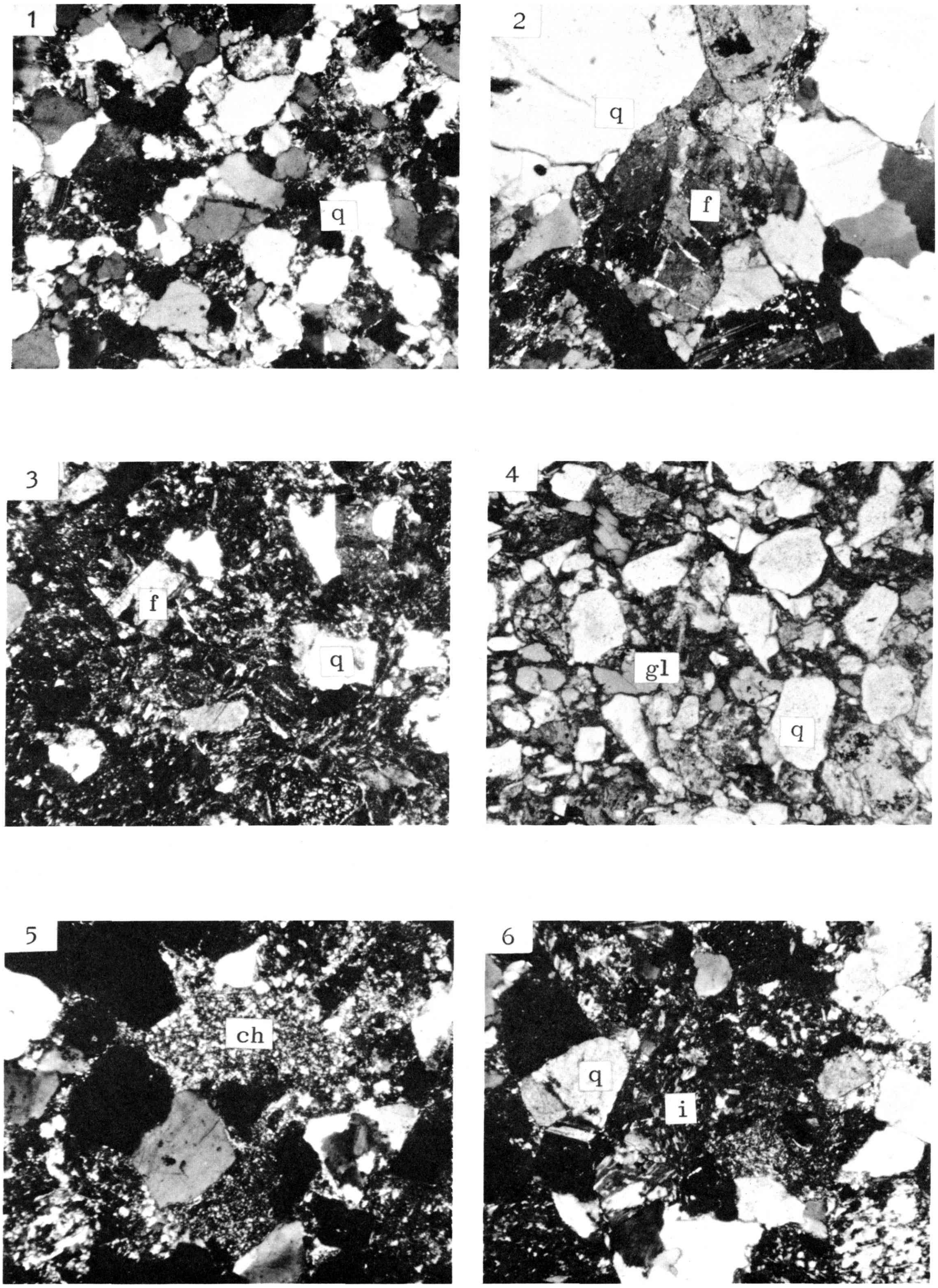
Explanation of Plate 28

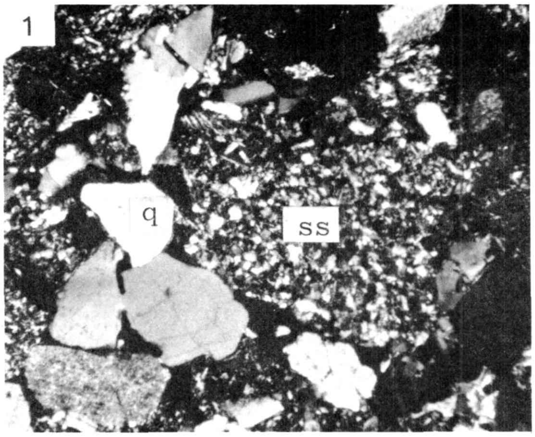
Micrographs of sandstone from the western part of Amakusa-Shimoshima (All figures ×50)

Fig. 1. Toishi Formation. +nicol
Fig. 2. Fukuregi Formation. +nicol
Fig. 3. Member H. +nicol
Fig. 4. Ittyōda Formation. //nicol
Fig. 5. Member F. +nicol
Fig. 6. Member D. +nicol

q: quartz, f: feldspar, gl: glauconite, ch: chert fragment, f: fragment of igneous rocks



T. Miki: Formation of Paleogene Sedimentary Basins in Amakusa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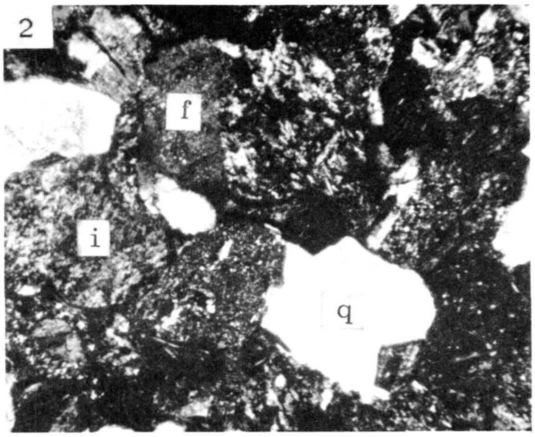
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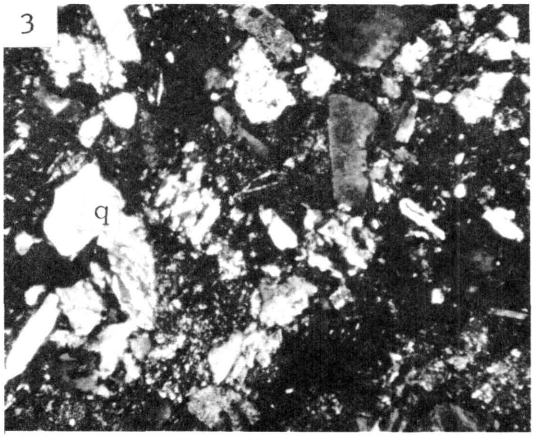
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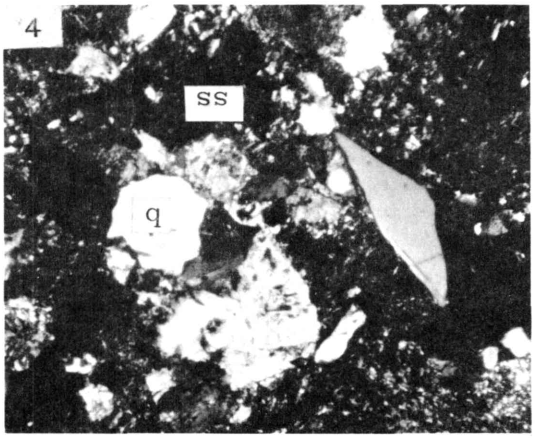
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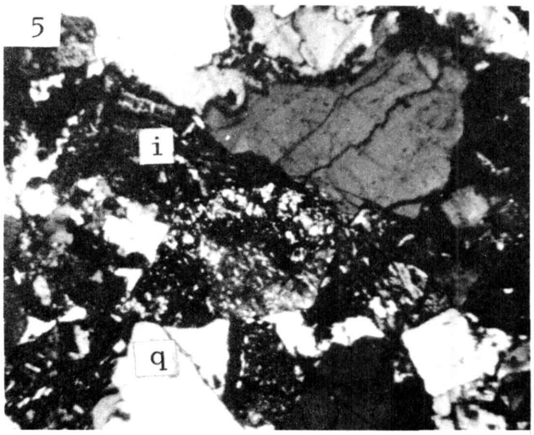
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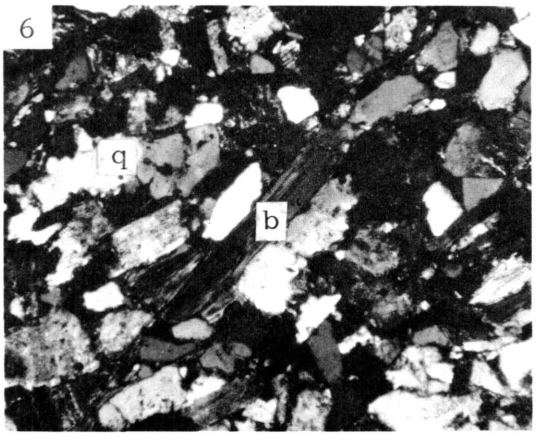
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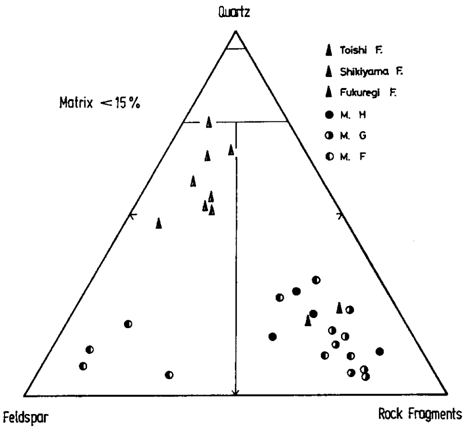

Fig. 16. Compositional diagram of sandstone from the eastern part of Amakusa-Shimoshima.

