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Basin analysis of the Lower Cretaceous Toyonishi and Kanmon Groups, Southwest Japan

By

Ken-ichi YOSHIDOMI

with 2 tables and 26 figures

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ABSTRACT: Neritic to fluvial sediments of 6,000 m thick are distributed in the Jurassic to Lower Cretaceous Kanmon Basin in the westernmost Honshu (Yamaguchi Prefacture), Inner Zone of the Southwest Japan. Sedimentological and geological investigations clarify the geometry, and reconstruct the tectono-sedimentary development process of the basin. The results may provide clues to elucidate the late Mesozoic tectonics in the East Asian continental margin.

The Jurassic to Lower Cretaceous sediments in the Kanmon Basin consist of the following three groups in ascending order; the Lower to Middle Jurassic Toyora Group comprising mainly of neritic shale, the uppermost Jurassic to lowest Cretaceous Toyonishi Group composed of the paralic, plant bearing lower and brackish molluscs bearing upper formations, and the middle to upper Lower Cretaceous Kanmon Group consisting of the lower clastic and the upper volcano-clastic subgroups.

Permian accretionary complexes and Upper Triassic shelf sediments are distributed on the southeast of the thick sediments of the Kanmon Basin, bounded by the NE-SW trending Nagato Tectonic Zone with serpentine melange. Provenance analyses of the Jurassic to Lower Cretaceous sediments indicate that the Permian accretionary complexes and the Upper Triassic shelf sediments supplied sandy and gravely clasts into the sediment basin during the Jurassic to Early Cretaceous time for ca. 100 m.y. Northwestward decrease in sediment thickness apart from the tectonic zone indicates that the geometry of the basin is a tilting basin (or half-graben) dipping southeastward.

Results of sedimantary facies analysis suggest that the differential movements between the basin and the provenance were caused by the intermittent growth dip-slip movement of the Nagato Tectonic Zone during the Jurassic to the Early Cretaceous. Volcanism of intermediate composition initiated and intensified in the late Early Cretaceous. Successive events around the Early/Late Cretaceous, i.e., acceleration of the differential movement along the Nagato Tectonic Zone, intensified volcanism, and plutonic emplacement, may represent a significant tectono-magmatic phase of the Yanshanian Movement in East Asia.

The Late Jurassic to Early Cretaceous Kyongsang Basin in the southeastern Korean Peninsular is a southeastward tilted basin and has a sedimentary history similar to that of the Kanmon Basin. These two large basins appear to occupy the northeastern end of the extensive area crowded by tilted basins in the East China Sea. These tilted basins dip commonly southeastward and are bounded by deep antithetic faults on their southeastern margins. The coming issue to be clarified is the dynamics generating such systematic arrangement of the late Mesozoic tilted basins gregarious in the East Asian continental margin.

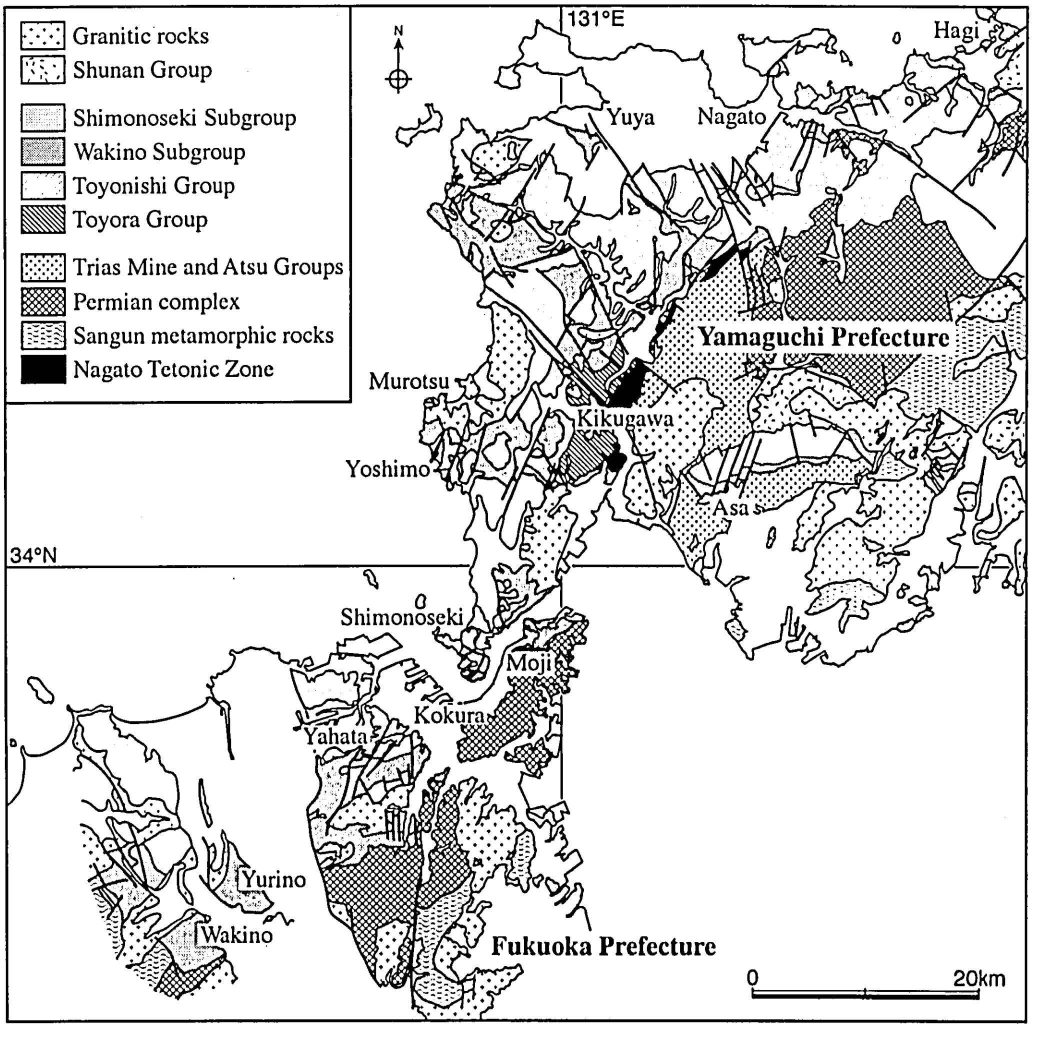


Fig. 1. Compiled geological map of the Upper Mesozoic in Western Yamaguchi and North Kyushu.

I. Introduction

Jurassic to Lower Cretaceous sediments, except for the accretionary complex, are widely distributed in western Chugoku and northern Kyushu district (Fig. 1), which geotectonically belong to the Inner Zone of Southwest Japan.

These Upper Mesozoic formations was included in the Inkstone (Kenseki) Series introduced by Inoue (1896). Koto (1909) pointed out the lithological resemblance between the Inkstone Group and the Kyongsang Supergroup of South Korea. But detailed stratigraphical definitions and accurate geological ages of the Inkstone Group were not available. Yokoyama (1904) reported the Jurassic ammonites from Kikugawa-cho, Toyora-gun in Yamaguchi Prefecture. The Jurassic Toyora Group was introduced and separated from the Inkstone Group (Yabe, 1920). Thus, the name of the Inkstone Group was confined to the Cretaceous strata containing red or variegated rocks distributed in the Inner Zone of Southwest Japan (Yabe, 1927).

Since the occurrence of fossil shells was first reported by Yokoyama (1902) from the sea-coast of Yoshimo, north of Shimonoseki City in Yamaguchi Prefecture, the stratigraphy and geological ages of the shell beds have been studied by many scientists. The Yoshimo shell beds and the underlying "Kiyosue plant bearing beds" were included in the later defined Toyonishi Group (Matsumoto, 1949). Since the term of the Inkstone Group was confused in usage, the Kanmon Group was proposed by Matsumoto (1951).

These Jurassic to lower Cretaceous groups display a wide range of sedimentary facies. They consist of marine and brackish sediments in the lower part and fluvial sediments associated with lava and phyroclastic rocks in the upper part. They were highly deformed in the Yoshimo-Kikugawa area (northern Shimonoseki in Yamaguchi Prefecture: Fig. 1), with a total thickness up to 6,000 m.

The geology of the northern Shimonoseki area has been investigated by many geologists (e.g., Matsumoto, 1951; Ueda, 1957; Hase, 1958, 1960; Takahashi et al., 1965, 1966; Hirano, 1971, 1973a, 1973b; Takahashi & Mikami, 1975a, 1975b). Hase (1958) summarized the stratigraphy and the geologic structure of the Toyonishi and Kanmon Groups. However, sequence stratigraphy still need to be investigated. Moreover, the available geological maps are not clarified so that the characteristics of the sedimentary basin can hardly be recognized.

The purposes of this study are to clarify:
(1) Provenance of the sediments
(2) Geometry of the basin
(3) Depositional environments of the sediments
(4) Evolution process of the basin

Through detailed investigation of stratigraphy, clastic components and facies were analysed in the Yoshimo-Kikugawa area.

Sequence stratigraphical studies was also applied. The "sequence stratigraphy" is the study of lithological relationships between the depositional environment and chronostratigraphic framework, from which the succession of rock cycles and genetically related stratal units can be established (Posamentier et al., 1988) and a reasonable understanding on the depositional history of sediments can be obtained (Vail et al., 1977; Vail et al., 1984; Van Wagoner et al., 1990; Wilson, 1992). Non-marine sediments are important components in the study of sequence stratigraphy. They occur in a wide range of tectonic setting and are sensitive indicators of allogenic (extrabasinal) controls such as tectonism and sea level changes (Miall, 1992). By sequence stratigraphical investigation, it is able to understand the changes of depositional environments in a sedimentary basin resulted from tectonic movements.

Because tectonic movements of the basins may have been recorded in the changes of sediments, the evolution processes and changes of the provenances can also be recognized by detailed examination of the clastic sediments of different components (Crook, 1974; Dickinson & Suczek, 1979; Valloni & Maynard, 1981; Schwab, 1981), but methodological problems have been experienced. It has become clear from a recent study of Kumon et al. (1992), that in order to evaluate the provenance factor, which controls sandstone composition, the "Gazzi-Dickinson point-counting" method (Ingersoll et al., 1984; Kumon et al, 1992) is much better than the traditional method (Okada, 1968), though the latter is still useful for the description of sandstones. In this study, the Gazzi-Dickinson point-counting method was adopted to minimize influences of sandstone grain size in modal composition. The counting data were plotted on a Dickinson Diagram (Dickinson et al., 1983), in which the provenances of the sediments were divided into three categories, i.e. continental block, magmatic arc and recycled orogen. Based on these data, specific provenances in Southwest Japan were elaborated.

The Kanmon Basin is one of the well known sedimentary basins widely distributed from East China Sea to Southwest Japan. The Yoshimo-Kikugawa area is loceted in the middle of the basin. From a tectonic viewpoint, the East Asian continental margin was characterized by remarkably developed NNE-SSW trending large-scale faults, most of which were formed in the Late Jurassic to Early Cretaceous (Chen & Qin, 1989; Xu et al., 1989; Zhou et al., 1989; Natal'in, 1993; Okada & Sakai, 1993). All of the sedimentary basins have been developed in the northeast side of these faults.

The characteristics of these basins are: (1) they developed in close relations to major faults, and in parallel to each other, (2) they show a half-graben structure with southeast-tilted basement and depocenter along the fault (Okada, 1993).

The evolution processes of these basins and tectonics of the East Asian continental margin of the Late Jurassic to Early Cretaceous have been discussed by many scientists (e.g., Zhou et al., 1989; Sakai et al., 1992; Okada, 1993; Yano & Wu, 1995). There are mainly two theories proposed: (1) model of strike-slip movement, (2) model of tilting movement of half-graben.

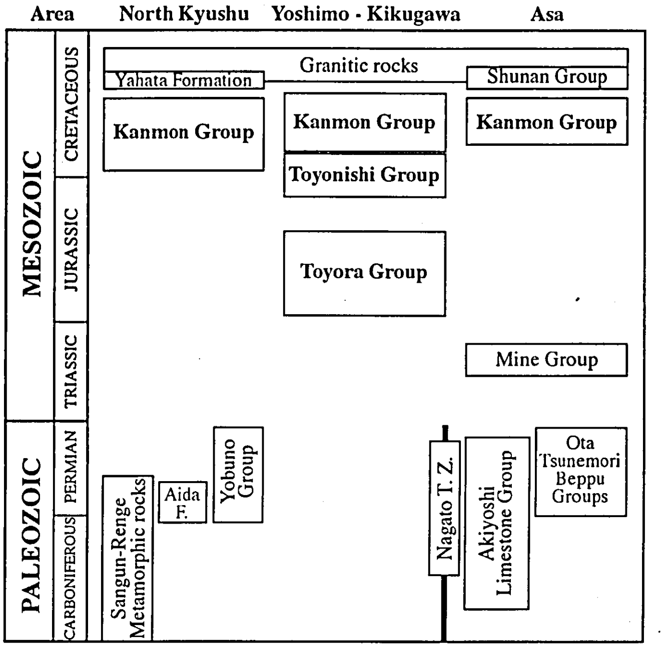


Fig. 2. Geologic units around the study area.

The clarification of the tectonic setting of the Kanmon Basin may provide not only the geological history of southwestern Japan, but also the tectonic evolution of the East Asian continental margin in Late Mesozoic.

II. Geologic Outline

Late Mesozoic formations covered various older geological formations with various types of unconformity, and is intruded by granitic rocks (Figs. 1 and 2). The geologic outline of western Yamaguchi Prefecture is described below.

A. Basement rocks

The basement rocks of the Late Mesozoic formations can be divide into three groups mainly, Nagato Tectonic Zone constituent rocks, Paleozoic formations of the Akiyoshi Terrane and Triassic formations.

1. Nagato Tectonic Zone

The Nagato Tectonic Zone constitutes a narrow belt extended for about 35 km, with only few kilometers width, trending from NNE to SSW in western Yamaguchi Prefecture (Matsumoto, 1949). This tectonic zone defines a boundary of the Akiyoshi Terrane and the Upper Mesozoic formations, and contacts with former by faults and is overlain by latter. The tectonic zone consist of various rocks, i.e. weak metamorphosed Paleozoic formation, crystalline schists and serpentinites accompanied with amphibolites, orthogneisses, meta-gabbro, diorite, granodiorite. It is known that igneous rocks of the Nagato Tectonic Zone have low K_2O/Na_2O ratio (Murakami & Nishimura, 1979). These rocks are exposed as lenticular bodies, and are separated into five areas, i.e. Misumi, Dai, Nishiichi, Toyoga-take and Ozuki from north to south (Murakami and Nishimura, 1979).

The high-P/T type schists of the Toyoga-take area show geologic ages from 264 to 303 Ma (Nishimura et al, 1983), and the Late Carboniferous radiolarians were reported from andesitic tuffaceous mudstone of the Dai area, Mine City. Such kind of andesitic tuffaceous mudstone is not known at all the Chugoku district but in the Hida marginal Belt (Isozaki & Tamura, 1989). These data strongly support the recent understanding that the Nagato Tectonic Zone is continuous with the Hida Marginal Belt in central Japan, and are belong to the Sangun-Renge Belt (Nishimura, 1989) in conjunction with the occurrence of coeval high-P/T type schist in both zones.

2. Akiyoshi Terrane

Central region of Yamaguchi Prefecture mainly consists of the Paleozoic formations, which are divided into three geological parts; central part of the Akiyoshi Limestone Group, southeast part of the Ota Group and northwestern part of the Beppu and Tsunemori Groups.

The Akiyoshi Limestone Group (Ozawa, 1925) is composed of limestone mainly. Basis on the biostratigraphic study of fusulinids, these limestones were formed between Lower Carboniferous to Upper Permian (Ota, 1977). The Ota Group is composed of chert and sandstone with thin shale beds (Fujii, 1972). The Tsunemori Group is composed of dark-colored shale beds with lenticular chart and limestone. The Beppu Group is composed of chert formation with small amount of sandstone and shale (Mikami, 1974). Radiolarian and foraminifer studies indicates that these formations are the Permian accretionary complexes.

3. Triassic

Distributions of the Triassic formations in western Yamaguchi Prefecture are separated into three areas i.e. Omine, Asa, and Atsu areas by faults (Kobayashi, 1926; Tokuyama, 1962). The formations distributed in Atsu area are called the Atsu Group, and depositional age was estimated to be from late Ladinian to early Carnian. Similarly, the lower Carnian to lower Norian formations distributed in both Omine and Asa areas are defined as the Mine Group (Takahashi & Mikami, 1975a).

The Mine and Atsu Groups are characterized by arkose shelf basin sediments, which are coarse grained, lithic fragment rich, and were derived from an area correspond to the Hida Belt (Tokuyama, 1958).

These Triassic formations hace fault contacts with the Nagato Tectonic Zone. Their contacts with the Permian Tsunemori and Beppu Groups are faults or unconformity.

B. Jurassic to Lower Cretaceous

The Jurassic to Lower Cretaceous in western Yamaguchi Prefecture are divided into four groups (Fig. 3). These groups are whole or partly unconformable with each other.

1. Toyora Group

The Toyora Group, distributed arround the Kikugawa Town, Yamaguchi Prefecture, is composed of neritic shale mainly (Yabe, 1920). The stratigraphy and biostratigraphy of the group are studied by Hirano (1971, 1973a, 1973b), and are summarized Takahashi & Mikami (1975b). The Group is subdivided into three formations, which form one sedimentary cycle. They are in ascending order, the Higashinagano Formation - the product of transgression phase, the Nishinakayama Formation - the product of flooding phase, and the Utano Formation - the product of regression phase (Hirano, 1971, 1973a, 1973b).

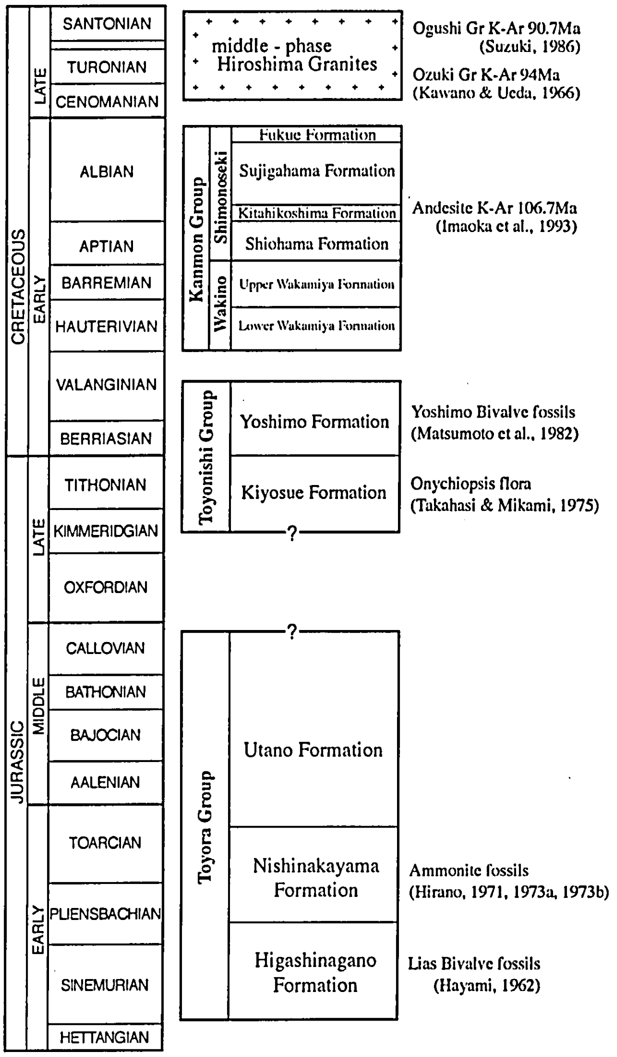


Fig. 3. Geological ages of the Jurassic to Lower Cretaceous in Yoshimo-Kikugawa area.

The Lias bivalves were reported from the lower Higashinagano Formation, and many ammonite fossils were also reported from the Nishinakayama Formation (Hirano, 1973a, 1973b). The Utano Formation contains many fossils, i.e. ammonites, belemnites and Inoceramus in the lower part, while Onychiopsis flora are frequently observed in the upper part (Takahashi & Mikami, 1975b). Based on these fossils, the geological age of the Higashinagano Formation is considered to Sinemurian of the Early Jurassic, and the Nishinakayama Formation is Pliensbachian, and the Utano Formation is Toarcian to Bathonian of the Middle Jurassic, respectively.

The distribution of the group are separated into two main areas of the Ishimachi and the Tabe areas by the Kikugawa fault (a Quaternary fault) trending from NW to SE.

In the Ishimachi area, these formations attain to 1,900m in thickness, and unconformably overlies the Toyohigashi Group and metamorphic rocks of the Nagato Tectonic Zone, and are covered by the Kanmon Group directly (without the Toyonishi Group).

In the Tabe area, the lower Higashinagano Formation makes a contact with the Nagato Tectonic Zone. The upper Utano Formation is covered by the Toyonishi Group by clino-unconformity. Lithological characters and thickness of the group varies from north to south. The south side of the Utano Formation is coarser grained and contains more abundant plant fossils than the north side.

2. Toyonishi Group

The Toyonishi Group (Kobayashi & Suzuki, 1939) shows separated distributions of Yoshimo and Utsui areas, northern Shimonoseki City, Yamaguchi Prefecture. This Group subdivided into two formations, the lower Kiyosue Formation and the upper Yoshimo Formation, on the basis of the bearing fossils and lithological properties (Matsumoto, 1949; Hase, 1958). In northern part of Utsui area, the Yoshimo Formation was dissected by clino-unconformity, and the Kiyosue Formation is covered by Wakino Subgroup directly.

a. Kiyosue Formation

The Kiyosue Formation is consist of mudstone dominantly alternating beds of plant-bearing coaly mudstone and coarse-grained arkose sandstone. The plant fossils are well known as the Kiyosue-type or the Toyonishi-type Flora (Takahashi, 1957, 1959), and have both elements of the Tetori-type Flora of Inner Zone and the Ryoseki-type Flora of Outer Zone of Southwest Japan (Takahashi & Mikami, 1975b). Depositional age of the Kiyosue Formation is estimated to be latest Jurassic.

b. Yoshimo Formation

The Yoshimo Formation consists of the alternating beds of fine-grained sandstone and mudstone containing brackish molluscs fossils. It has been pointed out that the molluscs of this formation can be correlate with the ones of the Nankai Group of Shikoku district, and of the Kawaguchi Formation and Uminoura Formation of Pre-Sotoizumi Group in Kyushu, Outer Zone of Southwest Japan (Tashiro et al., 1994). Accordingly, depositional age of the Yoshimo Formation is estimated to earliest Cretaceous.

Okada (1981) reported that the Yoshimo Formation is characterized by highly matured quartz sandstone. Furthermore, Ishiga, et al. (1997) described that element composition of mudstone of the Yoshimo Formations resembles to PAAS (Post Archean Australian Shale, Taylor & McLennan 1985).

3. Kanmon Group

The Kanmon Group is distributed in an area extending from northern Kyushu through Kanmon straits to the Chugoku district. The group not only covers the Toyora and Toyonishi Groups, but also overlies various formations of older ages, and is intruded by dioritic and granitic rocks.

This group is divided into two subgroups, the lower Wakino Subgroup and the upper Shimonoseki Subgroup based on lithological characters (Matsumoto, 1951). The former is characterized by clastic sediments intercalating small amounts of felsic tuff or tuffaceous sediments, while the latter is characterized by large-volume of andesitic to dacitic clastic sediments.

a. Wakino Subgroup

The Wakino Subgroup is typically subdivided into four formations, the Sengoku, Nyoraida, Lower Wakamiya and Upper Wakamiya Formations in ascending order, at the type locality of Wakino area, in Northern Kyushu (Hase, 1958). Each formation begins with a basal conglomerate.

In the Yoshimo-Kikugawa area, the Lower Wakamiya Formation covers the Toyora and Toyonishi Groups with slightly clino-unconformity.

Non-marine bivalves and gastropods are reported from the Wakino Subgroup by Ota (1960). It is difficult to determine the depositional age of the Wakino Subgroup, but basis on the subgroup covered the Toyonishi Group unconformably, the ages from Valanginian to Hauterivian of the early Cretaceous are estimated.

Seo (1992) reported that the Wakino Subgroup in the north Kyushu displays a wide range of depositional facies, and it change from fluvio-alluvial to marginal lacustrine and lacustrine environment in ascending order. And Seo (1992) also concluded that sandstone of the formation is characterized by a predominance of lithic components which mainly consist of schist and subordinate slate, andesite and other igneous rocks, thus, two different provenances might be inferred for the Wakino Subgroup; one was related to older plutonic rocks probably continental granitic rocks, and the other was directly underlying Sangun metamorphic rocks.

b. Shimonoseki Subgroup

The Shimonoseki Subgroup is characterized by the enormous thickness (attaining about 2,000m in the type area) and the frequent occurrence of purple-red or variegated sediments. This subgroup is divided into four formations, the Shiohama, Kitahikoshima, Sujigahama and Fukue Formation in ascending order (Hase, 1958).

Fission track age (115.4±3.8 Ma) of zircon in acidic tuff from the Fukue Formation are reported by Murakami (1985), and also K-Ar ages of hornblendes in andesite and dacite from the Kitahikoshima Formation are reported. These K-Ar ages are identical within uncertainity; the andesite being 105.2±3.3 Ma, and dacite 106.7±3.3 Ma (Imaoka et al., 1993). These data indicate that the sedimentation process of the Kanmon basin continued until Albian of the Early Cretaceous at least. Primitive basaltic andesite containing chromite and Cr-endiopside are reported by Imaoka et al. (1989). These indicate that the volcanism, prior to the Late Cretaceous igneous activities, were already activated at the Albian.

C. Granitic rocks

In western Yamaguchi Prefecture, the Late Cretaceous granites, widely distributed and intruded into older sedimentary formations, are called the Hiroshima Granites.

In the Yoshimo-Kikugawa area, these granitic rocks distributed in northwestern and southeastern parts. The former called the Ogushi Granite and the latter called the Ozuki Granite. The K-Ar age of biotite of the Ogushi Granite (90.7±4.5 Ma: Suzuki, 1986) resembles to the Ozuki Granite (94 Ma: Kawano & Ueda, 1966).

III. Descriptions of Local Stratigraphy

Lower Cretaceous sediments in western Chugoku and northern Kyushu districts are distributed in separated area by intrusions of the upper Cretaceous igneous rocks (e.g. Hiroshima Granites) or blankets of younger sediments (e.g. Ashiya Group, Ube Group). Hase (1958, 1960) recognized the followong nine areas of these Lower Cretaceous formations.

(1) The Kodaijiyama and Oshima area
= Northeast of Akama-cho.

(2) The Yamaguchi-mura area
= South of Akama-cho, Fukuoka Prefecture.

(3) The Wakino area
= Southwest of Nogata City, Fukuoka Prefecture.

(4) The Yurino area
= Adjoining to the west of the Nogata City, Fukuoka Prefecture.

(5) The Kokura, Yahata, Tobata and Wakamatsu area
= The mountainous quarters of these four adjacent cities, Fukuoka Prefecture.

(6) The Moji and Shimonoseki area
= Along the Kanmon strait.

(7) The Toyonishi and Utsui area
= North of Shimonoseki City, Yamaguchi Prefecture.

(8) The Nishiichi, Takibem, Tawarayama, Senzaki and Hagi area
= The wide and continuous exposure in the northwestern part of Yamaguchi Prefecture.

(9) The Asa area

= North of Asa, Sanyo-cho, Yamaguchi Prefecture.

The study area mostly corresponds to the Toyonishi and Utsui area. However, in this paper, the name of the Yoshimo and Kikugawa area is newly introduced because of that the locality name of the Toyonishi is not used currently. The study area exposes the Jurassic Toyora Group, in addition to the Lower Cretaceous formations. The geological map of the study area is shown in Fig. 4 and the geological profile is shown in Fig. 5.

A. Toyora Group

This Group is exposed from Kiyosue to Tabe, the most western part of the study area.

1. Higashinagano Formation

a. Basal conglomerate, alternating with very coarse grained quartzose sandstone. The conglomerates are ill-sorted, usually consisting of subrounded to subangular cobble and pebble size of chert and schist clasts, highly lithified.

b. Massive or bedded coarse to fine grained quartzose sandstone, intercalating with conglomerates which consist of subrounded small pebbles to granules chert and schist.

2. Nishinakayama Formation

a. Basal conglomerate: consisting usually of subrounded to rounded pebbles and granules of chert and schist, highly lithified.

b. Main part: well bedded coaly mudstone with small amounts of fine grained quartzose sandstone or sandy shale.

3. Utano Formation

a. Basal part: coarse grained quartzose sandstone, with conglomerate consisting mainly of well rounded pebbles of chert.

b. Main part: alternating beds of very coarse to medium grained arkose sandstone and black to greenish gray coaly mudstone, containing abundant plant fossils. Thickness of sandstone beds tend to increase upwards.

B. Toyonishi Group

This group exposed both Kiyosue and Kami-nanami, the western part of the study area and in the coastal area around Yoshimo.

1. Kiyosue Formation

This formation quite resembles to the main part of the Utano Formation in lithology. But, remarkable basal facies are observed continuously in the basal part of the Kiyosue Formation.

a. Basal part: massive, medium to coarse grained arkose sandstone, with conglomerate consisting mainly of well rounded granule to small pebble size of chert clasts (dark or milky in color).

b. Main part: alternating beds of arkose sandstone and dark to dark blue colored coaly mudstone with frequent intercalation of lenticular small pebbly sandstone or granule conglomerates. Mudstone prevails over others, and contains abundant plant fossils and their fragments. Sandstone is usually arkose, massive or well bedded, partly cross-laminated, fine to coarse grained and sometimes pebbly.

2. Yoshimo Formation

a. Lower part: alternating beds of fine to medium grained quartzose sandstone and mudstone. The sandstone is white to light gray colored and the mudstone is black to dark. They are well bedded in several centimeters to several ten centimeters order. Generally, the sandstone is dominant in alternating beds, and the mudstone contains abundant brackish molluscs fossils.

b. Upper part: massive or bedded sandstone, white to light gray colored, fine to coarse grained intercalating of granule conglomerate, which consists mainly of well rounded granule size of chert clasts (dark color).

C. Wakino Subgroup

The Wakino Subgroup begins with a remarkable basal conglomerate, and it overlies the Yoshimo Formation in parallel, in southern part of the study area. In contrast, the group in the northern part entirely denuds the Yoshimo Formatiton with angular unconformity, and the basal conglomerate overlies the Kiyosue Formation directly.

This subgroup consists of the following two formations in this area.

1. Equivalent of the Lower Wakamiya Formation

a. Basal conglomerate: ill-sorted, rounded to subangular cobbles and boulders sandstone with cobbles to pebble size of chert, occasionally limestone clasts of pebble or cobble size are observed.

b. Main part: alternating beds of medium to coarse grained quartzose sandstone and fine to medium grained calcareous sandstone, intercalating of conglomerate and dark to gray mudstone. Sandstones are bedded in several ten centimeters order.