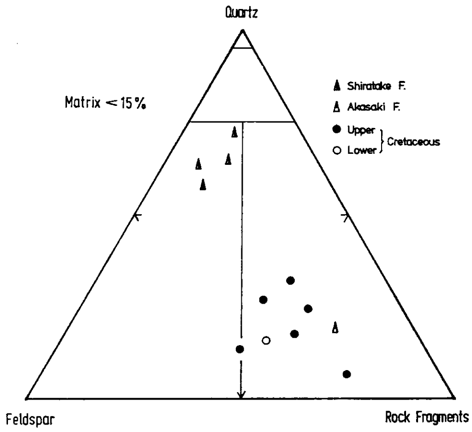

Fig. 17. Compositional diagram of sandstone from Amakusa-Kamishima.

differ above and below the unconformity. Petrographic data of sandstone from this region would be also useful to consider the paleogeography and paleoenvironment (see Chapter IV).

Explanatory descriptions of the analysed data are omitted but shown in a series of figures, with short annotations.

a. Modal compositions

180 thin sections have been prepared for the microscopic examination. About a half of them which were collected from the western and southern parts of Shimoshima and in the Hondo area (drilling cores) have already been described (MIKI, 1972a, 1973; MIKI and UEMATSU, 1973). The percentage compositions of the modal analyses were plotted in the triangular diagrams according to OKADA (1968a, 1968b)'s representation, in which quartz, feldspar and rock fragments (including chert) are taken as the end members.

a) Eastern part of Amakusa-Shimoshima: Total 30 samples are classified into three groups on the triangular diagram; one of the Paleogene and two of the Cretaceous. Samples from Member F, G and H occupy the two fields. Two samples from the Fukuregi Formation are plotted in the same field as the Cretaceous.

Explanation of Plate 29

Micrographs of sandstone from the various areas in Western Kyushu
(All figures ×50, +nicol)

Fig. 1. Fukuregi Formation in the eastern part of Shimoshima.
Fig. 2. Member G in the eastern part of Shimoshima.
Fig. 3. Himenoura Group in Shishi-jima.
Fig. 4. Hashima Formation in Takashima.
Fig. 5. Mitsuse Formation in Takashima.
Fig. 6. Minamise Formation in Minamise.

q: quartz, f: feldspar, b: biotite, ss: sandstone fragment, i: fragment of igneous rocks

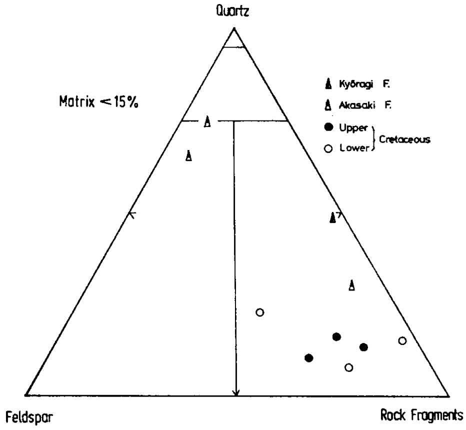

Fig. 18. Compositional diagram of sandstone from Uto Peninsula and its vicinity.

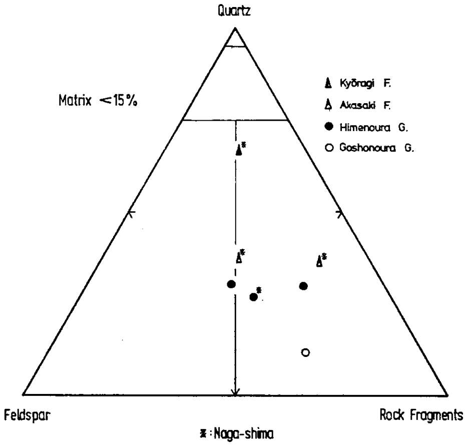

Fig. 19. Compositional diagram of sandstone from Shishi-jima and Naga-shima.

b) Amakusa-Kamishima: A sample of the Akasaki Formation is plotted in the Cretaceous area containing a great amount of rock fragments, but strictly inspected, the Akasaki having a large quantity of chert* fragments is different from the Cretaceous containing a large amount of igneous rocks.

c) Uto and its vicinity: The Paleogene samples are discriminated from the Cretaceous ones in the quantity of quartz and rock fragments, but are rather markedly scattered on the diagram.

d) Shishi-jima and Naga-shima: In spite of an insufficient number of samples, the modal compositions of sandstone in Shishi-jima and Naga-shima show an interesting fact. The samples from the Akasaki Formation show more intimate composition with samples of Cretaceous formations rather than with those of the Kyōragi Formation.

* A term "chert" is used as a general name of the siliceous rocks in this paper.

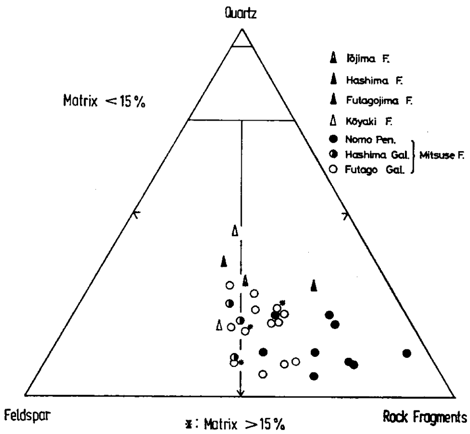

Fig. 20. Compositional diagram of sandstone from the Takashima area.

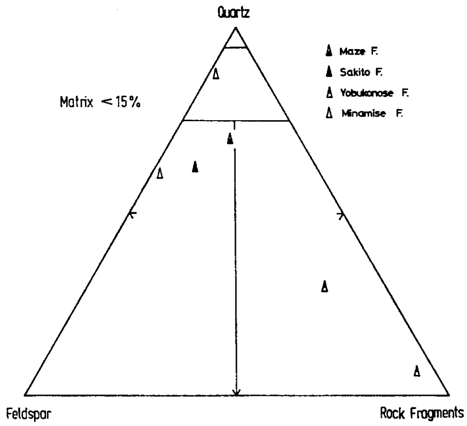

Fig. 21. Compositional diagram of sandstone from the Seto-Minamise area.

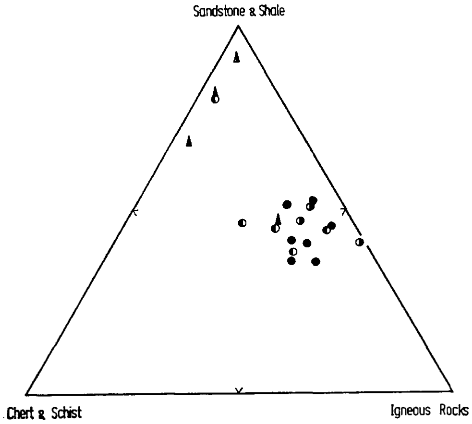

Fig. 22. Compositional diagram of rock fragments in sandstone from the southern part of Amakusa-Shimoshima. Legends are common with those in Fig. 16.

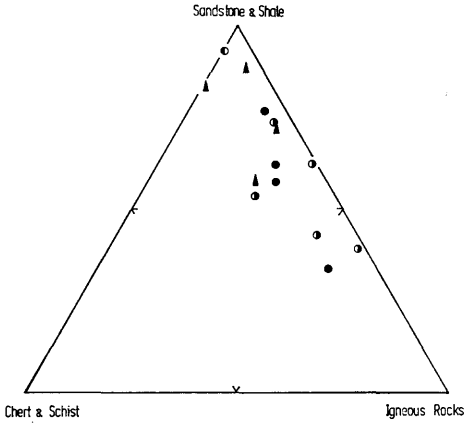

Fig. 23. Compositional diagram of rock fragments in sandstone from the eastern part of Amakusa-Shimoshima. Legends are cmmon with those in Fig. 16.

e) Takashima: Samples with matrix of more than 15 percent are rarely present in purple colored rocks. The samples collected in the Nomo Peninsula are generally more or less different in the quantity of rock fragments from those in galleries. The modal compositions of these Cretaceous sandstone do not differ remarkably from those in Amakusa. The Paleogene samples, on the other hand, contain quite similar composition as the Cretaceous ones.

f) Seto-Minamise: Samples from the Minamise Formation contain a high quantity of quartz and a low quantity of rock fragments, showing a striking contrast to those from the Yobukonose Formation, which have a large amount of rock fragments.

The light mineral assemblages of the Sakito and Maze Formations resemble

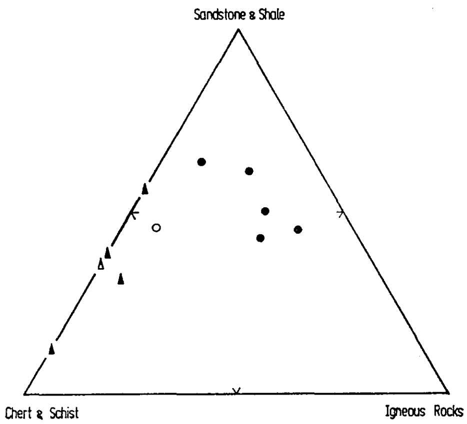

Fig. 24. Compositional diagram of rock fragments in sandstone from Amakusa-Kamishima. Legends are common with those in Fig. 17.