2. Equivalent of the Upper Wakamiya Formation

a. Basal conglomerate, ill-sorted, rounded to subangular large cobbles to pebbles sandstone with small cobbles to pebble size of chert, alternating with fine to medium grained quartzose sandstone.

b. Main part: alternating beds of fine to medium grained sandstone and black to dark purple colored mudstone, in

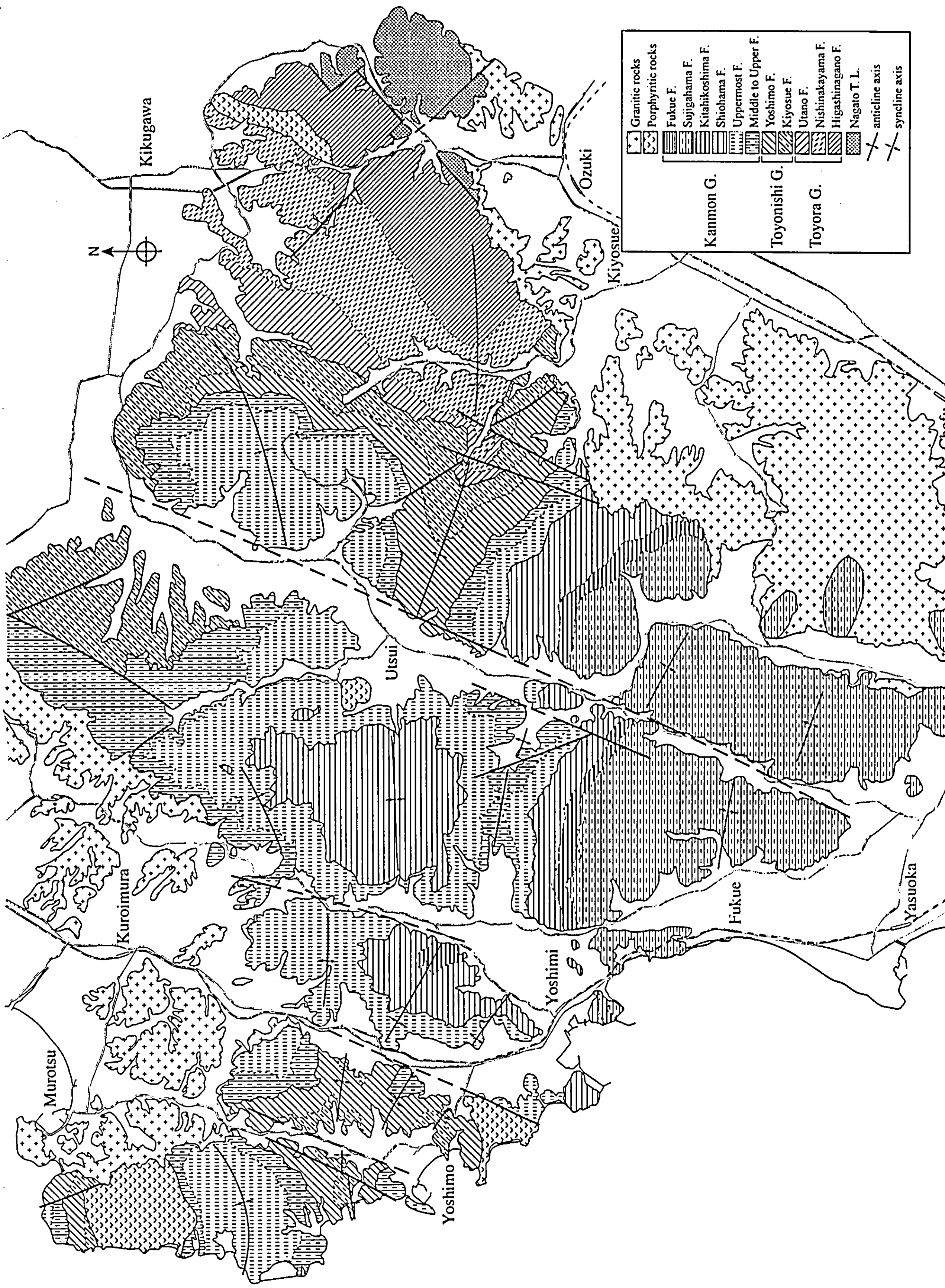


Fig. 4. Geological Map of Yoshimo - Kikugawa area.

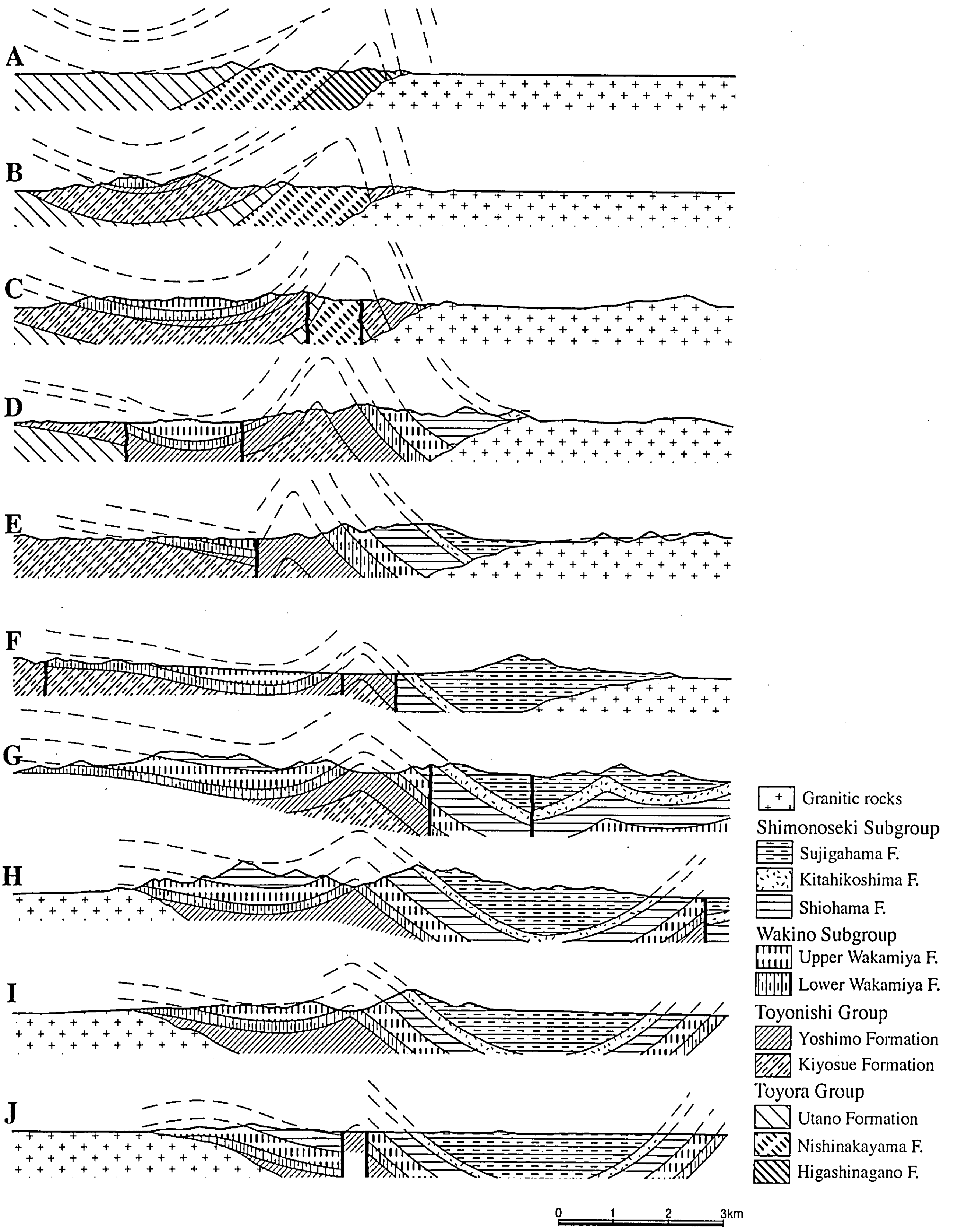


Fig. 5. Geological Profile of the Yoshimo-Kikugawa area.

several ten centimeters order.

c. Upper part: red to magenta colored mudstone, intercalating fine to medium grained greenish gray colored sandstone in several centimeters order. The mudstone contains nodular of lenticular calcretes sporadically.

D. Shimonoseki Subgroup

1. Shiohama Formation

a. Basal part: alternating beds of conglomerate and sandstone. The conglomerate consists of rounded to subrounded pebble to cobble size of chert, sandstone and andesite. Sandstone is fine to medium grained, gray to light reddish gray in color and immatured, intercalating red to magenta mudstone with calcareous nodular and bedded calcretes.

b. Main part: red to purple colored mudstone containing calcareous nodular and bedded calcretes, intercalating conglomerate. The color of mudstone around Mt. Onigajiro is black or dark gray, and calcretes are few observed.

2. Kitahikoshima Formation

Dark red to purple colored andesitic to dacitic lavas and pyroclastic rocks. This volcanic formation is a key bed distributed very continuously and well exposed.

3. Sujigahama Formation

a. Basal part: red to purple colored mudstone intercalating several ten centimeters conglomerate. This part quite resembles to the upper part of the Shiohama Formation in lithology.

b. Main part: alternating beds of conglomerate and sandstone. The conglomerate is ill-sorted, rounded to subrounded granule and large pebble size of andesite, chert and sandstone, and the sandstone is fine to coarse grained. This part consists of several normal grading units that grading from conglomerate to fine sandstone or mudstone in several meters order.

c. Upper part: alternating beds of thick dark red or purple colored mudstone and coarse grained sandstone, intercalating of tuffaceous silt or sandstone.

d. Uppermost part: alternating beds of well-developed conglomerate and purple colored pebbly mudstone, intercalating thin red colored mudstone. The conglomerate consists of ill-sorted subangular to subrounded pebble to cobble size of andesite, sandstone and chert clasts. Thickness of the conglomerate increase upward.

4. Fukue Formation

Andesitic to dacitic pyroclastic rocks. Clasts are mainly composed andesite, but strongly alterated. Exposure of the formation restricted to the sea side of Fukue.

IV. Provenance Analysis

The analysis of composition of clastic sediments was carried out in order to obtain information of the provenances. In this study, compositions were analyzed for conglomerate and sandstone.

A. Composition of conglomerate

Clast compositions in conglomerates are shown in Table 1. Considering the viewpoint of the combination of characteristic compositions, Jurassic to Lower Cretaceous formations divided into three major periods.

(1) The Toyora and Kiyosue composition, is characterized by diversed types of clastics, e.g., schists, plutonics and orthoquartzite, etc.

(2) The Yoshimo to Wakino composition, is characterized by relatively simple combination such as sandstone and chert.

(3). The Shimonoseki composition, is characterized by domination by volcanics.

Compositional variation of conglomerate in the Kanmon Group are shown in Fig. 6. Sample of conglomerate were gathered at six localities of the Kanmon Group (one locality in the Lower Wakamiya Formation, one locality in the Shiohama Formation and four localities in the Sujigahama Formation). They were counted about 100 gravels based on the line analysis.

1. Lower Wakamiya Formation

The conglomerate of the Lower Wakamiya Formation contains predominantly subrounded to rounded sandstone rocks, boulder to cobble in size. Diameter of chert gravels tends to smaller than that of sandstone gravels, and cobble to pebble size of limestone are observed occasionally.

2. Shiohama Formation

The conglomerate of the Shiohama Formation is composed mainly of rounded to subrounded pebbles of sandstone and chert, and contains pebble size of andesitic rocks.

3. Sujigahama Formation

The conglomerate of the Sujigahama Formation consists of rounded to subrounded pebbles and cobbles of andesite, rhyolite, chert and sandstone. Large number of volcanics occur in the lower part of the formation, but they tend to decrease to the upward.

B. Composition of Sandstone

For the provenance analysis of the sediments, modal composition of the particles (mineral grains and rock fragments) in sandstone specimens was analyzed. Examined samples were medium to coarse-grained

Table 1. Clast components in the conglomerate.

Group	Subgroup	Formation	Schist	Pultonic rocks	Acidic tuff	Quartzite	Orthoquartzite	Sandstone	Chert	Mudstone	Limestone	Andesite	Dasite
Kanmon Group	Shimonoseki	Sujigahama Formation	●					●	●	●	●	●	●
		Kitahikoshima F.											
		Shiohama Formation						●	●			●	
	Wakino	Upper Wakamiya F.						●	●				
		Lower Wakamiya F.	●					●	●		●		
Toyonishi		Yoshimo Formation						●	●				
		Kiyosue Formation	●	●	●	●	●	●	●				
Toyora Group		Utano Formation											
		Nishinakayama Formation	●	●				●	●	●			
		Higashinagano Formation	●			●		●	●	●			

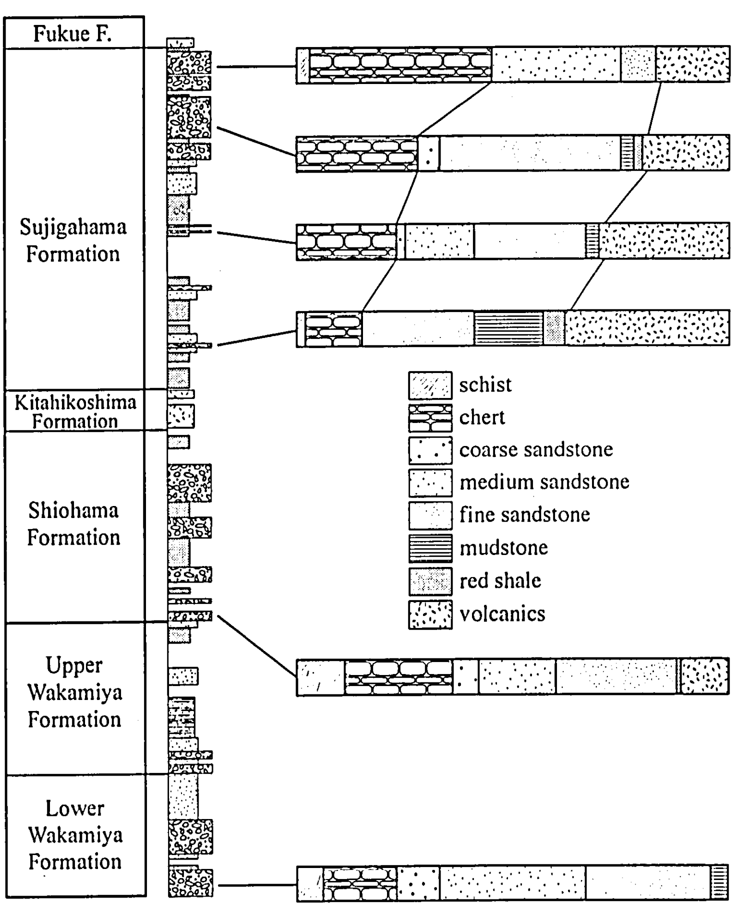


Fig. 6. Compositional variation of conglomerates in the Kanmon Group.

specimens collected from the Toyora, Toyonishi and Kanmon Groups. The samples are four from the Nishinakayama Formation, three from the Utano Formation, seven from the Kiyosue Formation, eight from the Yoshimo Formation, six from the Lower Wakamiya Formation, six from the Upper Wakamiya Formation, six from the Shiohama Formation and twelve from the Sujigahama Formation. 1,000 counts are examined in each thin section based on Gazzi-Dickinson point-counting method (Ingersoll et al., 1984; Kumon et al, 1992) and the results are shown in Figs. 7 and 8. The major constituents of sandstone are classified into monocrystalline quartz (single crystal lattice for entire grain), polycrystalline quartz (two or more crystals of quartz within the grain), potash feldspar, plagioclase, rock fragments and matrix. Rock fragments are composed from chert (cryptocrystalline quartz forming the grain), mudstone, sandstone, slate, schist, plutonic rocks and volcanic rocks.

Figs. 9 and 10 are Q-F-L and Qm-F-Lt ternary diagrams to clarify the tectonic setting of sedimentary basin from modal analysis of sandstone (Dickinson et al., 1983). For Q-F-L diagrams, Q = monocrystalline quartz +

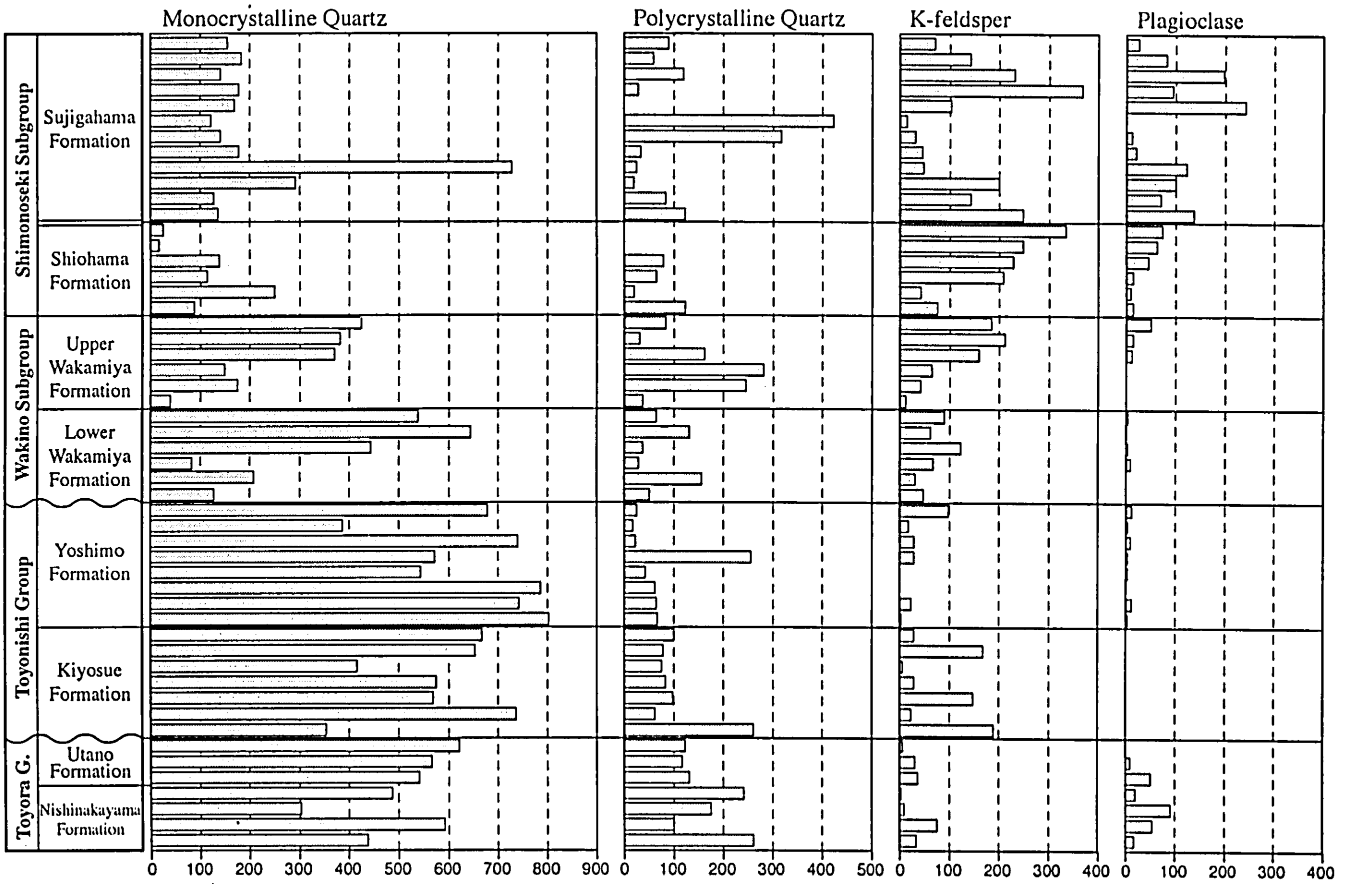


Fig. 7. Conpositional variation of sandstone (Mineral grains).

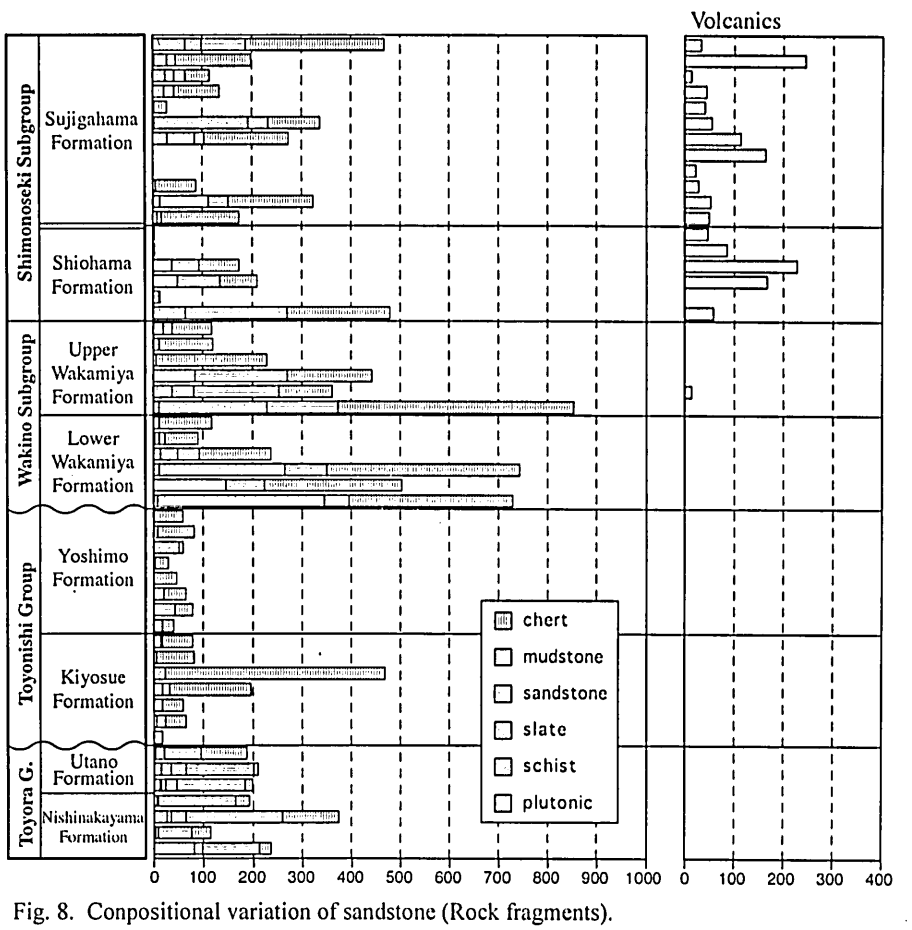
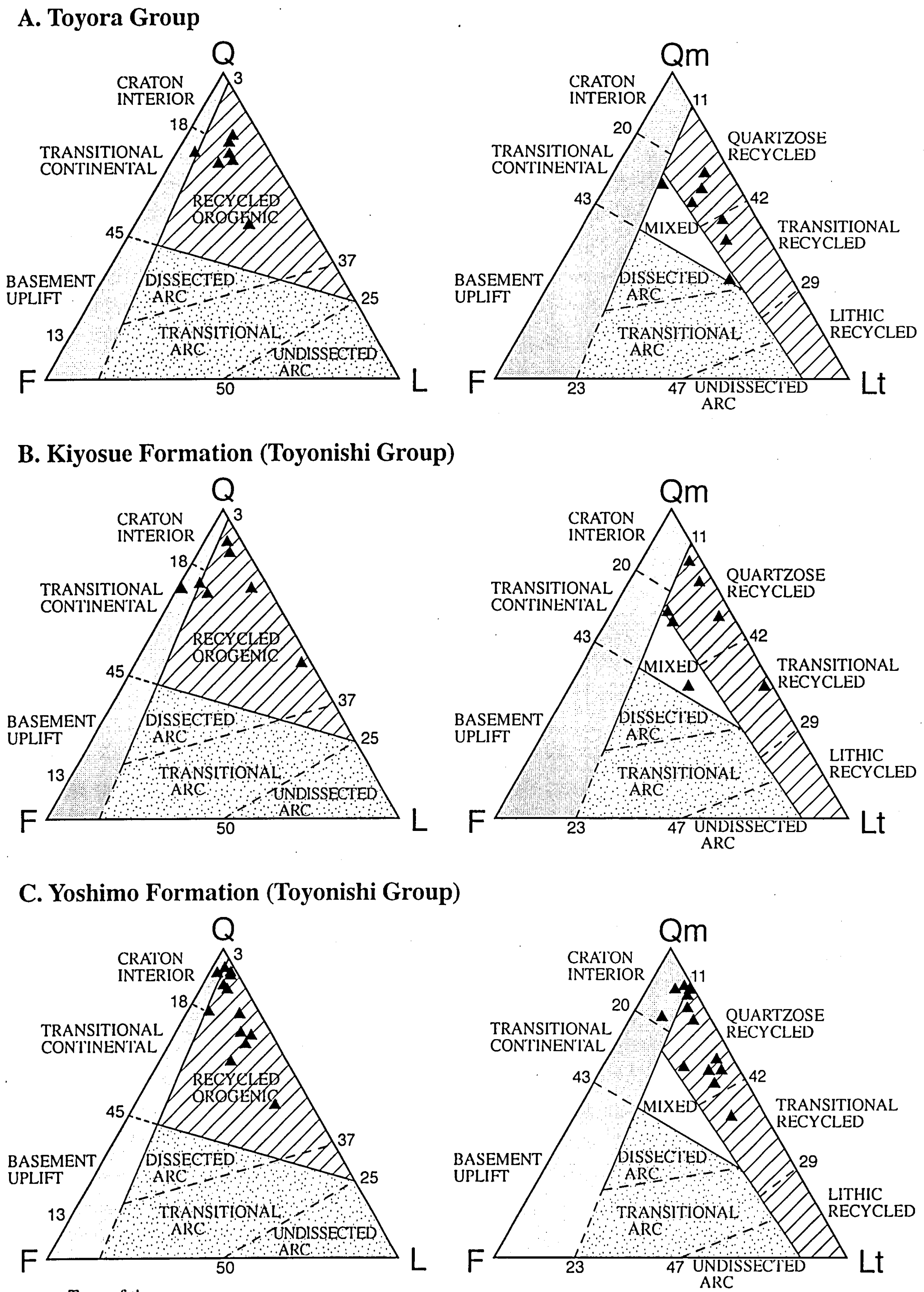


Fig. 8. Conpositional variation of sandstone (Rock fragments).



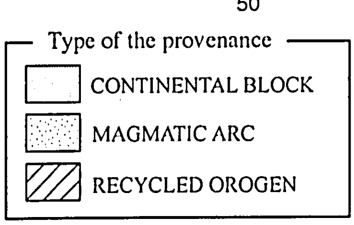


Fig. 9. Triangular plots of the framework mode of the Toyora and Toyonishi Groups.

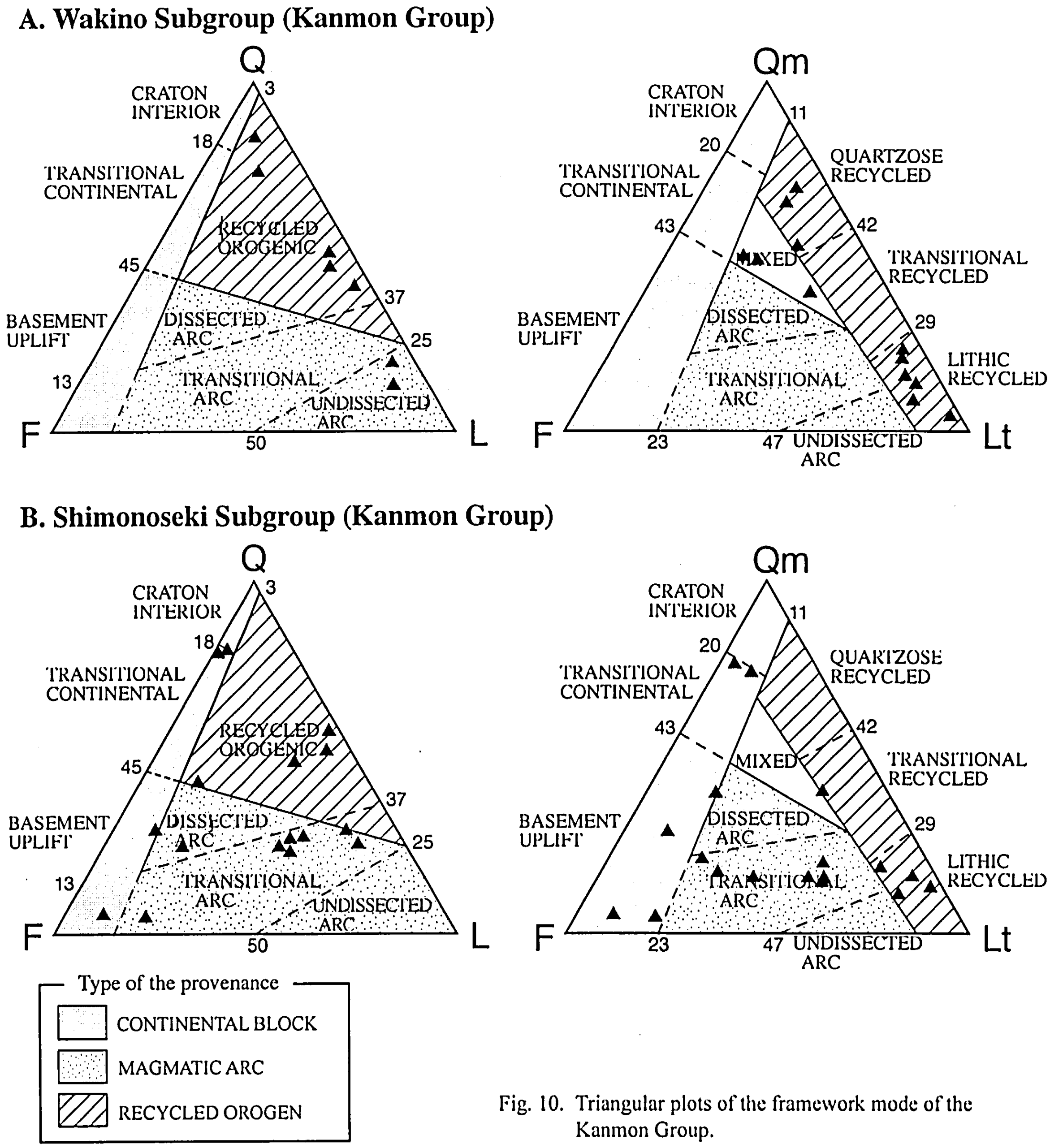


Fig. 10. Triangular plots of the framework mode of the Kanmon Group.

polycrystalline quartz grains, F = feldspar grains, L = rock fragments, and for Qm-F-Lt diagrams, Qm = monocrystalline quartz, F = feldspar grains, Lt = rock fragments including polycrystalline quartz. In the diagrams, tectonic setting divided into three types, continental block, magmatic arc and recycled orogen, and each type is further subdivided.

1. Toyora Group

The Nishinakayama and Utano Formations are similar in terms of distribution of sandstone composition. The sandstones of these formations are dominant in monocrystalline and polycrystalline quartz grains, and poor in potash feldspar grains. Rock fragments consist of mudstone mainly, and contains slate and schist lithologies. Some particles of plagioclase porphyroblasts are found in the Nishinakayama Formation. In the Dickinson diagram, plots are distributed in recycled and transitional recycled subtypes in category of recycled orogen (Fig. 9; A).

2. Kiyosue Formation

The sandstones of the Kiyosue Formation are dominant in monocrystalline and polycrystalline quartz and potash feldspar grains, and poor in plagioclase grains. Rock fragments are mostly composed of chert fragments. In the Dickinson diagram, plots are distributed in recycled to transitional recycled subtypes in category of recycled orogen (Fig. 9; B).

3. Yoshimo Formation

The sandstone of the Yoshimo Formation mostly consist of monocrystalline and polycrystalline quartz, and contains a small amount of rock fragments. In the Dickinson diagram, plots are distributed in quartzose recycled subtype in category of recycled orogen and craton interior subtype in category of continental block (Fig. 9; C). This indicates that the sandstones of the formation are very matured ones.

4. Wakino Subgroup

The sandstones of the Wakino Subgroup are characterized by a predominance of lithic fragments, which mainly consist of sandstone and chert. Volcanic particles are rarely contained. In the Dickinson diagram, plots are distributed into two different areas; quartzose recycled and lithic recycled subtypes in category of recycled orogen (Fig. 10; A). This suggests that the sandstones of the Wakino Subgroup is derived from two different provenances.

5. Shimonoseki Subgroup

The sandstones of the Shimonoseki Subgroup are characterized by volcanics rock fragments. A less amount of monocrystalline quartz grains are contained, in comparison with the other formations. In contrast, feldspar grains are more common. In the Dickinson diagram, plots are distributed in wider areas (Fig. 10; B). The wide distribution of the plots indicates that major volcanic activities were started in this period.

V. Sedimentary Facies Analysis

A. Facies analysis and depositional environment

Sediments deposited in a cretain environment have a distinct characteristics, i.e., texture, sedimentary structures, mineralogical and chemical compositions, preserved fauna and flora, trace fossils, etc. The body of sediments characterized by them is called facies (Walker, 1992). An individual facies type can be combined to characteristic facies associations. The morphological evolution of ancient sedimentary basin can be reconstructed with the aid of such facies associations (Einsele, 1992).. Nineteen sedimentary facies are recognized from the study section on the basis of the sedimentary facies analysis (Table. 2).

Based on the facies analysis, it is enable to reconstruct a five types of typical depositional model (Fig. 11) for the Toyonishi and Kanmon Groups in the Yoshimo-Kikugawa area. Recognition of the types is independent of the formation boundary. These depositional environments are described as follows.

1. Lagoon model

Lagoonal environment is formed at the river mouth, and consists of barrier island and estuarine systems. Wave-dominated shorelines in inter-deltaic and nondeltaic coastal regions are characterized by elongate, shore-parallel sand deposits. Lagoon area is separated by the narrow barrier islands developed wholly or partially, and tidal channel that cuts through the barrier and connect the lagoons to the open sea. In case of the microtidal environment (0-2m tidal range), barrier islands tend to be long and narrow, with abundant storm-washover features and few tidal channels. Because there are few channels, storm surges tend to overtop the barrier forming extensive washover fan. It is considered that the mudstone containing brackish molluscs are deposited in a normal weather, and washover sandstone are formed under a stormy weather. This environment is formed when the relative sea-level is high.