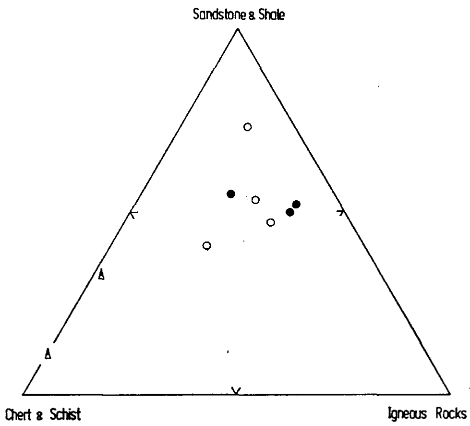

Fig. 25. Compositional diagram of rock fragments in sandstone from Uto Peninsula and its vicinity. Legends are common with those in Fig. 18.

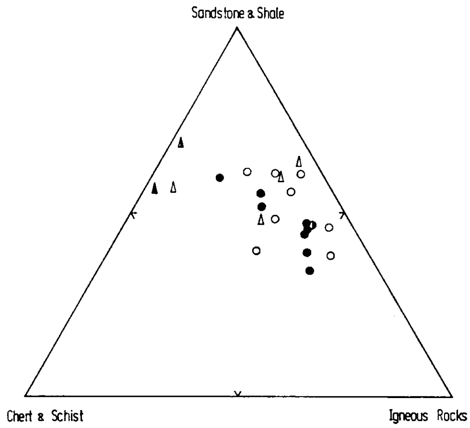

Fig. 26. Compositional diagram of rock fragments in sandstone from the Takashima area. Legends are common with those in Fig. 20.

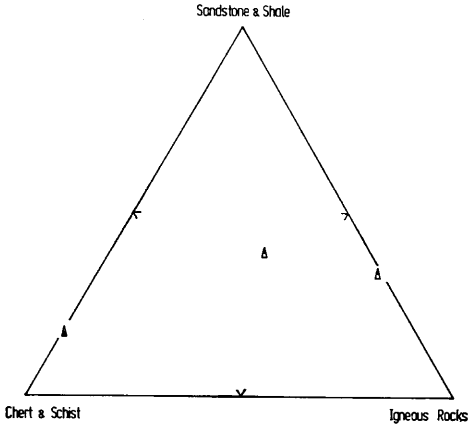

Fig. 27. Compositional diagram of rock fragments in sandstone from the Seto-Minamise area. Legends are common with those in Fig. 21.

those of the Paleogene sandstone of other areas.

b. Analysis of rock fragments

The sandstone in the studied area contain a considerable amount of rock fragments. They are mainly those of sandstone, shale, chert, acidic to intermediate volcanic and/or hypabyssal rocks, and subordinately those of schist. The quantitatively analysed data are plotted in the diagrams, in which sandstone (plus shale), chert (plus schist) and igneous rocks are selected as the end members. The results on the samples from the western part of Shimoshima have already been discussed (MIKI, 1972a).

a) Southern part of Amakusa-Shimoshima: The Paleogene and Cretaceous samples are generally discriminated on the diagram.

b) Eastern part of Amakusa-Shimoshima: The analysed data are scattered rather widely on the diagram. Such a compositional variation shows a peculiarity of the area as indicated by the modal composition of sandstone.

c) Amakusa-Kamishima: The values of the Cretaceous samples roughly occupy the central part of the diagram. A large amount of chert attaining to 87 percent in maximum characterizes the Paleogene in the area.

d) Uto and its vicinity: The general tendency similar to that of Kamishima

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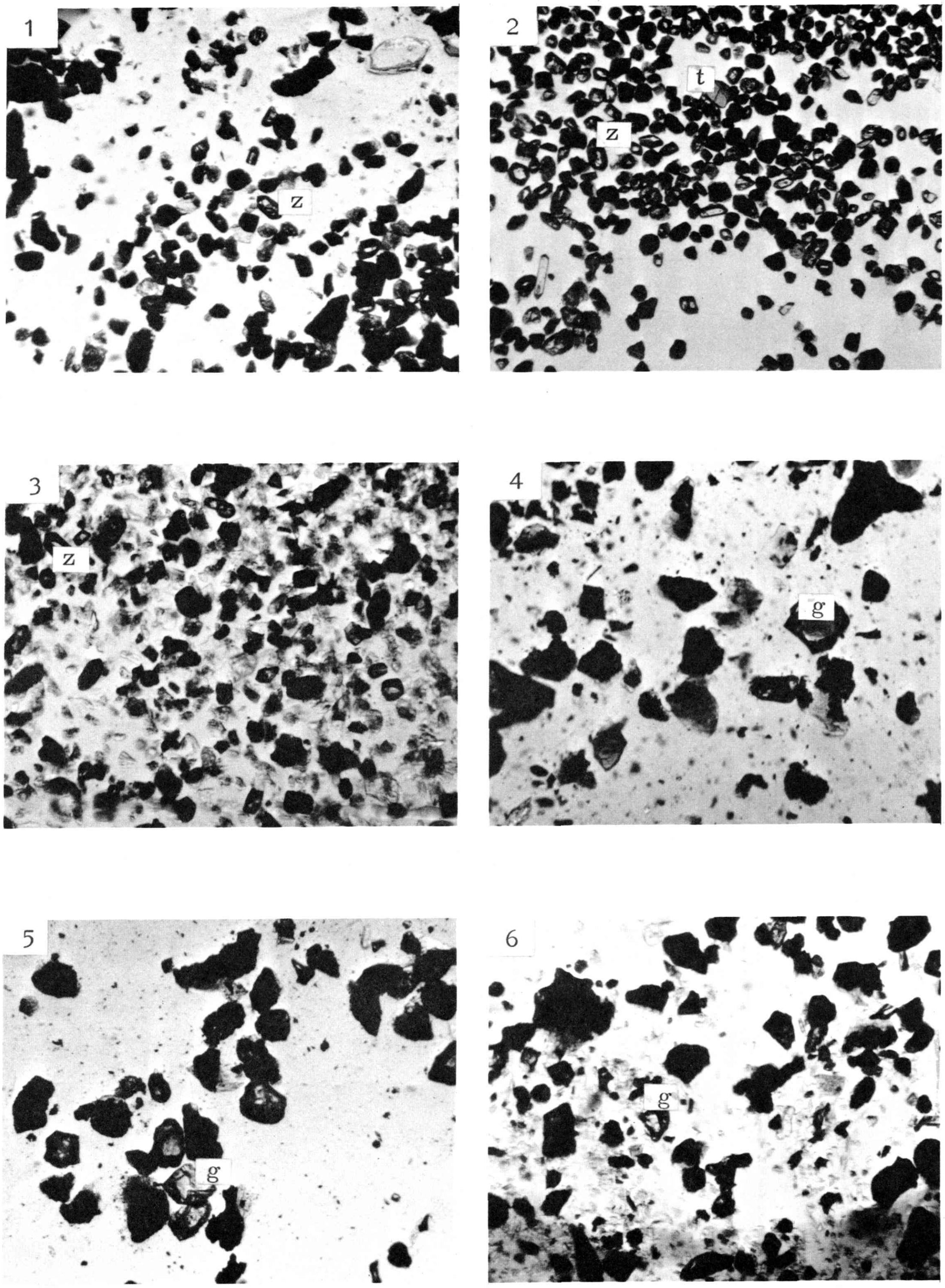
Explanation of Plate 30