2. Lacustrine model

When relative sea level is not very high, lakes occur in areas of crustal subsidence, and they are not inundated by the seawater. Because of many deltas are formed at the point where a river enters a huge water mass, lacustrine sediments contains both lake and delta characteristics. The sediment in a delta is normally derived directly from a river that feeds water. Coleman and Wright (1975) presented a series of composite vertical facies successions through the prodelta, delta front and delta plain environment. A delta produces a thick coarsening-upward facies succession, and

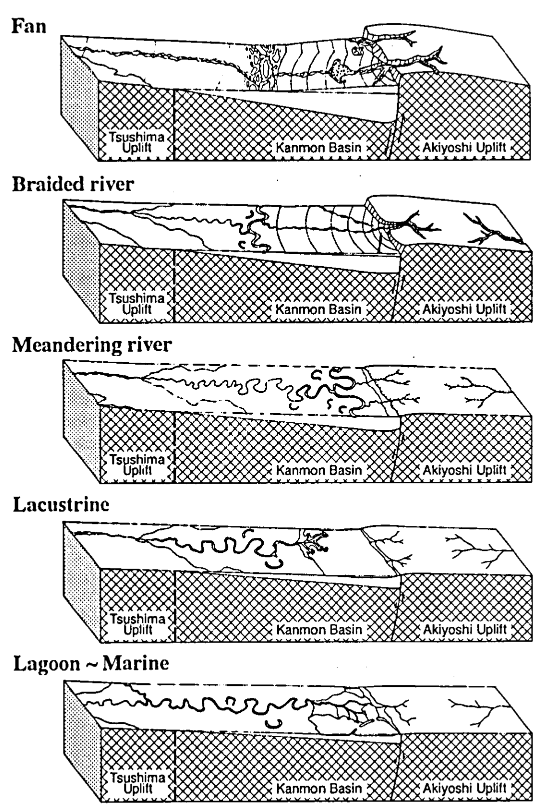


Fig.23. Schematic depositional environments.

Table 2. Division of sedimentary facies and interpreted depositional environments.

Facies Assoc.	Facies	Lithofacies	Sedimentary Structures	Interpretation
Braided River (Proximal Fan)	BP1	matrix supported gravel, poorly sorted	structureless	debris flow deposits
	BP2	clast supported gravel	horizontal bedding, imbrication, erosional surface on the bottom	longitudinal bars, channel floor, lag deposits
	BP3	coarse sandstone to siltstone	massive, normal grading erosional surface on the bottom	crevasse splay
	BP4	medium to fine sandstone	trough cross-bedding, normal grading, including mud clasts	sinuous-crested, linguoid dunes
	BP5	medium to fine sandstone	parallel lamination	upper flow regime plane beds
	BP6	medium sandstone to siltstone	massive, plant fragments	back swamp, abandoned channel deposits
Braided River (Distal Fan)	BD1	clast supported gravel, sorted	massive, imbrication erosional surface on the bottom	longitudinal bedform channel floor
	BD2	pebble gravel to medium sandstone	trough cross-bedding, normal grading, including mud clasts	sinuous-crested, linguoid dunes
	BD3	fine sandstone to siltstone	parallel lamination	overbank, abandoned channel deposits
	BD4	fine sandstone to siltstone	massive, plant fragments	flood plain
Meandering River	MR1	small pebble gravel to siltstone	normal grading, trough cross-bedding	point bar
	MR2	fine sandstone to siltstone	massive, normal grading, inverse grading	crevasse splay
	MR3	fine sandstone to mudstone	massive, fine ramination very small ripples	flood plain
Delta	DF1	granule gravel to medium sandstone	massive, normal grading erosional surface on the bottom	distributary channel, crevasse channel
	DF2	coarse to fine sandstone	massive, normal grading, matrix supported clasts	turbidite
	DF3	fine sandstone to calcareous mudstone	normal grading, trough cross-bedding, parallel lamination	suspension from turbidity currents
Beach-Barrier island system	BB1	medium to fine sandstone	massive, trough cross-bedding	tidal bar, tidal inlet intertidal sand bar
	BB2	siltstone to mudstone	massive, brackish molluscs	lagoon
	BB3	medium to fine sandstone	massive, parallel lamination	washover fan

it is considered that the thickness of the succession is almost equal to the innitial water depth. Delta plain to delta front facies shows the predominance of deposition by fluvial processes, on the other hand, prodelta facies is characterized by the lacustrine deposits.

3. Meandering River model

Meandering streams typically occupy a position downstream from braided rivers and upstream from deltas in the fluvial systems. They occur in coastal plain regions, where water flows along a single channel more or less perpendicular to the coast.

Meandering streams accumulate two distinct sediment types within the channels; channel lag deposits, which are located in the channel floor, and point bar deposits, which form on the inside of the meander loops. The normal grading unit of this sediment type is thicker compare to that of braided rivers. When extreme discharge events happen, a stream overtops its banks, and sediment is carried out of the channel and deposited in the form of overbank deposits. These sediments occur in various forms such as natural levee, crevasse splay deposits, and oxbow lake. Calcretes containing red shale is typical sequence of the overbank deposit in arid climate.

4. Braided River model

Braided streams are developed on steeper slopes than meandering streams, and are characterized by broad, shallow and numerous channels separated by bars and small islands. Deposition is characterized by shifting of channels and bar aggradation, and according to Miall (1977), four types of sedimentologic events may take place in the braided stream environment:

(1) flooding, where formation of beds is superimposed under decreasing velocity

(2) lateral accretion as side or point bars develop

(3) channel aggradation as a channel fills owning to waning energy

(4) reoccupation of a channel, causing cut and fill.

Because of these depositional process, braided river sequences consist of normal grading of gravely or coarse-grained sediments, repeated in short intervals.

5. Fan model

A fan requires an area of high relief and an adjacent lowlying area for sediment accumulation. In many case, fans are related to the tectonic activity developing high topographic relief. A fan is normally divided into proximal, middle and distal portions. Channel patterns are characterized by deeply incised channels in the proximal fan. The middle fan contains numerous braided channels separated with numerous longitudinal bars. The distal fan areas contain braided channels patterns similar, but less densely braded, to those of the middle fan.

Fan sequence consists of debris flow deposits, stream channel deposits, sheetflood deposits and sieve deposits. Imbrications are observed in gravels. Generally, fan sediments are more gravely and thicker than the other environments.

B. Descriptions of each formation

The recognition of the facies is mostly available in the coastal outcrops. Facies observed localities are shown in Figs. 12 and 13. Results of facies analysis of the Toyonishi and Kanmon Groups are described as follows.

1. Toyonishi Group

a. Kiyosue Formation

Along the southern part of the Yoshimo coast, the coarse-grained sandstone intercalating with black mudstone is exposed. It appears a point bar deposit of the meandering river that begins with channel lag deposits of pebble size gravels and grading normally to shale. It is about ten meters thick (Fig. 14; Ky).

b. Yoshimo Formation

Along the north side of the Yoshimo, the alternating beds of white to light colored fine-grained sandstone and black to dark colored shale are exposed. They belong to the lower part of the Yoshimo Formation. They consist of deltaic facies in lower, and lagoon facies in the main part (Fig. 14; Yo).

2. Wakino Subgroup

a. Lower Wakamiya Formation

Along the northern part of the Ogawara coast, the conglomerate intercalating with sandstone is exposed. They appear a basement facies of the Lower Wakamiya Formation, and consist of braided river sequence (Fig. 14; WL01 and WL02). The facies is composed of a channel deposit and an abandon channel deposit of the upper fan.

b. Upper Wakamiya Formation

Along the northern part of the Toyano-hana, the alternating beds of fine-grained sandstone and black mudstone are exposed. It is a middle part of the formation, and consists of deltaic and lacustrine facies (Fig. 15; Wu). The coarsening-upward sequences are repeated in four times.

Along the northern part of the Ajirono-hana, the alternating beds of red shale and fine-grained greenish gray sandstone of the uppermost Bishanohana Formation are exposed. They consist of a floodplain deposit and crevasse splay deposits of the meandering river facies (Fig. 15; lower part of Si01).

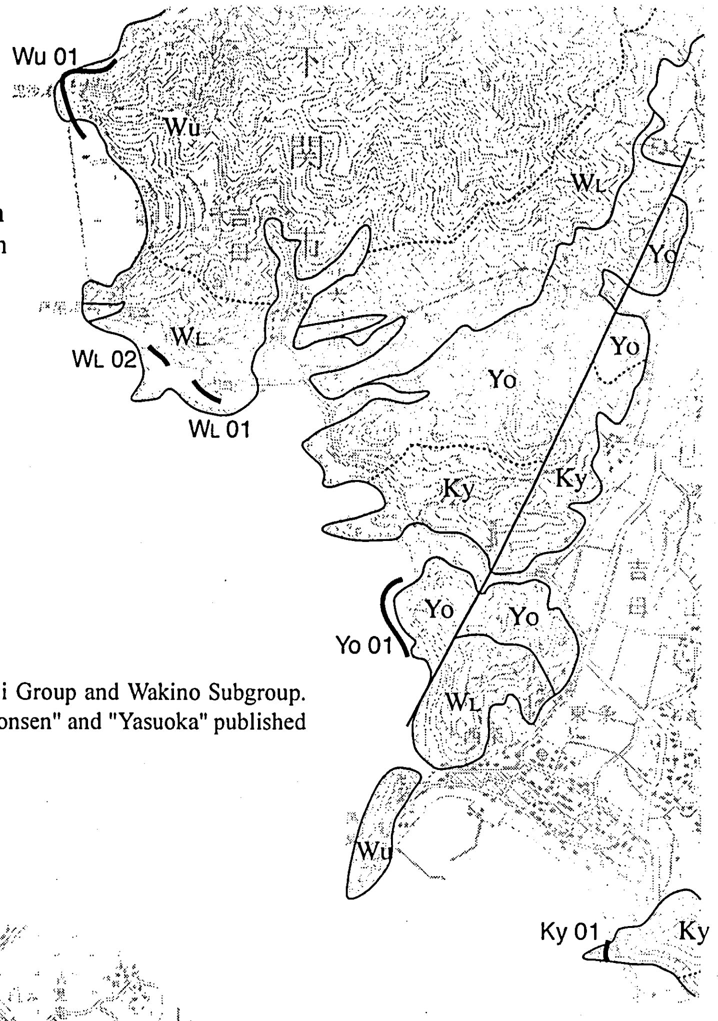
3. Shimonoseki Subgroup

a. Shiohama Formation

Along the coast of Ajirono-hana to Kushimoto Cape, the alternating beds of conglomerate and red shale are exposed. They appear a basement facies (Fig. 15; Si01). The outcrops also expose the uppermost part (Fig. 15; Si02) of the formation, which is mainly composed of meandering rivers deposits.

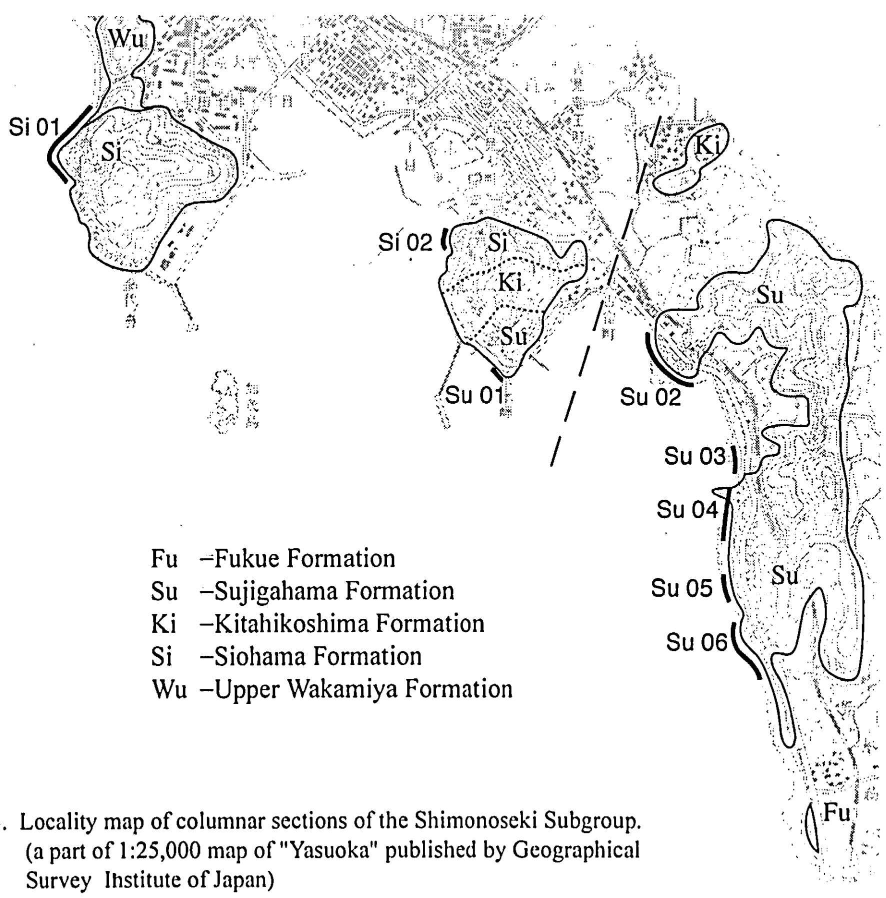
b. Sujigahama Formation

From Kushimoto to Fukue coast, the Sujigahama Formation is exposed. The meandering river facies are dominated in the lower part of the Sujigahama Formation (Fig 16; Su01 and Su02). Matrix supported conglomerate that containing huge superimposed gravels appears in the middle part, and it can be interpreted as a debris flow deposits (Fig. 16; Su03 and Su04). Upper part of the formation consists of very thick conglomerates sequences (Fig 17; Su05 and Su06).



Wu =Upper Wakamiya Formation
WL =Lower Wakamiya Formation
Yo =Yoshimo Formation
Ky =Kiyosue Formation

Fig. 12. Locality map of columnar sections of the Toyonishi Group and Wakino Subgroup. (a part of 1:25,000 map of "Futaoijima", "Kawatanaonsen" and "Yasuoka" published by Geographical Survey Institute of Japan)



Fu –Fukue Formation
Su –Sujigahama Formation
Ki –Kitahikoshima Formation
Si –Siohama Formation
Wu –Upper Wakamiya Formation

Fig. 13. Locality map of columnar sections of the Shimonoseki Subgroup. (a part of 1:25,000 map of "Yasuoka" published by Geographical Survey Institute of Japan)

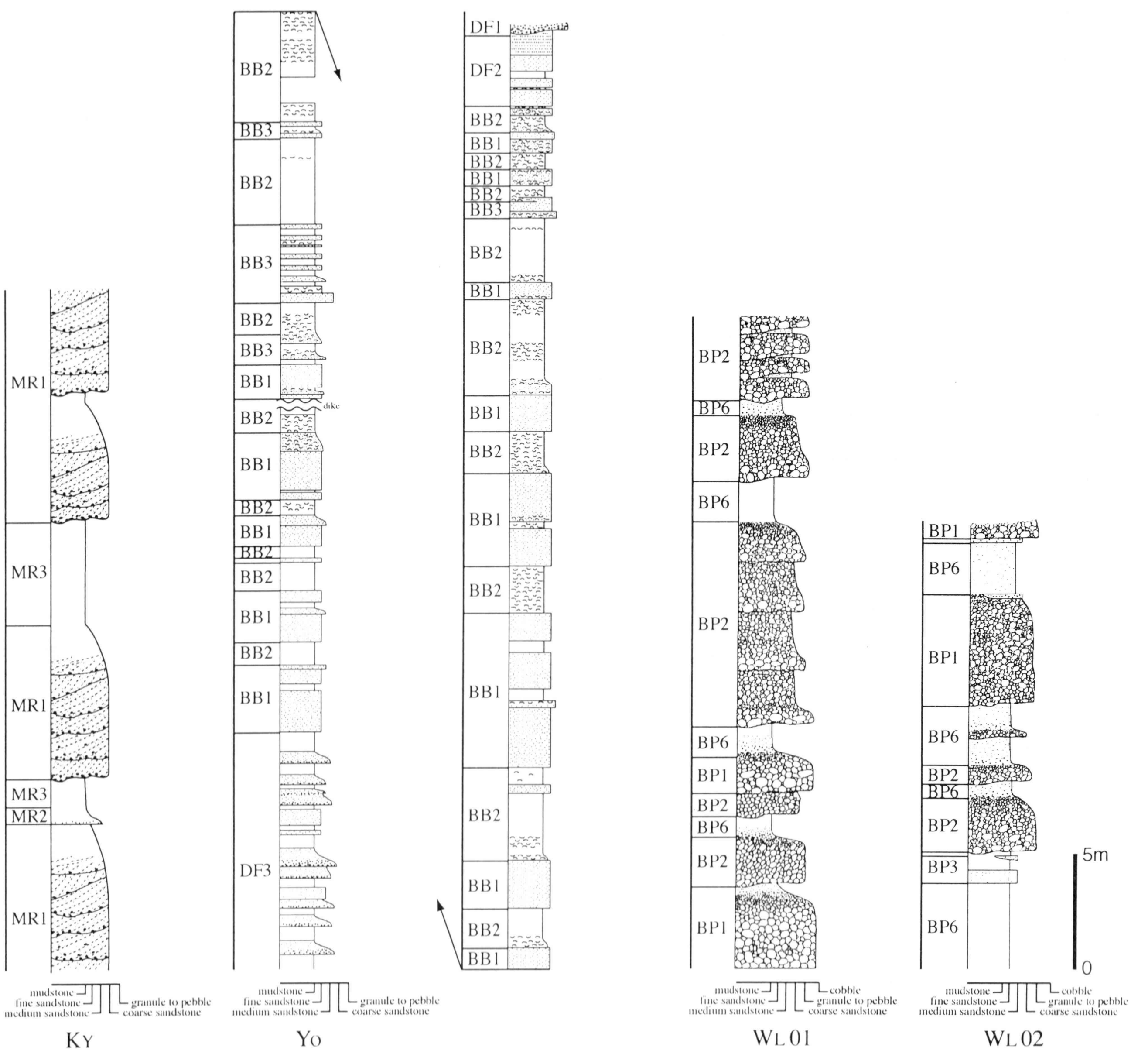


Fig. 14. Columnar section showing sedimentary facies of the Toyonishi Group and the Lower Wakamiya Formation.