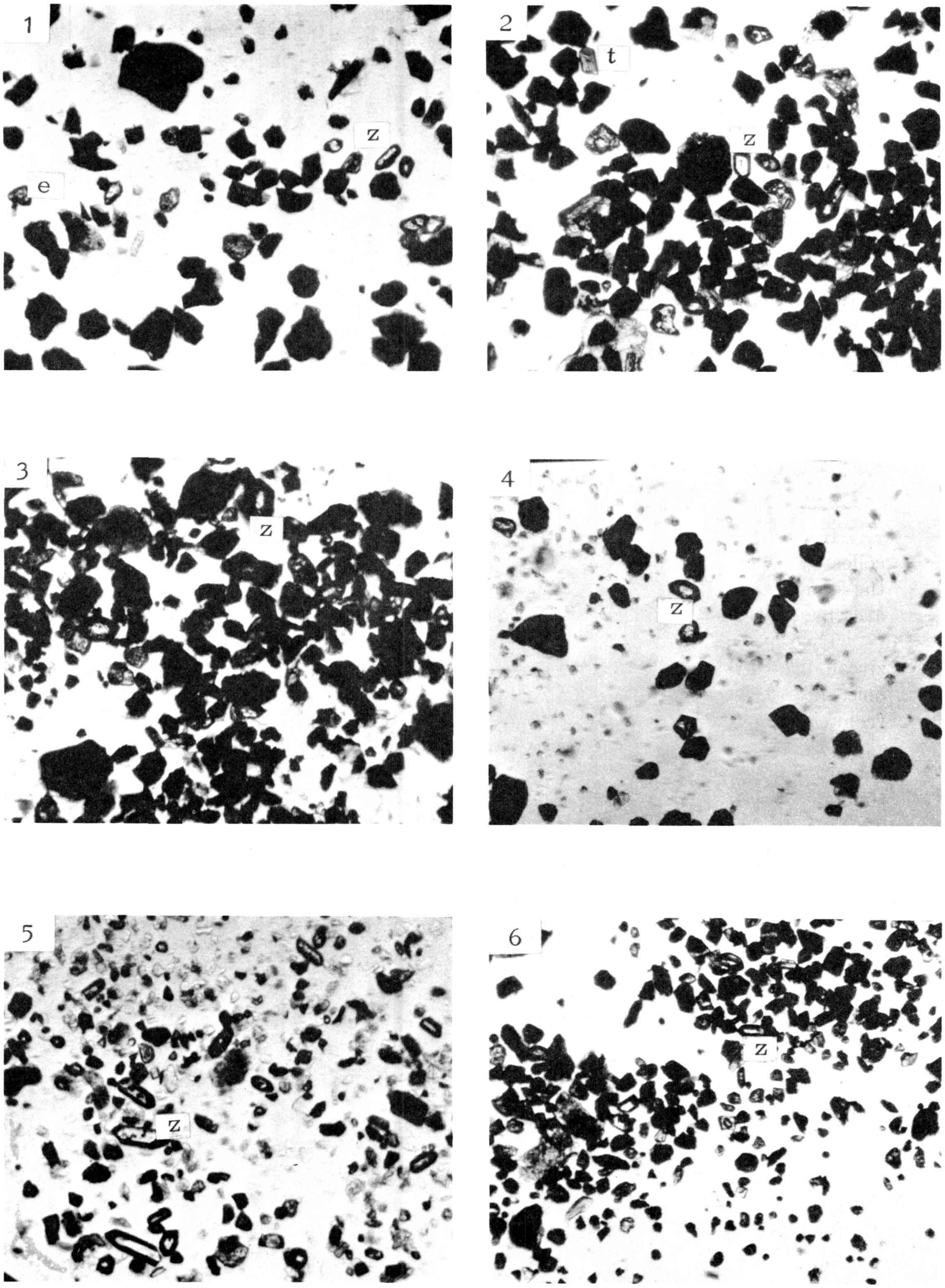
Heavy minerals in sandstone from Amakusa-Shimoshima
(All figures ×38, // nicol)

Fig. 1. Shikiyama Formation.
Fig. 2. Member G.
Fig. 3. Member H.
Fig. 4. Member G.
Fig. 5. Fukuregi Formation.
Fig. 6. Member F.

z: zircon, t: tourmaline, g: garnet



T. MIKI: Formation of Paleogene Sedimentary Basins in Amakusa



T. Miki: Formation of Paleogene Sedimentary Basins in Amakusa

is also recognized here. The two Paleogene samples are of the Akasaki Formation and are characterized by the abundance of chert fragments as in Kamishima.

e) Takashima: Aside from a few exceptions, most of the total 23 samples of sandstone are plotted in two areas in accordance to their ages as clearly shown in the figure. The values of the samples of the Futagojima and Hashima Formations are not much different from those of the Paleogene samples in the western part of Shimoshima. An overlapped distribution of three points of the Kōyaki Formation with the Cretaceous area reflects the macroscopic resemblance of the formation to the Cretaceous Mitsuse Formation.

f) Seto-Minamise: The samples from the Yobukonose Formation contain a large quantity of igneous rocks, particularly acid to intermediate rocks, whereas those from the Maze Formation contain a large amount of metamorphic rocks.

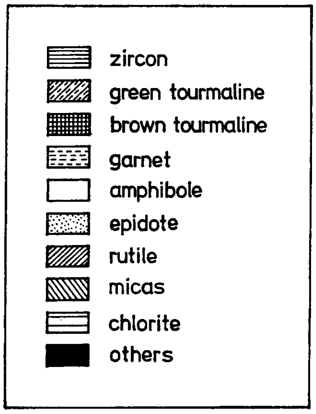


Fig. 28. Legends for heavy mineral compositions.

c. *Heavy mineral associations*

Heavy mineral analysis was performed using about 180 samples of sandstones collected from the exposures in respective areas. Analytical method and results of the samples from the western and southern parts of Shimoshima and the Hondo area have already been given (MIKI, 1972a, 1973; MIKI and UEMATSU, 1973).

The following non-opaque minerals were identified in the samples studied; zircon, brown and green tourmaline, garnet, epidote, rutile, micas, chlorite, amphibole and other minute amount of accessary minerals. Iron oxides were excluded from counting. The minerals are depicted in the graph in percentage.

a) Eastern part of Amakusa-Shimoshima: The Cretaceous minerals characterized by abundance of garnet and epidote are generally discriminated from the Paleogene ones which contain a large amount of zircon. Two Paleogene samples which have exceptional modal compositions as described above show also the peculiar heavy mineral assemblage like that of the Cretaceous samples.

b) Amakusa-Kamishima: Three types of heavy mineral assemblage are distinguished in the samples from Kamishima, here named the types A, B and C for convenience sake. They correspond roughly to the main part of the Himenoura Group, the Akasaki Formation and the Shiratake plus Kyōragi Formation, respec-

Explanation of Plate 31

Heavy minerals in sandstone from various areas in Western Kyushu
(All figures ×38, // nicol)

Fig. 1. Himenoura Group in Kamishima.
Fig. 2. Himenoura Group in Uto.
Fig. 3. Himenoura Group in Naga-shima.
Fig. 4. Akasaki Formation in Naga-shima.
Fig. 5. Hashima Formation in Takashima.
Fig. 6. Mitsuse Formation in Takashima.

z: zircon, t: tourmaline, e: epidote

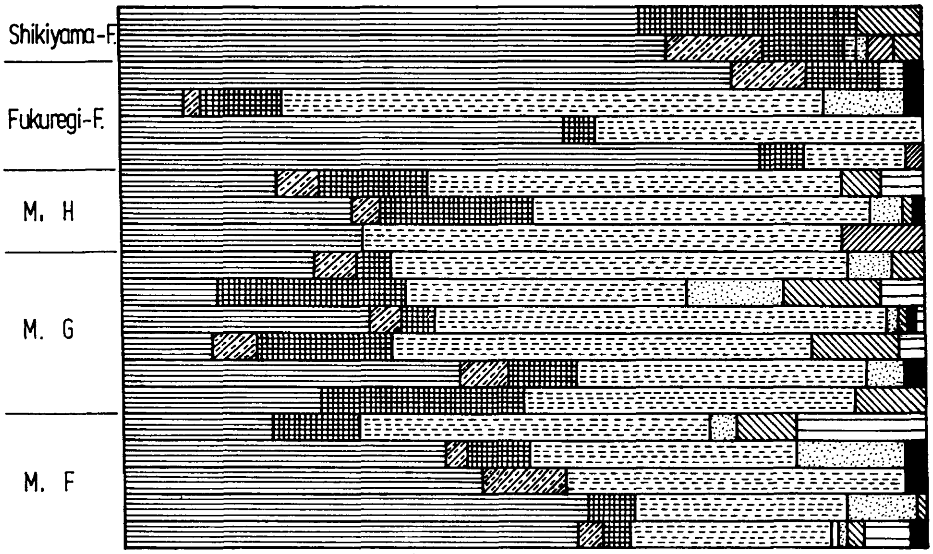


Fig. 29. Heavy mineral compositions of the Cretaceous and Paleogene sandstone from the eastern part of Amakusa-Shimoshima.

tively. The type A is characterized by abundance of garnet with a considerable amount of zircon and tourmaline, and the type C by prominence of zircon and brown tourmaline and inferiority of garnet. The type B has an abnormal characteristic in extreme abundance of epidote*, which reaches 97 percent in maximum

* This characteristic mineral was identified under polarizing microscope and X-ray analysis.

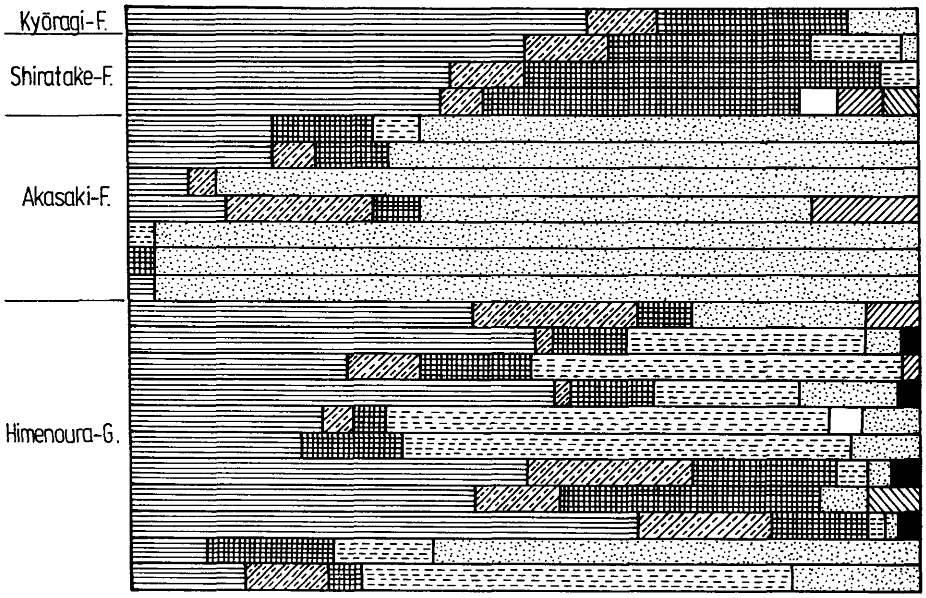
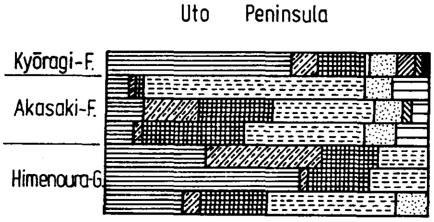


Fig. 30. Heavy mineral compositions of the Cretaceous and Paleogene sandstone from Amakusa-Kamishima.