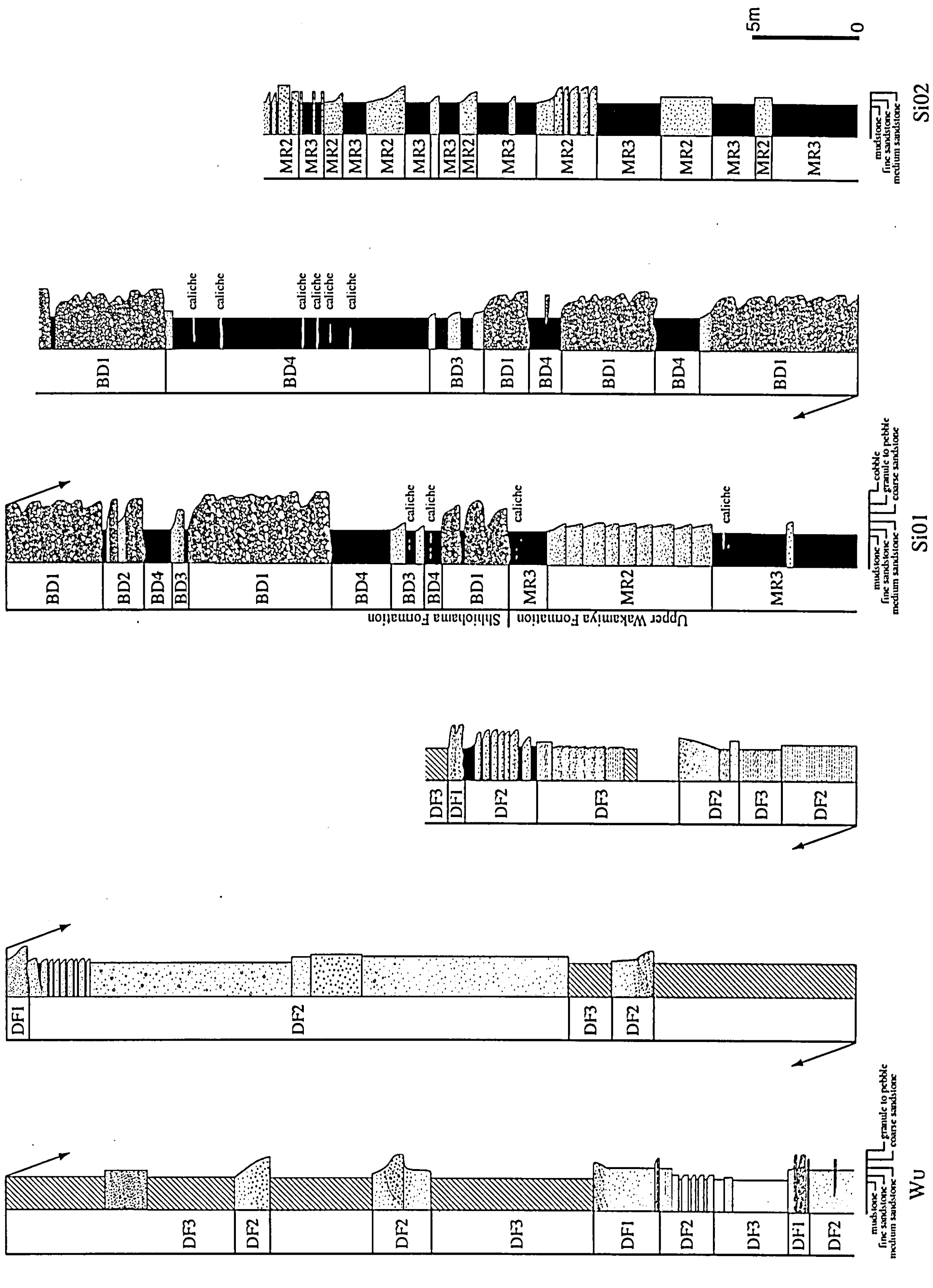


Fig. 15. Columnar section showing sedimentary facies of the Kanmon Group.

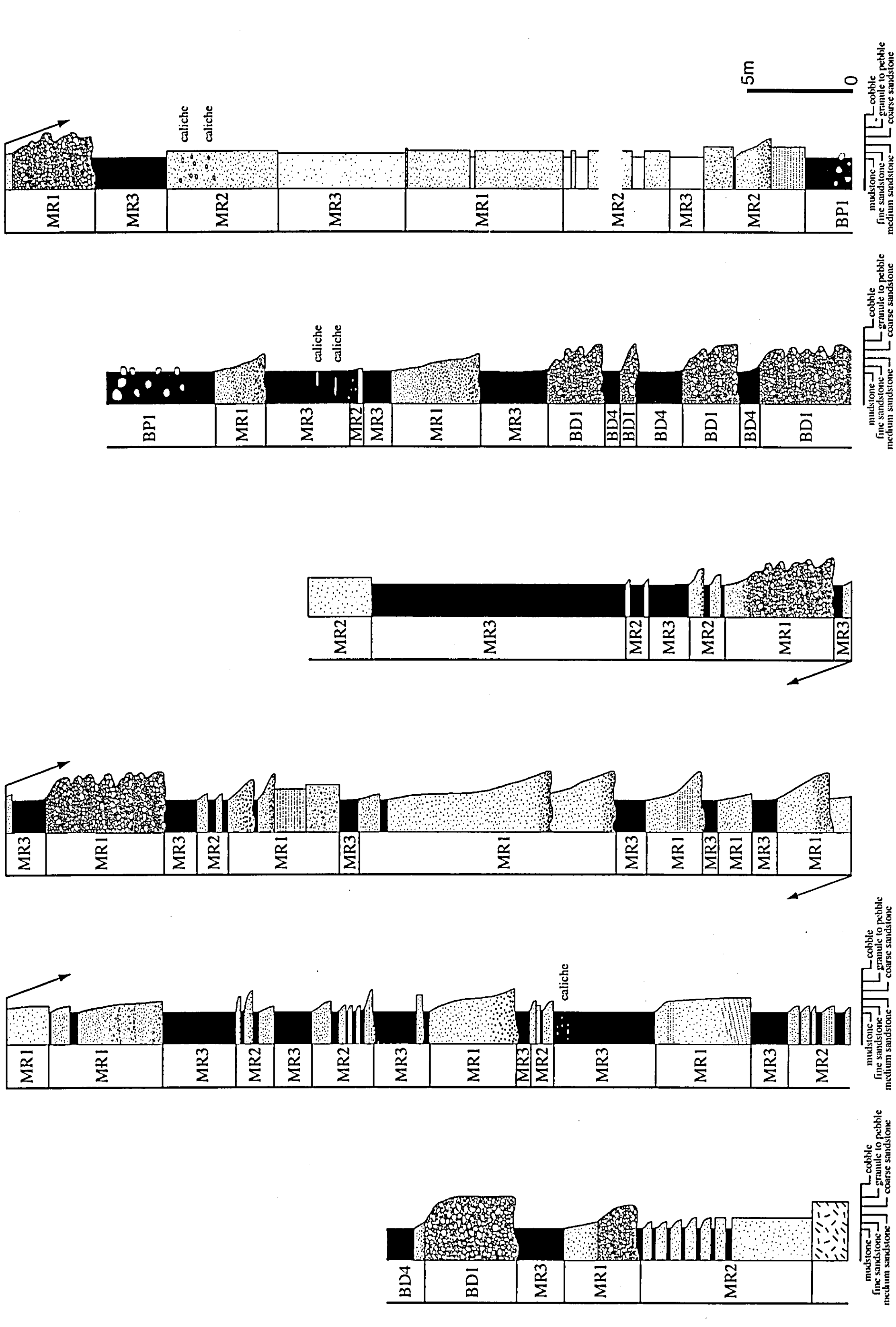


Fig. 16. Columnar section showing sedimentary facies of the Kanmon Group.

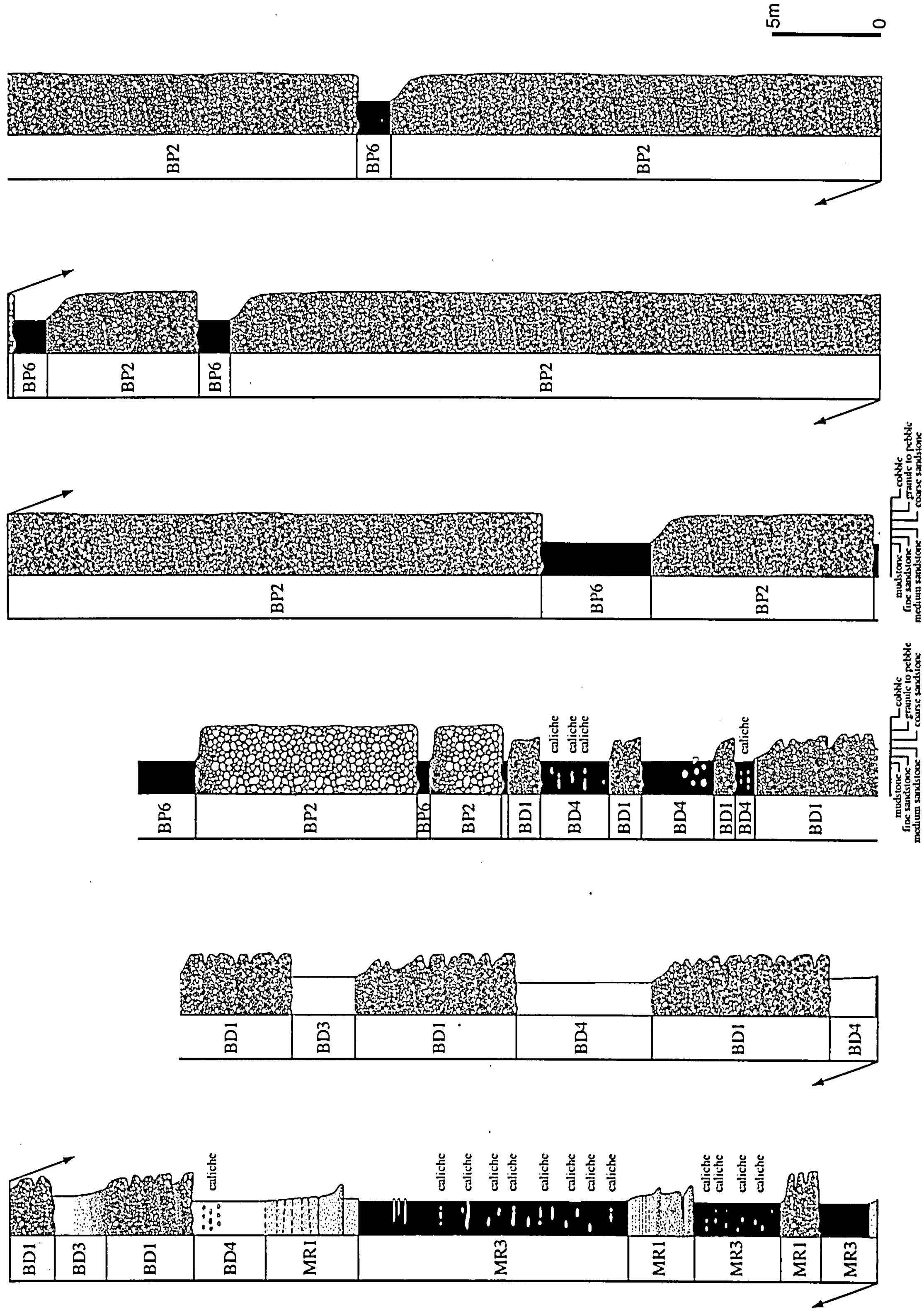


Fig. 17. Columnar section showing sedimentary facies of the Kanmon Group.

VI. Discussion

A. Diachronous changes of provenance

Compositional variation in rock fragments (Fig. 8) indicate provenance areas, most typically. Judging from features described above, the following provenances change are reconstructed.

1. Toyora Group

The provenance of the group was constituents of the Nagato Tectonic Zone. This is based on schists, which were supplied for gravels in conglomerate and rock fragments of sandstone. As well, another supporting evidence is the plagioclase porphyroblasts in sandstone of the Nishinakayama Formation. It is known that the igneous rocks of the Nagato Tectonic Zone have low K_20/Na_2O ratio (Murakami and Nishimura, 1979), it is the reason why the contained potash feldspar grains are seldom.

2. Kiyosue Formation

The provenance of the group was originated from the Triassic Mine and Atsu Groups. This is based on the fact that granitic clasts are contained abundantly in conglomerates, and that potash feldspar grains are richly contained in the sandstone.

3. Yoshimo Formation

Judging from the sandstone mainly composed of fine-grained monocrystalline quartz, and rarely containing other minerals and lithic fragments, as well as from the fact that the conglomerate is poor clastics of large size, highly matured sediments were derived for a long distance from continental area, which was porbably located in the northwest direction of the basin.

4. Wakino Subgroup

Two different provenances might be inferred for the Wakino Group; one is the Permian accretionary complex, and the other is continental blocks. This is based on the fact that large size of limestone clasts are observed in the basal facies. They may have been derived from the Akiyoshi Limestone Group. Similarly, cobble-sized chert clasts were derived from the Ota and Tsunemori Groups.

The matured quartzose sand was derived from continental area, in the same way of the Yoshimo Formation.

5. Shimonoseki Subgroup

The voluminous volcanic clasts occur in Shimonoseki Subgroup, and the lower part of the Sujigahama Formation mostly, and they tend to decrease to the upward. The main provenance of the Subgroup is andesitic to dacitic lavas and phyroclastic rocks in the same period.

To summarize these data, most of the sediments were derived from the Akiyoshi Terrane, distributed east of the Nagato Tectonic Zone. Continental provenance, such as the Hida Terrane, may have been exposed in northwest of the basin.

B. Geometry of Sedimentary Basin

The columnar sections of the Toyonishi and Kanmon Groups in the Yoshimo-Kikugawa area are shown in Fig. 18, showing the thickness change of the formations. Although there is 2,300m of thickness of the Kanmon Group on the east side of the study area, along the western seashore, it decreases even to 1,800m.

As discussed in the foregoing paragraph, clastic components were transported from the adjacent Akiyoshi Terrane to the basin. Thus, it is possible to make a schematic reconstruction of the sedimentary basin as shown in Fig. 19, in which the thickness and intervals of the columnar sections are proportionally drawn.

The characteristics of the Kanmon Basin are as follows:

(1) The sedimentary basin and provenances are bordered by the Nagato Tectonic Zone as boundary fault.

(2) The sedimentary basin has a half-graben structure tilting toward southeast.

(3) The sediments are thicker along the boundary fault.