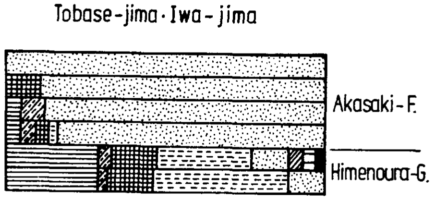
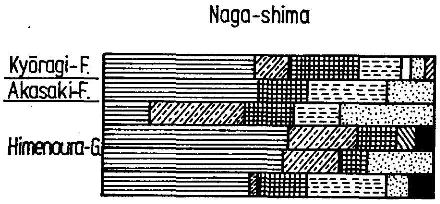


Fig. 31. Heavy mineral compositions of the Cretaceous and Paleogene sandstone from Uto Peninsula and its vicinity.



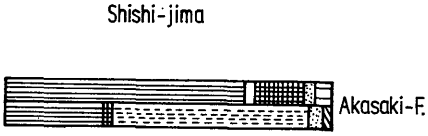


Fig. 32. Heavy mineral compositions of the Cretaceous and Paleogene sandstone from Naga-shima and Shishi-jima.

and inrarity of normally common minerals such as zircon, tourmaline and garnet.

c) Uto and its vicinity: The exposed part of the Himenoura Group in Tobase-jima and Iwa-jima has a similar heavy mineral composition to that in Uto, containing zircon, tourmaline and garnet. The Akasaki Formation shows a remarkable difference between the two areas; namely epidote is extremely predominant in the former islets, whereas garnet is common in the latter area.

d) Shishi-jima and Naga-shima: In the heavy mineral association there

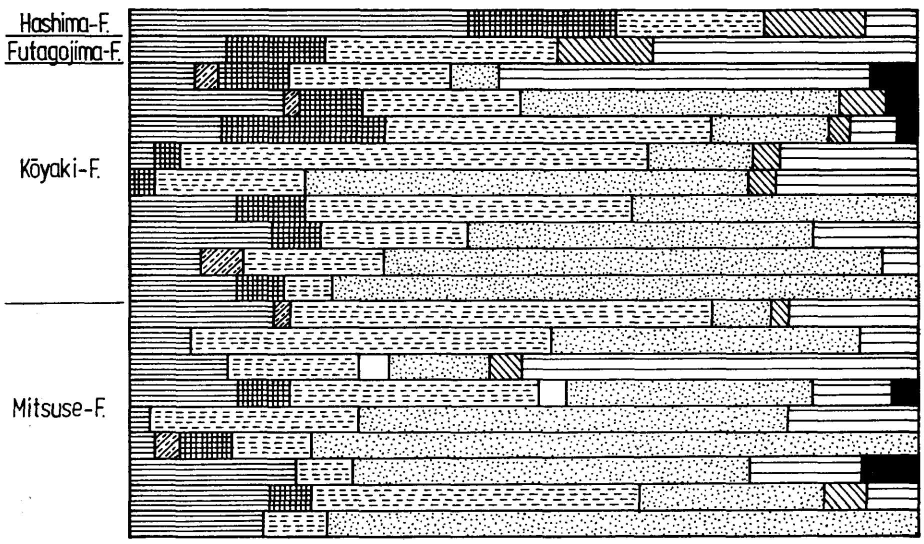


Fig. 33. Heavy mineral compositions of the Cretaceous and Paleogene sandstone from the Takashima area.

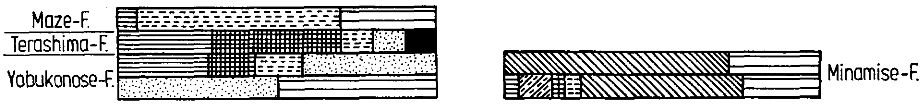


Fig. 34. Heavy mineral compositions of the Tertiary sandstone from the Seto-Minamise area.

seems to be no difference between the Paleogene and the Cretaceous, but because of insufficient number of samples, no detailed discussions can be given.

e) Takashima: 20 samples for analysis were collected chiefly from the subsurface galleries. The most striking property is that the B type composition established in Kamishima is recognized throughout the samples below the Kōyaki Formation. The frequency of epidote reaches 75 percent in maximum. The assemblages of the Futagojima and Hashima Formations can be easily discriminated from those of the above-mentioned formations in inferiority of epidote.

f) Seto-Minamise: Epidote appears with high frequency in the Yobukonose Formation, and its amount reduces upwards. The heavy mineral composition of the samples from the Minamise Formation which is characterized by abundance of biotite is markedly different from that of the samples from the above-mentioned formations.

As apparently known from the above descriptions and figures, the petrographic characters of sandstone are clearly different above and below the unconformity in most areas, although in some local places there is no great difference of petrographic characters across the boundary. Judging from the above described kinds of rock fragments, heavy minerals and pebbles of conglomerate, main source rocks for the Cretaceous deposits are regarded as igneous rocks and clastic rocks such as sandstone and shale in Amakusa and as metamorphic rocks in Takashima. The facts that the Akasaki Formation is characterized by extreme abundance of epidote in heavy mineral assemblage and predominant pebbles of schist which contains epidote as a metamorphic mineral in it show that the source rock for the formation was chiefly epidote-bearing schist. The Paleogene formations above the Fukuregi and its equivalents show a nearly constant composition which is characterized by stable light and heavy minerals. In other words the Paleogene sandstones are characterized by prominence of quartz and zircon. This is internationally recognized in Tertiary sediments in the circum-China Sea region (OHARA, 1962). The writer is inclined to consider that the Cretaceous-Tertiary unconformity marks the change of sedimentary environments including not only that of source rocks but also that of physiographic conditions from the Himenoura stage to the post-Shiratake stage of extensively stable environments by way of the abnormal condition of the Akasaki stage.

D. A summary of the relationship between the Upper Cretaceous and Paleogene formations

As described in the foregoing pages, the Upper Cretaceous-Tertiary boundary has been set up chiefly from field evidence in a number of areas. The unconformity separating the Cretaceous and Tertiary formations is recognized beneath the Fukuregi Formation in Shimoshima and the Akasaki Formation and its equivalent in

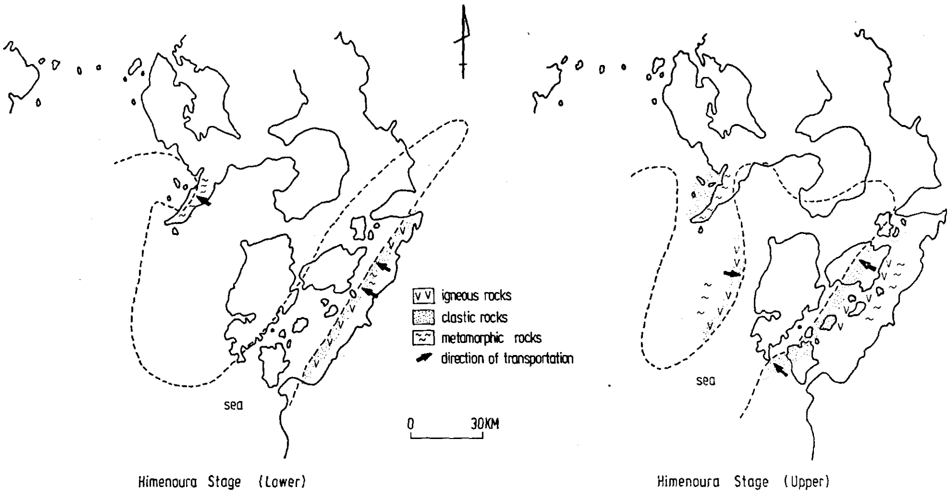


Fig. 35. Paleogeographical map of Western Kyushu in Himenoura stage.

Kamishima, Uto and its vicinity, Shishi-jima, Naga-shima and Takashima. The time-interval involved in the unconformity generally tends to become larger eastward and locally changes to some extent from place to place. In conclusion, the unconformity reflects a remarkable structural movement which occurred in an age of post-Member H and pre-Akasaki Formation. The magnitude of the movement was large in the west and small in the east and, as a whole, larger than what was previously reported. Furthermore, from petrographic study of sandstone samples, it can be generally concluded that the environments in and around the sedimentary basins remarkably changed from the Late Cretaceous to the Paleogene, especially in the time-interval shown by the unconformity but for a local exception.

IV. Geological History during Upper Cretaceous and Paleogene in Amakusa and its Adjacent Areas

In this chapter the writer attempts to outline the geological history at ten stages ranging from the Upper Cretaceous to the Tertiary chiefly in Amakusa on the basis of the above-described data.

a. Himenoura Stage

In the Urakawan (K5, approximately Lower Senonian), Western Kyushu was invaded by a marine transgression that was a part of an extensive Urakawa transgression (MATSUMOTO, 1941). The sea area extended from the southwest towards the northeast obliquely across the distribution area of the crystalline basement rocks. By this marine invasion and subsidence of the basin the Cretaceous thick sequences were formed. The correlation of the Cretaceous formations already described supports the opinion that the invaded sea water retreated towards the southwest. This may imply that the center of the basin gradually shifted westward with a lapse of time.

In the Early Senonian (K5) age, the uplift of source area is presumed to have been in the east of the Uto-Kamishima area, as UEDA and FURUKAWA (1960) reported, for the western part show a more off-shore litho- and bio-facies than the eastern part. The uplifted terrain may be composed of older clastic rocks and acidic igneous rocks judging from the petrographic characters of sandstone. The land presumed to exist near Takashima, on the other hand, must have been composed of predominant schists and igneous rocks.

In the Late Senonian (K6) age, the axis of the sedimentary basin seems to have shifted westward. The facts that the cross-beddings show a leading direction of the paleocurrent from west to east and that the epidote-content increases in the west suggest that there were mountains which were composed mainly of epidote-bearing schists and igneous rocks on the westside of Shimoshima. Besides the main detritus transport from the west, subordinate supply from the east is recorded in the southern and eastern parts of the island, as shown by local variation in mineral composition of sandstone.

b. End of Cretaceous or beginning of Tertiary

At the end of the Cretaceous Period, the area was subject to a remarkable tectonic movement. The structures formed by the movement at this stage are classified into two groups from their major trend; one has a direction of NW-SE or NNW-SSE of the so-called Korean direction and the other shows a direction of NNE-SSW of the so-called Ryūkyū direction, although the order of construction is questionable.

The structures belonging to the former in Amakusa are Takahama Fault, Ozaki Anticline and a fault running through the Yōkaku Inlet, and those to the latter are the fault presumed between Kamishima and Shimoshima, Ōe Anticline, Tororo Semi-dome and Asami Dome. Most of these structures in Amakusa are presumed to be of pre-Tertiary construction judging from the difference in magnitude of dislocation of beds between the Cretaceous and Paleogene. The eastern part of Kamishima subsided at first in Early Tertiary age, where the Akasaki Formation was deposited. The Shiratake and Kyōragi Formations are remarkably thicker in Kamishima than in Shimoshima as described above. The Kyōragi Formation shows a number of probably syngenetic disturbed structures. These affairs suggest that a fault between Kamishima and Shimoshima, which was originated immediately after the Cretaceous sedimentation, became reactive during the Eocene sedimentation.

The poorly sorted conglomerate with angularly shaped pebbles at the base of the Tertiary indicates transportation of short distance and the remarkable variation of thickness and litho-facies of the formation from place to place suggest that the Early Paleogene basin in Amakusa in which the Akasaki Formation was formed is a kind of graben formed by the above-mentioned tectonic movement at the end of the Cretaceous or the beginning of Tertiary. Geochemical data that these purple sediments may have been formed in a small-scale depression near the source area (MIKI and MATSUEDA, 1974) support this opinion.

The same kind of faults as in the Amakusa area which were probably formed before the deposition of the Paleogene are recognized also in other areas. NAGAHAMA (1962) clarified that the Yobukonoseto Fault along with the mylonitization of granite was formed in the pre-Tertiary age, based on the lithological differences of the Paleogene sediments on both sides of the fault, although the fault was activated again later.

As described above, the faults presumed to have been formed at the end of

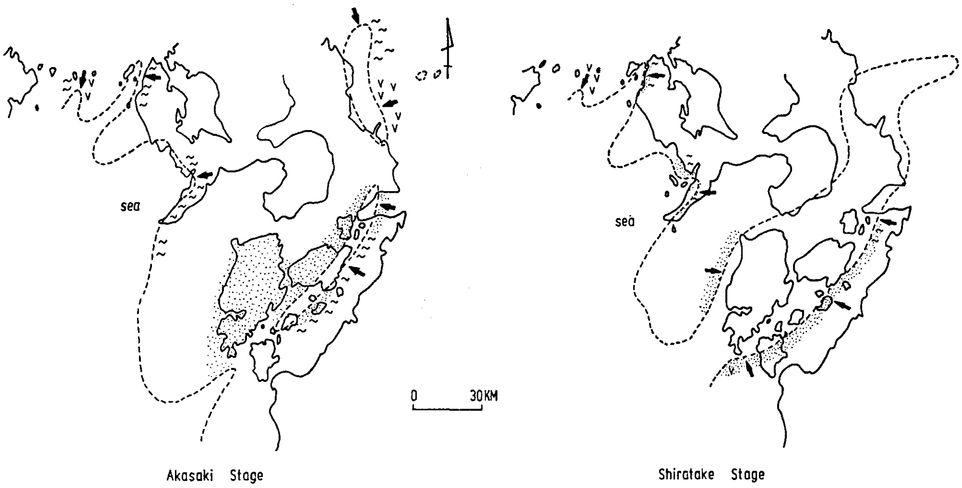


Fig. 36. Paleogeographical map of Western Kyushu in Akasaki-Shiratake stage.

Cretaceous or beginning of Tertiary are recognized not only in Amakusa but also in other areas in Western Kyushu. And judging from the situation that the Early Tertiary basin in Amakusa was initiated as a tectonic graben as described above, other basins in Western Kyushu may possibly have had a similar tectonic framework.

c. Akasaki Stage

At the beginning of the Tertiary, a depression of the Akasaki basin was formed as shown in the paleogeographical map as a result of local differential subsidence of lands caused by the above described faulting. Judging from a narrow distribution of outcrops, a fanglomeratic appearances of the basal conglomerate, a remarkable lateral change of litho-facies, and high quantities of hematite and limonite in spite of absence of siderite and pyrite, the depression is conjectured as of river flood plain (BERNER, 1971) showing the earliest stage in the cycle of sedimentation (MIKI and MATSUEDA, 1974). As mentioned above, crystalline schists, particularly hematite- and epidote-bearing green schist, are contained in a large amount as cobbles and boulders in conglomerate, and epidote displays a high frequency in heavy mineral composition. These facts suggest the characteristic source rocks of metamorphics probably derived from Kiyama or Manotani metamorphic mountains in the east which were under erosion in this stage.

It is well known that the Tertiary basin in the Ōmuta area was surrounded by the basement rocks except in the south where the sea water invaded and that the clastics in the early stage were derived from metamorphics and granites (KIKUCHI, 1963; OHARA, 1961).

The source materials in the Takashima area were not changed in this stage.

Judging from an isolated outcrops and such litho-facies as indicating transportation of short distance, the basins in the Hokonokō and the Yamaga areas were not connected with that of Ōmuta.

d. Shiratake Stage

A large-scale marine invasion named *Nummulites* transgression progressed

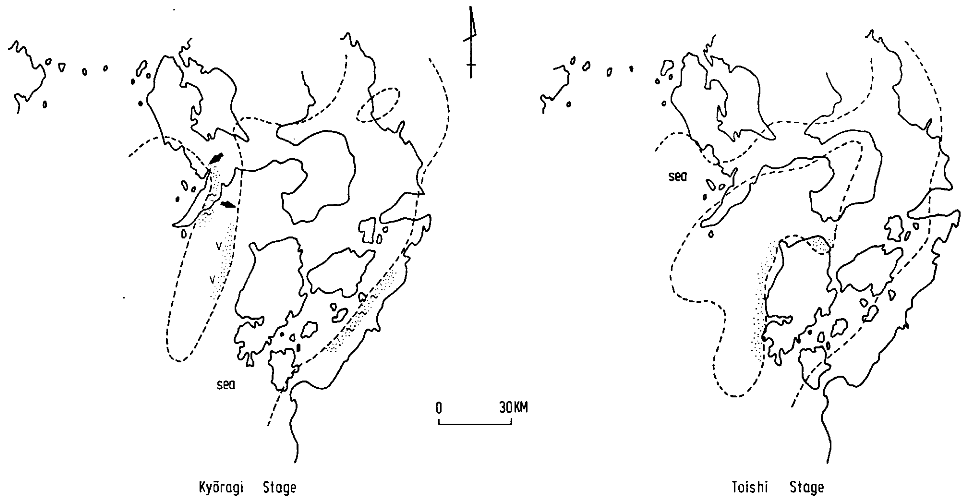


Fig. 37. Paleogeographical map of Western Kyushu in Kyōragi-Toishi stage.

from the southwest. Species of *Nummulites* are also known in Ryūkyū Island (HANZAWA, 1935) and in some sea bottoms in the north Philippine Sea (SHIKI, 1975) as well as in the Bonin Island (HANZAWA, 1947), and, in consequence, the Eocene transgression is a large-scale one invaded a large area in East Asia. In the area of Amakusa, depressions where the Akasaki was deposited became a lowland that include swampy environment where coal or coaly shale were probably formed. This was followed soon by the shallow sea condition. The Komenoyama Formation in Ōmuta contains siderite that indicates fresh water swamps (BERNER, 1971). A widespread occurrence of the "Lower *Orthaulax japonicus* Zone" in the investigated areas implies that the most of the areas were under shallow sea waters. The main source rocks of the sediments in this stage were on the western side of Shimoshima and Takashima, and on the east side of Uto and Kamishima. They were, respectively, sandstone with subordinate chert in the west and chert in the east.

e. Kyōragi Stage

The marine water widely spreaded over the area, and neritic sediments were deposited. The Kyōragi Formation in Kamishima is not so different from its equivalent in Shimoshima in fossil assemblages not only of mega-fossils such as *Venericardia, Crassatella, Lima, Pholadomya,* and *Solen* but also of smaller foraminifera (FUKUTA, 1962; ASANO and MURATA, 1957). This affair indicates that the bathymetrical condition of that formation was not so different between two areas in spite of remarkable variation in thickness. The writer considers that the thickness variation of the formation in two islands was caused by differential subsidence of basins. No other evidence is available to explain the phenomena. A change of the paleocurrent direction from east to west in Shiratake stage to that from west to east in this stage (NAGAHAMA, 1970) may support this interpretation.

f. Toishi Stage

After the retreat of marine water from the Kyōragi basin, coal was deposited

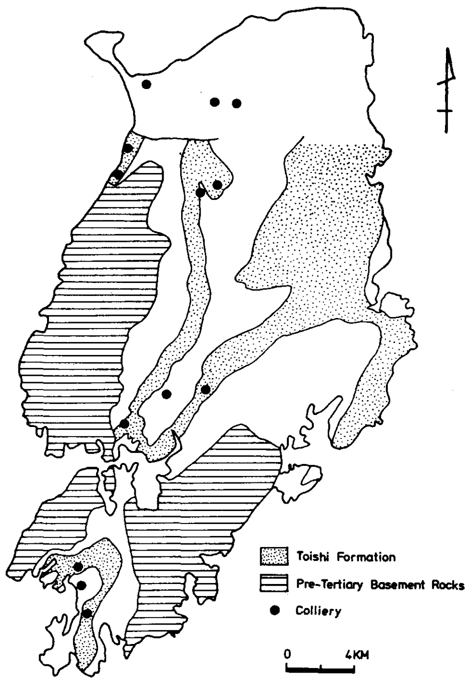


Fig. 38. A map showing the distributions of the Toishi Formation, basement rocks and collieries in Amakusa-Shimoshima.