(4) The sediments were mainly derived from uplifted area in southeast.

These facts are in accord with other basins widely distributed in East Asia to Southwest Japan.

Provenances of the Wakino Subgroup are probably originated from the Sangun metamorphic rocks in northern Kyushu (Seo, 1992), and might be Akiyoshi Terrane in Yamaguchi. Similarly, arkose sandstone of the Kiyosue Formation derived from the Mine Group. The clastics analysis indicates that the sediments of the basin were continuously supplied from adjacent areas. It is considered that the locations of provenance area and sedimentary basin are not so different from the present, and large-scale movement of the boundary fault may hardly be expected.

It is newly clarified that,

(5) The boundary fault of the Kanmon Basin is dominated by dip-slip movement.

C. Sedimentary Basins in East Asia

Distribution of the Lower Cretaceous sedimentary basins from East China Sea to Southwest Japan is shown in Fig. 20. It is recognized that large-scale NNE-SSW trending strike-slip faults are developed in parallel to each other, and basins are distributed in a close relation to these major faults.

Most fundamental trend is that three tectonic units arranged in parallel with the general trend of NNE-SSW.

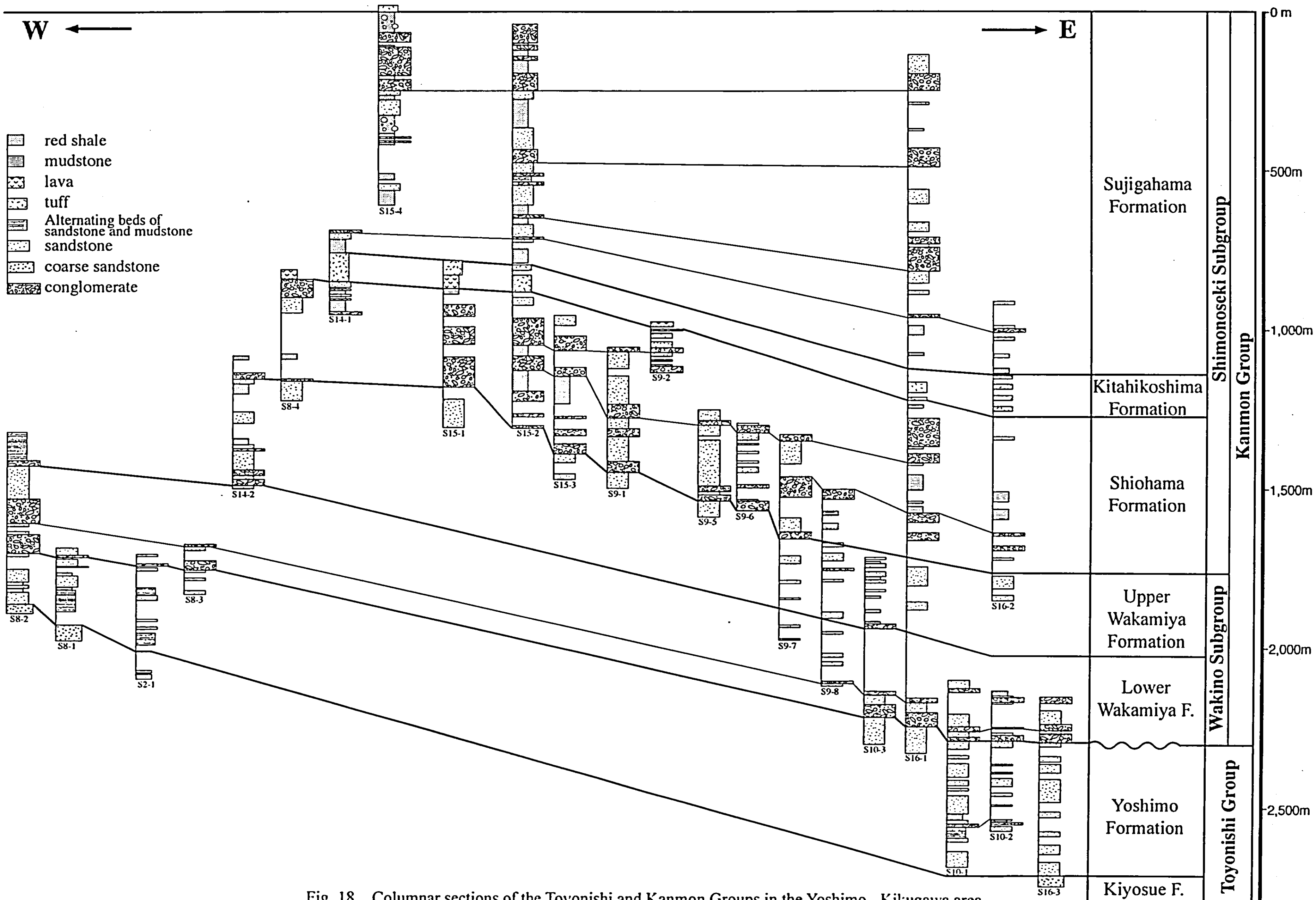


Fig. 18. Columnar sections of the Toyonishi and Kanmon Groups in the Yoshimo - Kikugawa area.

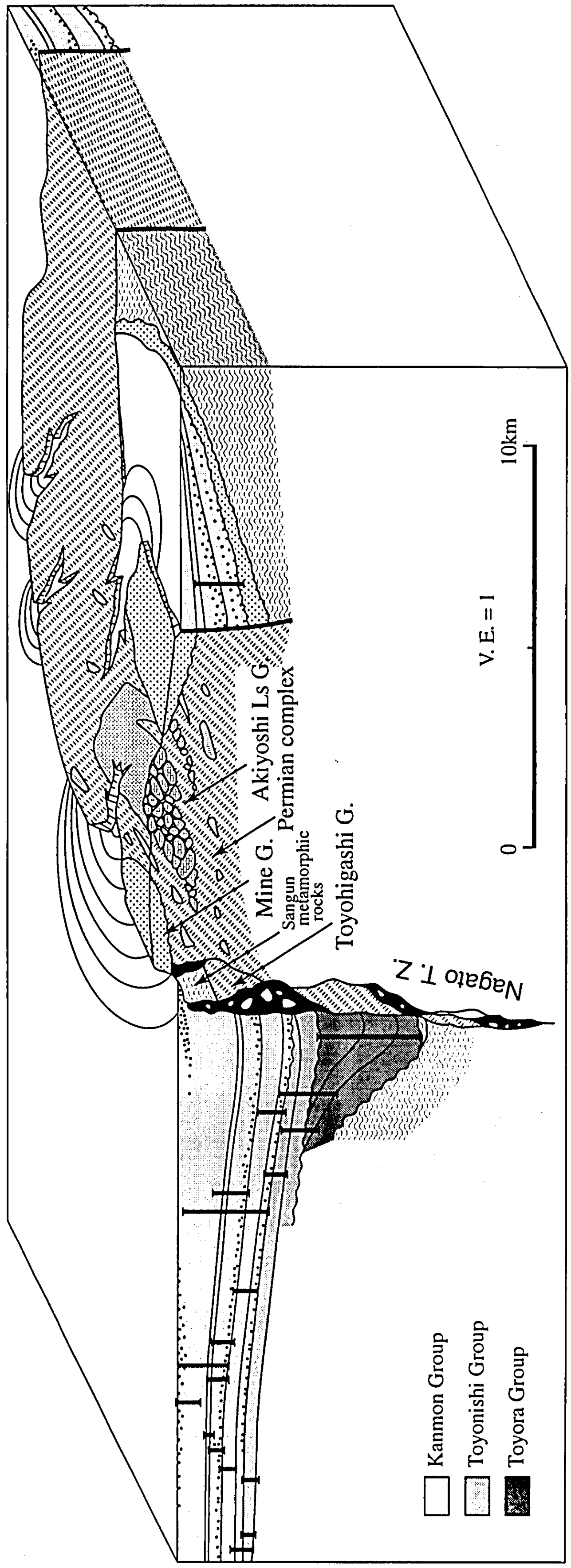


Fig. 19. Schematic reconstruction of the sedimentary basin.

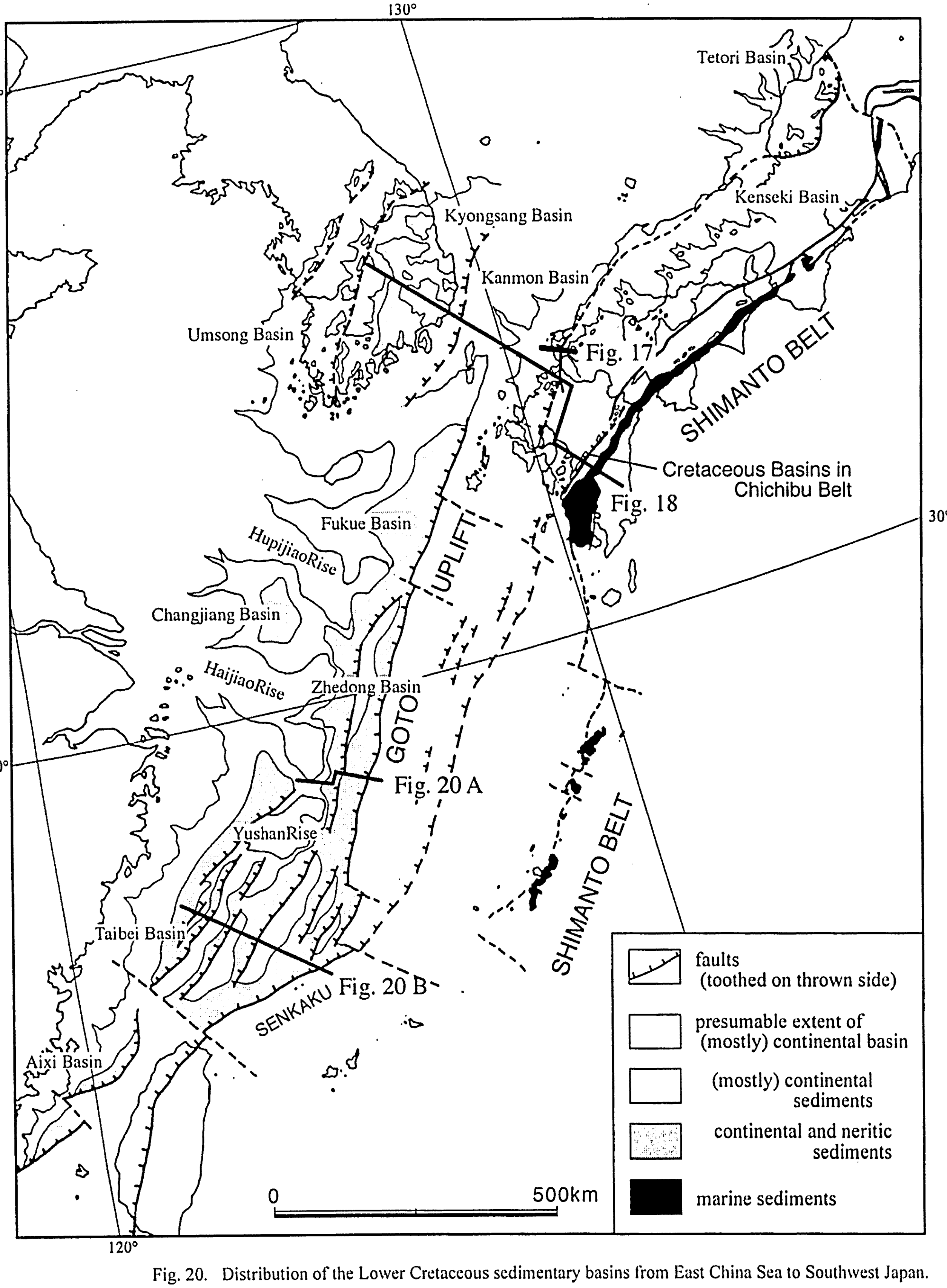


Fig. 20. Distribution of the Lower Cretaceous sedimentary basins from East China Sea to Southwest Japan.

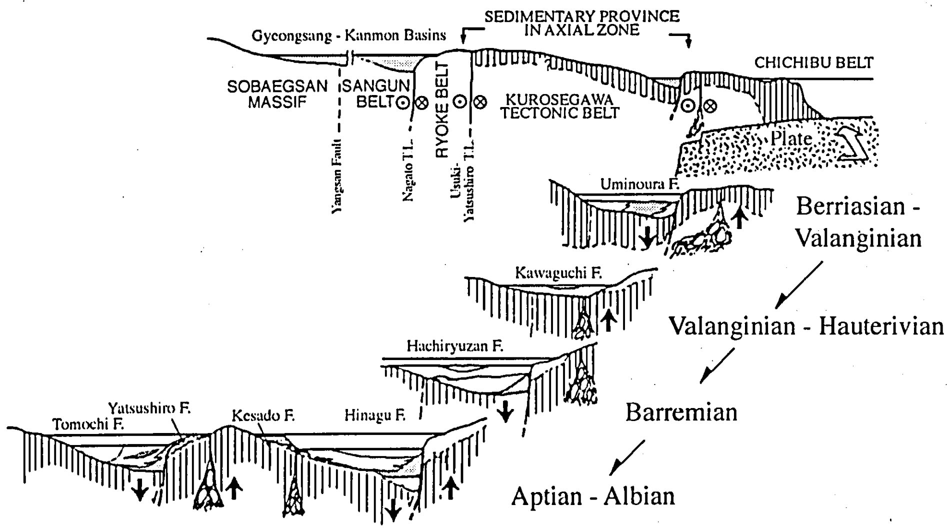


Fig. 21. Basin profiles from South Korea to Kyushu (Sakai et al., 1992).

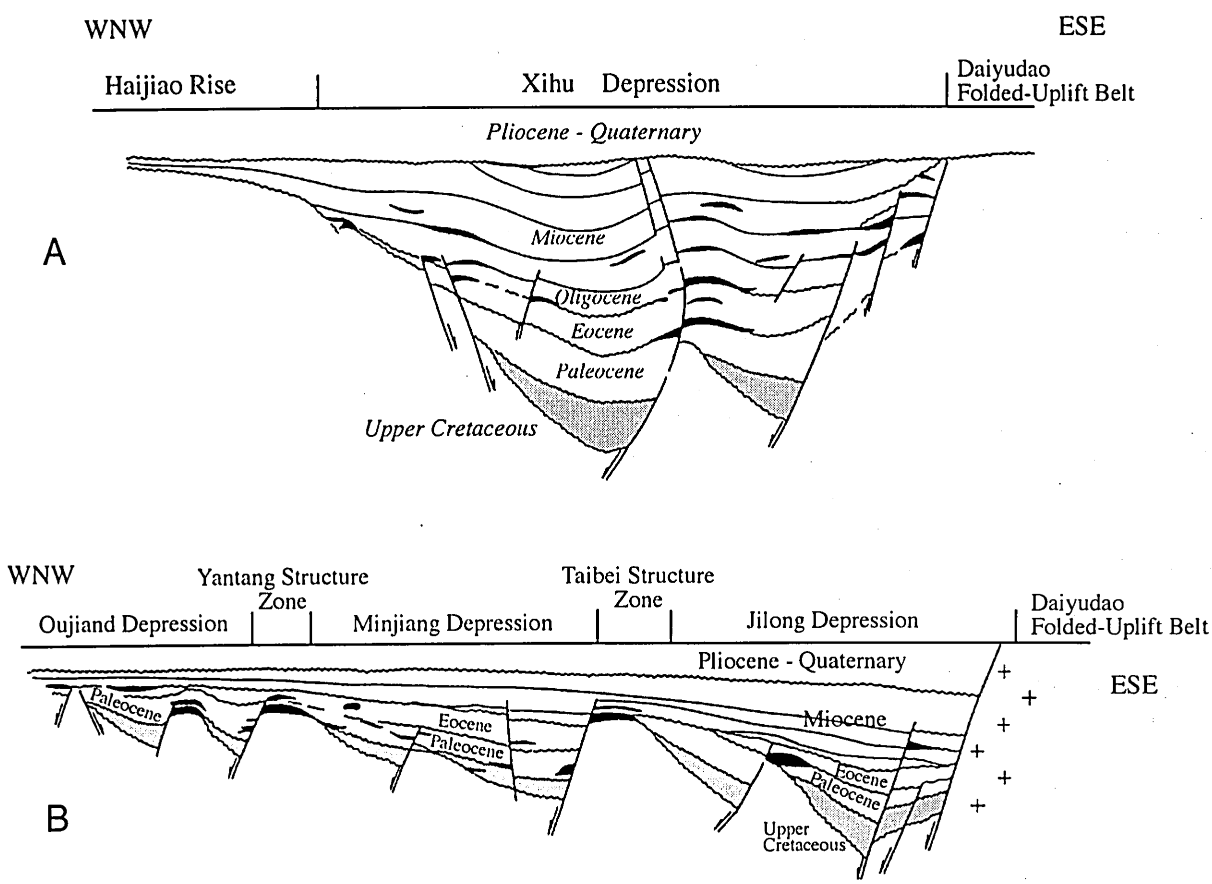


Fig. 22. Sketch of seismic profiles in the East China Sea (Zhou et al., 1989).
A : the Zhedong Basin, B : the Taibei Basin

They are, from the continental side, an fluvial to lacustrine sediments through the southeastern coast of China and Korea, fluvial to neritic sediments of the Inner Zone of Southwest Japan, and marine sediments of the Outer Zone of the Southwest Japan.