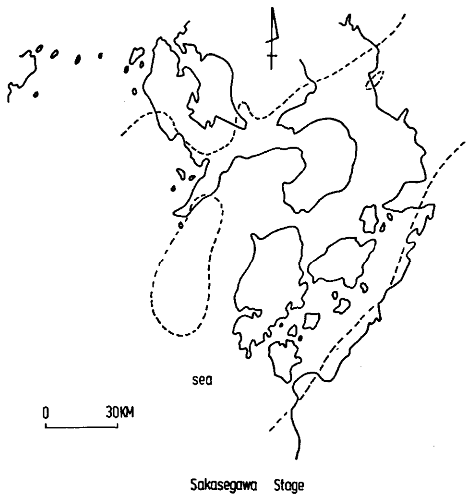


Fig. 39. Paleogeographical map of Western Kyushu in Sakasegawa stage.

in Ōmuta, Takashima and Shimoshima. In Amakusa Islands coal is limited in distribution in the western margin and the Hondo area of Shimoshima. This strongly suggests that the land was present to the west of Shimoshima.

Summarizing the lines of field evidence that the Toishi Formation sometimes contains marine fossils, coal seams are found along the marginal areas of the presumed land, and the formation is considerably thick, the writer regards that the sediments in the Toishi stage were formed under the subsiding basin facing to the shallow sea.

g. Ittyōda Stage

At this stage in which the so-called Ittyōda Formation and its equivalents were deposited, the environment was like that of shallow bank (BERNER, 1971) suitable for glauconite production. The marine area was remarkably stable as clearly understood from the homogeneous lithology of the strata all over the area in spite of its thinness. The sediments represent the beginning of the second transgression in this area.

h. Sakasegawa Stage

The marine area was further enlarged, and thick shale with neritic foraminifers was formed. The Kirimiya and Iōjima Formations which are the equivalents of the Sakasegawa Formation in Isahaya and in Takashima respectively, are of sandy facies in contrast with muddy facies in Amakusa, Ōmuta and Shima-

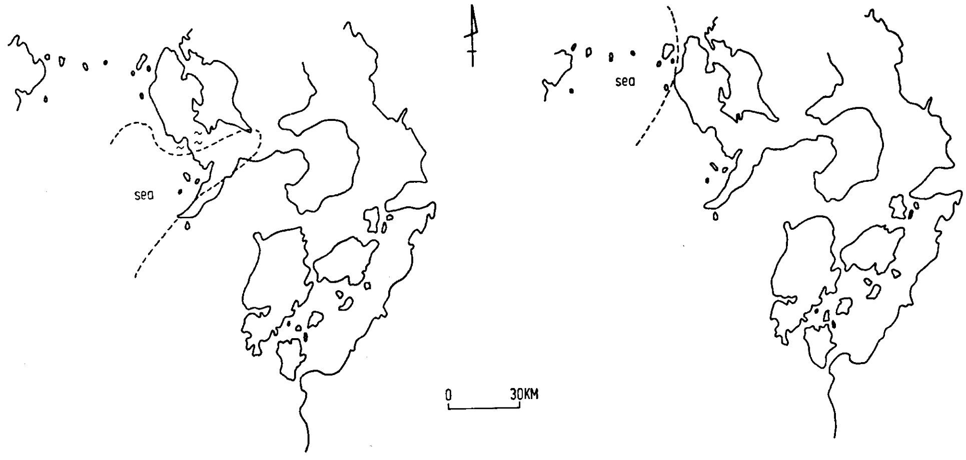


Fig. 40. Paleogeographical map of Western Kyushu in final Sakasegawa-Nishisonoki stage.

bara.

i. Nishisonoki Stage

The uppermost part of the Sakasegawa Formation and its equivalents, which contain a considerable amount of sandstone in Amakusa and conglomerate and coal in Isahaya and Takashima, indicates a rather regressive facies. At the final substage of Sakasegawa stage, the sea area retreated from Amakusa but remained in the Isahaya, Takashima and Nishisonoki areas. In the next Nishisonoki stage, coarse-grained sediments of sandstone and conglomerate with some shale were deposited in the Nishisonoki area, the sole sea area of this time.

j. post-Paleogene structural movements

After Paleogene, Western Kyushu was again subject to a remarkable crustal movement. As a result the so-called "Amakusa Type structure" described in previous chapter was formed in Amakusa. The faults originated at the end of Cretaceous or beginning of Tertiary became again active and some of them cut the Paleogene strata, whereas the faults of different directions from that of the pre-Tertiary ones are few if not absent in the Tertiary. Therefore, some of the post-Paleogene faults are considered to have been formed by re-activation of the earlier ones. General trends of the above-mentioned two groups of structures are NNE-SSW direction and NW-SE direction respectively.

The former group has long been seriously counted, the writer, however, emphasizes here the structural importance of the latter. A structural movement which formed the faults and foldings of NW-SE direction is recorded by the change of the direction from NNE-SSW to NW-SE in the Ittyōda Syncline, Hondo Syncline and others near Hondo City.

Granodiorite in the Tomioka Peninsula of Amakusa-Shimoshima, the age of which is measured at 19 m.y. (SHIBATA and TOGASHI, 1975), is neither cut nor crossed by the faults described above. The geological structure of the Upper Oligocene Nishisonoki Group is similar to that of other areas, although the details are

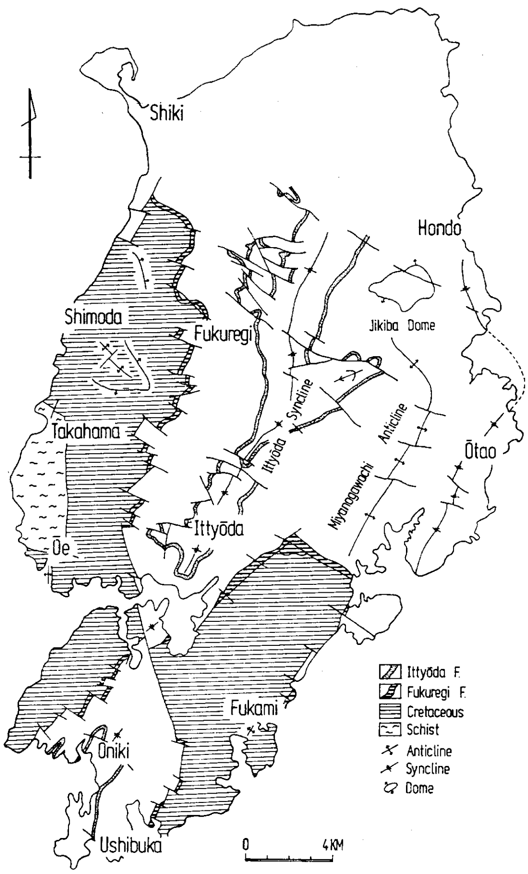


Fig. 41. Idealized structural map of Amakusa-Shimoshima.

somewhat different in complexity and direction, and, in consequence, the main movement which formed the "Amakusa Type structure" happened after the deposition of the Nishisonoki Group and before the intrusion of Tomioka granodiorite. That would be Lower Miocene, if the dating datum is rightly taken into account.

V. A Comparison of the Tectonic History between Amakusa and Other Areas in Kyushu

In this chapter the tectonic history recognized in Western Kyushu is compared with that in other areas where the Paleogene formations are widely developed. The Paleogene formations are well observed in Northern Kyushu and in Southeastern Kyushu besides the studied area.