The basin of the East China Sea has accommodated thick sediments ranging from the Jurassic to Quaternary in age (Zhou et al., 1989). Seismic reflection data indicate that the structure of the basin is characterized consistently by the systematic arrangement of southeastward-dipping tilted basins bounded by faults (Figs. 21 and 22).

A new paradigm for understanding these tectonical evolution has been developed to cover the crust by plate tectonics and the whole mantle by plume tectonics. According to this, tectonic features in East Asia are related to large-scale igneous activity (Okada and Sakai, 1993), and thus, superplume volcanic events during the Cretaceous played an important role in controlling the Cretaceous environments in East Asia (Okada, 1995).

D. Developing process of sedimentary basin

Based on the facies analysis, changes of the depositional environments of these Upper Mesozoic can be reconstructed as shown in Fig. 23. It is considered that the depositional environment have abruptly changed by the movement of the sedimentary basin due to the boundary fault activity. On the other hand, when tilting movement of the basin have been stopped or moved gently, depositional environment was gradually changed according to the dissection process of the provenances, consequently, the derived sediments became to decrease and be finer-grained. Unconformity surfaces were formed together with significant changes in depositional environments. Occasional high-rate movements of the boundary faults probably caused the adrupt depositional environments, and increased grain size of clastics due to uplifting movement of the provenance areas.

The whole trend of change in the depositional environments also suggest that the whole sedimentary basin uplifted. The environments begin with neritic (the Toyora Group) through brackish (the Toyonishi Group), lacustrine facies (the Wakino Subgroup), and finally to fluvial conglomerate of the Shimonoseki Subgroup. It means that a emerging movement was dominated in this area from Jurassic to early Cretaceous.

In the upper Sujigahama Formation, the sedimentary basin was emerged mostly, and sedimentation ended. It is considered that the trend of the sedimentary environmental change corresponded to the pre-stage activity prior to the active igneous event of late Cretaceous.

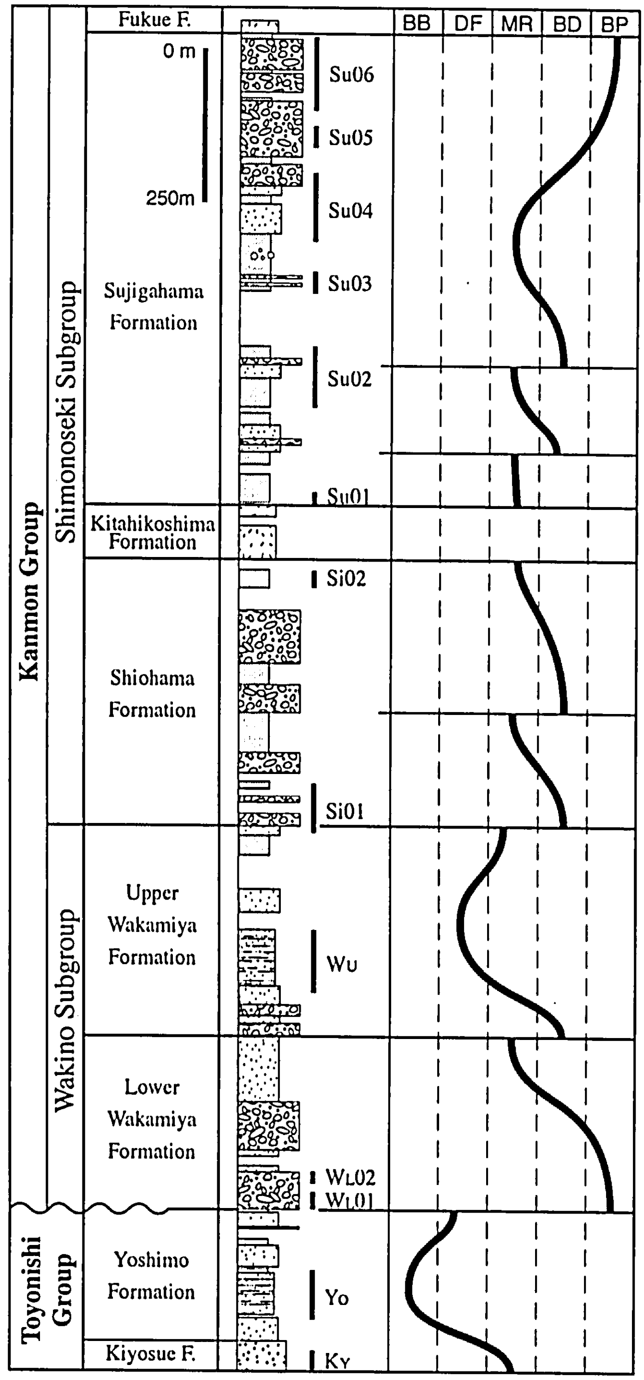


Fig. 23. Diagrammatic facies changes of the Toyonishi and Kanmon Groups.

E. Evolution processes of the Kanmon Basin

Jurassic to Cretaceous tectonics in East Asia have been discussed in many articles (e.g. Xu et al., 1989; Lee & Paik, 1990; Okada, 1995). The purpose of this section is to discuss the tectonics and developing processes of the Kanmon Basin based on the results of stratigraphy, composition of clastics, sedimentary environments and geological structures. Previous disscussions on evolution processes of the Kanmon

Basin (e.g. Okada, 1981; Seo et al., 1992) have suggested that the Kanmon Basin was formed as a strike-slip basin judging from the remarkable lateral changes in sediment thickness and lithological characters. But thickness and lithological characters can easily vary within a fluvial depositional system, and the remarkable lateral veriations in the Kanmon Group may have been independent with tectonic backbround of the sedimentary basin. In this study, it was clarified that the dip-slip movement along the boundary fault had been dominated at least during basin formational period. Strike-slip movement was dominant tectonic processes forming deformation (folding and faulting) rather in the post-depositional period. Schematic reconstruction of evolution processes for the Kanmon Basin is as follows.

1. Late Jurassic to Earliest Cretaceous

The Toyora sea was retreated and the marine environment had come to the end. The Toyonishi Group in the Yoshimo-Kikugawa area was deposited in lagoonal environment of the barrier-island complex (Fig. 24) in restricted extension, covering the eroded the Utano Formation of the Toyora Group with a remarkable basal facies. At the same time, northern Kyushu district are situated in a coastal plane, and clastics are transported by a meandering river (e.g. point bar, natural levee, crevasse splay and oxbow lake deposits). On the other hand, the north part of the Yoshimo-Kikugawa area became in marine environments, and the Torinosu-type limestones were formed as a fringing reef on the open sea side of the barrier island. Environmental change from the Murotsu Formation to the Yoshimo Formation reflected a prograding of barrier-island complex. Similarly, difference of the lithological character between the lower part and upper part of the Yoshimo Formation also indicate progradation of the coastal plane which are characterized by deltaic sediments (Fig. 24). These coastal sediments were overlain by the Wakino Subgroup unconformably.

2. Hauterivian to Barremian

Because of the boundary fault was activated, the provenance areas were uplifted in this period, a new sedimentary basin appeared in northern Kyushu district, and the basin was then extensively expanded towards the northeast. A high relief was formed owing to this tectonic movement. A considerably thick series of braided river sediments of relatively large size immature clastics, were accumulated there (Fig. 25A). Although fine-grained matured quartzose sandstone derived from the continental area which assumed in the northwest direction of the basin.

The uplifted provenance area was dissected and became low relief, and the quantity and size of derived clastics decreased. When a large scale lake was formed in a tectonically subsidenced area, diversity of the non-marine fauna become increase (e.g. Brotiopsis sp., Trigonioides sp. Viviparus sp. etc.), and well bedded fine grained calcareous sediment were developed in this time (Fig. 25B).

The lake was probably filled up progressively by delta deposits formed at rivers mouth. A floodplain, characterized by fine grained red colored overbank deposits, occupied a very large area.

The development of reddish colored sediments and the occasional occurrence of calcareous calcretes may suggest that the climate condition at that time was subtropical temperature with arid climate.

Late Jurassic - Earliest Cretaceous

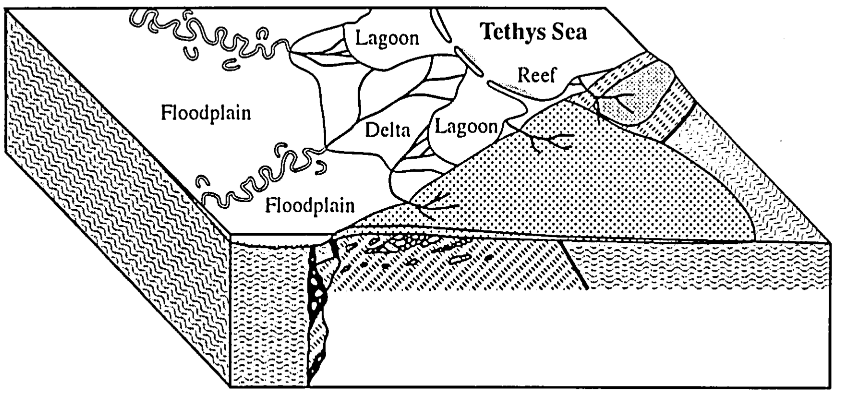


Fig. 24. Schematic paleogeographical profiles of the study area.

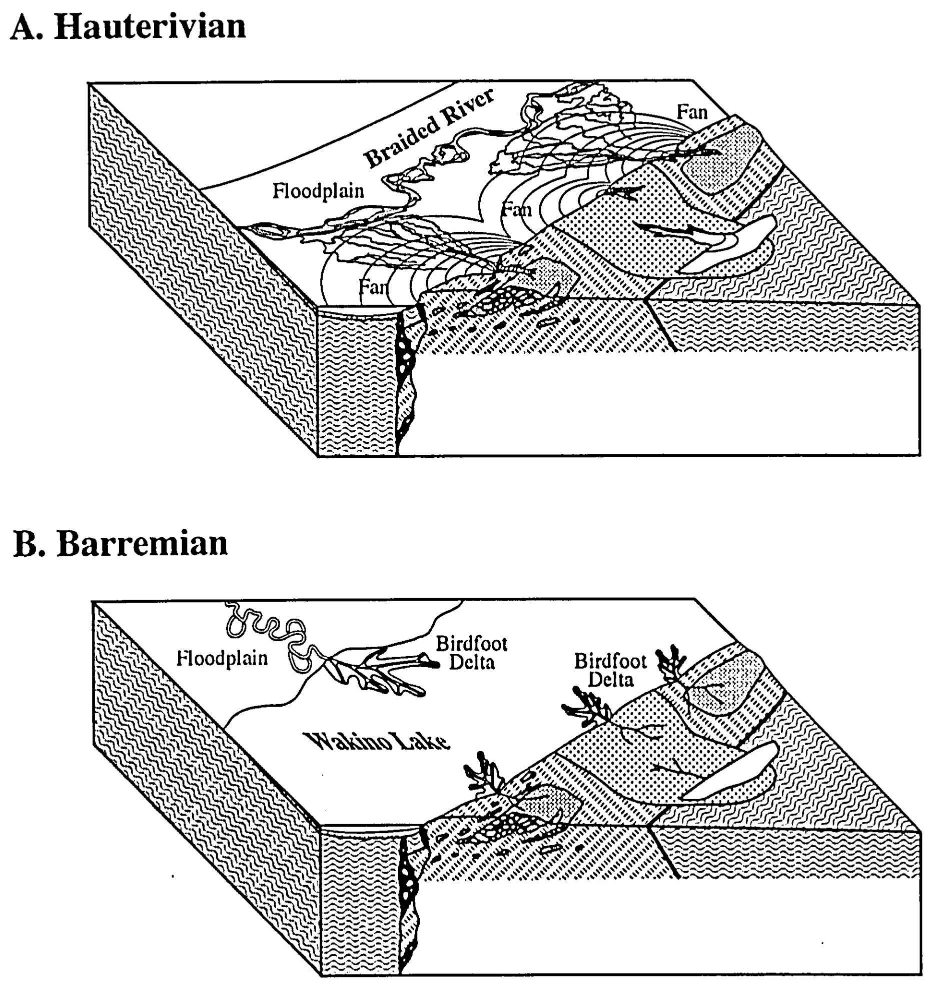


Fig. 25. Schematic paleogeographical profiles of the study area.

3. Aptian to Albian

At the beginning of the deposition of the Shiohama Formation, the volcanism became active, and reached maximum in the Kitahikoshima age. Lava and phyroclastic rocks were accumulated in considerable extension (Fig. 26A). According to the thickness of the Kitahikoshima Formation is thicker at the northern Kyushu and northern Yamaguchi Prefecture, in contrast it is comparatively thinner in Yoshimo-Kikugawa area where the center of volcanic activity is assumed to have been located.

Because of the major volcanic activity ended in the Kitahikoshima age, volcano-clastic are decrease into upward in the Shimonoseki Subgroup. The Upper Sujigahama Formation is characterized by abundant and thick conglomerate associated with red colored mudstone thin layer and lenses (Fig. 26B). These coarse grained ill-sorted fluvial sediments consisted of chart and sandstone clastics mainly, and huge clastic blocks were supplied as debris flow occasionally. These suggest deposition taking place mainly at the proximal part of a fan which developed in arid or semi-arid climates.

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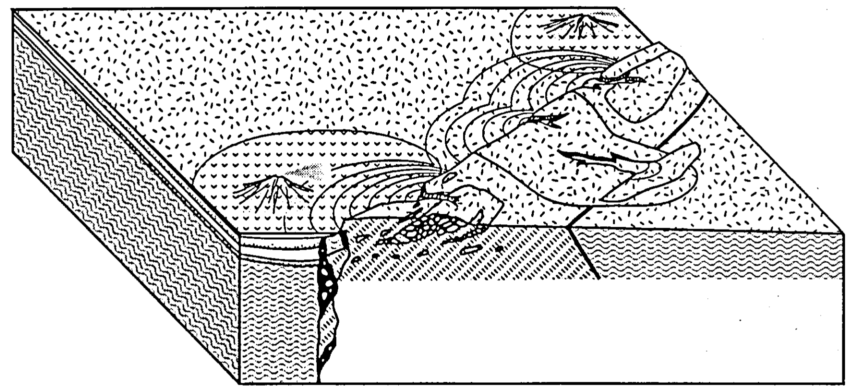
A. Aptian



B. Albian

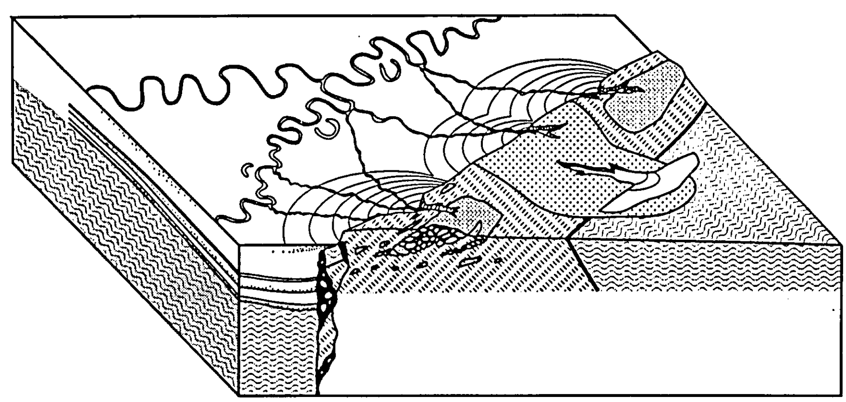


Fig. 26. Schematic paleogeographical profiles of the study area.

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* in Japanese with English abstract
** in Japanese with Japanese abstract

Ken-ichi Yoshidomi

Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, Kagamiyama 1-3-1, Higashi-hiroshima, 739-8526, Japan