In Southeastern Kyushu, it is evident that some crustal movements were happened in mid-Tertiary, although a movement at the end of Cretaceous or beginning of Tertiary has not been confirmed. In mid-Tertiary age the area was subject to a crustal movement mainly folding and faulting represented by the Iorigawa unconformity (HASHIMOTO, 1961). Another phase of movement is also shown by the unconformity beneath the Kadokawa Formation and still another by the uncon-

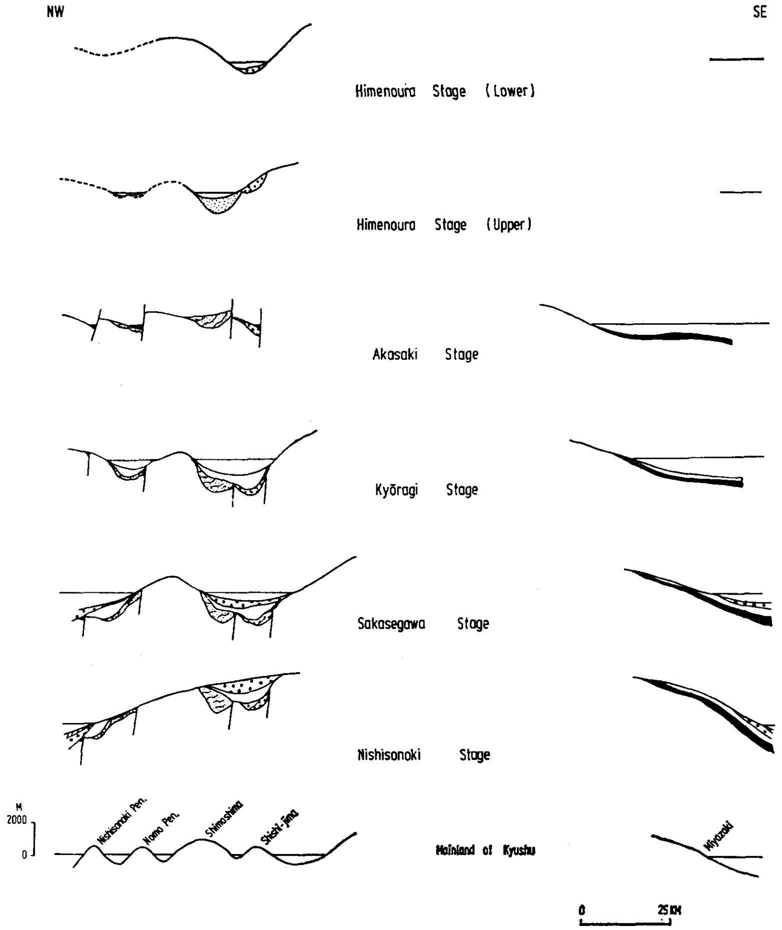


Fig. 42. Schematic cross sections of Kyushu showing the development of sedimentary basins during Cretaceous and Tertiary. Designs pictured at the uppermost part in each section show the sediments in that stage.

formity beneath the Miyazaki Group (SHUTO, 1952). The pre-Kadokawa phase which is regarded as a forerunner of the main movement of the pre-Iorigawa is approximately of the same age as that in Western Kyushu.

In Northern Kyushu, on the other hand, the great fault at the margin of the Chikuhō Coal Field may have been formed by the tectonic movement at the end of Cretaceous or beginning of Tertiary (TAKAHASHI *et al.*, 1971). Similarly the so-called Futsukaichi-Fukuoka Tectonic Line in Northern Kyushu may have been moved in that age (KARAKIDA, 1969). If the reverse fault in the Ijiri area (MATSUSHITA *et al.*, 1971) is a branch of this tectonic line, the fault may have been activated again in post-Paleogene.

As described above, the major tectonic movement occurred at two stages throughout Kyushu. One is at the end of Cretaceous or the beginning of Tertiary and the other is in mid-Tertiary, although the accurate ages may be somewhat different between provinces. The Tertiary tectonic history in Kyushu may be summarized as follows.

As a result of an uplift of the central region of Kyushu at the end of Cretaceous, the depositional basins were shifted outward; namely northwestward in Western Kyushu and southeastward in Southeastern Kyushu. In the Latest Cretaceous or Earliest Tertiary, Kyushu was subject to a remarkable tectonic movement. By this movement, the depressions caused by faulting were made in Amakusa and its adjacent areas where the Paleogene sediments were deposited. This is contrasted with the geosynclinal sedimentation in Southeastern Kyushu. Both areas were again subject to movements in mid-Tertiary age.

Let us compare the ages of the movements which formed and modified the Median Dislocation Line in Shikoku with those of the movements in Kyushu described above. Recently NAGAI (1973) has revised his former view on the tectonic history of the Median Line in Shikoku (NAGAI, 1958), and newly established three phases of movements. According to him the first phase of the tectonic movement may be dated at post-Upper Cretaceous and pre-Eocene, and this phase of crustal movement is designated as the Kaminada Phase. As shown by field evidence, the Sanbagawa metamorphic rocks thrust northward over rocks of the Upper Cretaceous Izumi Group by this tectonic movement. The next tectonic movement of the Tobe Phase took place after the deposition of the Eocene Kuma Group and before the deposition of the Miocene Ishizuchi Group. Field evidence for this tectonic movement is that the rocks of the Upper Cretaceous Izumi Group on the north side of the dislocation line are thrust over those of the Upper Eocene Myōjin Formation. Since Late Pliocene or Early Pleistocene, another tectonic movement represented by the uplift of Ishizuchi mountains accompanied by right lateral displacement occurred and still continues. This is designated as Niihama Phase of activity along the Median Line.

As apparent from the above descriptions, remarkable movements happened at the end of Cretaceous or beginning of Tertiary and in mid-Tertiary age in both Shikoku and Kyushu. Namely the movement of post-Himenoura and pre-Akasaki and that of Lower Miocene in Kyushu correspond chronologically to those of the Kaminada and the Tobe Phase in Shikoku respectively.

VI. Concluding Remarks

The Upper Cretaceous and Paleogene formations in Amakusa and the adjacent areas are studied in detail and the following conclusions are led.

The Upper Cretaceous-Paleogene boundary, on which several different views have been offered, is set up beneath the Fukuregi Formation in Shimoshima and the Akasaki Formation and its equivalent in other areas based on a detailed field data and petrographical, structural and paleontological lines of evidence. The boundary plane is, in every area, an unconformity formed as a result of crustal movement accompanying upheaval and erosion, although the intensity of the movement and time-interval represented by the unconformity are different from place to place. The structural difference is the greatest in Amakusa-Shimoshima.

The Paleogene sediments were accumulated in the tectonic depressions formed by the above-mentioned movement. The depressions were probably narrow and rather intermontain in the early stage, and then they were transformed to a large-scale one facing to the open sea. Two cycles of sedimentation are distinguished during the Paleogene.

The Paleogene was subject to a remarkable crustal movement in the Lower Miocene by which the structures of the strata are markedly modified so as to be closer to those observed at present. The movement involved the re-activation of the structures which were formed at the end of Cretaceous or beginning of Tertiary.

The two phases of movements are recognized also in other areas in Kyushu, and these ages are correlated to those in Kaminada Phase and Tobe Phase of the tectonic history of Median Dislocation Line in Shikoku.

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Appendix

Alphabetical list of place names with Japanese writing

Akasaki	赤崎	Kaminoshima	神ノ島
Akashimisaki	明石岬	Kamishima	上島
Amakusa	天草	Kannon-dake	観音岳
Asami	浅海	Kirimiya	切宮
Chikuhō	筑豊	Kiyama	木山
Dezaki	出崎	Kōjiro	神代
Eno-shima	江ノ島	Komenoyama	米ノ山
Fukami	深海	Koshiki-jima	甑島
Fukuoka	福岡	Kōyaki	香焼
Fukuregi	福連木	Kuchinotsu	口ノ津
Futagojima	二子島	Kuma	久万
Futsukaichi	二日市	Kumamoto	熊本
Ginsui	銀水	Kyōragi	教良木
Goshonoura	御所浦	Kyushu	九州
Hashima	端島	Manotani	間ノ谷
Higo	肥後	Matsushima	松島
Himenoura	姫ノ浦	Maze	間瀬
Hiraiwa	平岩	Minamise	南瀬
Hongō	本郷	Misumi-dake	三角岳
Hokkaido	北海道	Mitsuse	三瀬
Hokonokō	鉾ノ甲	Miyanogawachi	宮野河内
Hondo	本渡	Miyazaki	宮崎
Hotokenohira	仏ノ平	Mogi	茂木
Ichigojima	苺島	Mukaigoya	向小屋
Ijiri	井尻	Myōjin	明神
Ikara-jima	伊唐島	Nagasaki	長崎
Iōjima	伊王島	Naga-shima	長島
Iorigawa	庵川	Nagayo	長与
Isahaya	諫早	Nakaura	中浦
Ishizuchi	石鎚	Nemuro	根室
Ittyōda	一町田	Niihama	新居浜
Iwa-jima	維和島	Nishisonoki	西彼杵
Izumi	和泉	Nomo	野母
Jikiba	食場	Ōe	大江
Jusanno	十三野	Ogakura	小ケ倉
Kadokawa	門川	Ōgamenose	大亀ノ瀬
Kameura	亀浦	Okinoshima	沖ノ島
Kaminada	上灘	Ōkōchi	大河内

Ōmuta	大 牟 田
Ozaki	尾　崎
Ryūga-dake	竜 ヶ 岳
Ryūganji	立 願 寺
Ryūkyū	琉　球
Sakasegawa	坂 瀬 川
Sakito	崎　戸
Sakitsu	崎　津
Sanbagawa	三 波 川
Senzokuzōzō-jima	千束蔵々島
Seto	瀬　戸
Shikiyama	志 岐 山
Shikoku	四　国
Shimabara	島　原
Shimoshima	下　島
Shiratake	白　岳
Shishi-jima	獅 子 島
Shoura-jima	諸 浦 島
Takahama	高　浜
Takashima	高　島
Tamana	玉　名
Terashima	寺　島
Tobase-jima	戸 馳 島
Tobe	砥　部
Tomioka	富　岡
Tōmiyama	遠 見 山
Tororo	都 呂 々
Ushibuka	牛　深
Uto	宇　土
Yamaga	山　鹿
Yamaguchi	山　口
Yobukonose	呼子ノ瀬
Yobukonoseto	呼子ノ瀬戸
Yōkaku	羊　角